A

Abacus

Barbara E. Reynolds
Cardinal Stritch University, Milwaukee,
WI, USA

In contemporary usage, the word *abacus* refers to a computational device with beads sliding on fixed rods, often associated with the Japanese or Chinese. However, the word *abacus* has Latin roots, suggesting a rich history in Western as well as Eastern cultures.

The present-day abacus, called *Suan Pan* in China, *soroban* in Japan, and *schoty* in Russia, is still in use by shopkeepers throughout Asia and in Chinatowns around the world. It works on a place value or positional system of numeric notation, similar to that of our familiar Hindu-Arabic numerals. The number of beads on each rod represents the value of the digit in that place, with higher place values to the left (or, on the *schoty*, above) and lower place values to the right (or below). Numeric values are read from left to right (or top to bottom) similarly to the written numerals. For example, the numeral 341 is represented by three beads on the *hundreds* rod, four beads on the *tens* rod, and one bead on the *units* rod.

On Chinese and Japanese models, the rods are vertical, and the beads on these rods are divided into two groups by a horizontal bar, which separates the beads into a set of one or two beads above the bar and another set of four or five beads below the bar. The beads above this horizontal bar are valued at five times the beads below the bar. Thus, for example, the number 756 is represented by 1 five-bead and 2 one-beads on the *hundreds* rod, 1 five-bead and no one-beads on the *tens* rod, and 1 five-bead and 1 one-bead on the *units* rod. To operate the abacus, first clear it by pushing all the beads away from the horizontal bar, the beads in the lower section are pushed down, while those in the upper section are pushed up. This can be done quickly by tilting the abacus slightly so that all the beads slide down and then laying the abacus on a flat horizontal surface and running the index finger between the bar and beads in the upper section, pushing them away from the bar. The abacus is operated using the thumb and the index finger to push beads toward or away from the bar as values are added or subtracted. To add 341 + 756, first push the beads in place to represent 341, and then push additional beads in place to represent 756. On the *hundreds* rod, there will be 3 one-beads plus 1 five-bead and 2 additional one-beads; on the *tens* rod, there will be 4 one-beads and 1 five-bead, and on the *units* rod, there will be 1 one-bead, 1-five bead, and 1 additional one-bead. The result can be read as 10 *hundreds*, 9 *tens*, and 7 *ones*. In practice this is quickly simplified by regrouping the beads to 1 *thousand*, 0 *hundreds*, 9 *tens*, and 7 *ones*, or simply 1097. That is, whenever 5 one-beads are accumulated below the bar they are exchanged for 1 five-bead

H. Selin (ed.), *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*,
DOI 10.1007/978-94-007-7747-7

above the bar, and whenever 2 five-beads are accumulated above the bar, they are exchanged for 1 one-bead in the next column to the left.

The Chinese S*uan Pan*, which is first mentioned in the literature in the twelfth century, traditionally has 2 five-beads and 5 one-beads on each rod. So it is possible to accumulate a value of 15 (2 five-beads plus 5 one-beads) on each rod during the computation, and this must be simplified as described above before the result can be read out. The Japanese *soroban*, developed in the early 1930s, has shorter rods with 1 five-bead and 4 one-beads on each rod. With the *soroban* the value on any rod cannot go above 9 (1 five-bead plus 4 one-beads) so that simplifications must be carried out continuously throughout the computation. Since each bead is moved through a shorter distance, an experienced, skillful user can perform computations more quickly on the *soroban* than on the *Suan Pan*.

The Russian *schoty*, developed in the seventeenth century, has horizontal rods, with ten beads on each rod. Numeric values are read from top down, with each rod valued at 10 times the value of the rod immediately below it. That is, the *hundreds* rod is above the *tens* rod, which is above the *units* rod. Calculating with the *schoty* resembles finger counting, each bead representing one finger, or one unit in its respective place value. If you hold your hands out in front of you with the palms away from you, your two thumbs will be side-by-side, flanked by the four fingers of each hand. Similarly, the two middle beads on each rod of the *schoty* representing the thumbs are in a contrasting color to the two sets of four beads each on either side. This makes it easier to see the values without consciously counting the beads. To clear the value on the *schoty*, the beads are all pushed to the right. Beads are pushed to the left or right as numbers are added or subtracted.

Archaeological evidence in the form of bead-frame calculators as well as piles of small smooth rounded stones, which could have been used as counters for reckoning, suggests that in ancient times (300 BCE to 500 AD), computations in the marketplace throughout the Roman empire were commonly worked out by casting stones (*calculi*) in the sand or on a specially marked counting table (*abax*). Lines in the sand or on the table top would mark off space for *ones*, *tens*, *hundred*s, and so on. To make the values easier to read, stones placed on the line between two spaces would denote values halfway between the lower-valued unit on the right and the higher-valued unit on the left. For example, a stone on the line between the *ones* and the *tens* would be valued as *five*, and a stone on the line between the *tens* and the *hundreds* would be valued as *fifty*.

Roman numerals could have been used to easily record the results of computations done on a Sand-Reckoner or counting table. The Roman numerals I, X, C, and M represent stones in the units, tens, hundreds, and thousands spaces, respectively, while V, L, and D represent values on the lines, 5, 50, and 500. On some surviving counting tables, the Roman numerals I, X, C, and M have been scratched onto the table top in the appropriate spaces, making it a simple matter to record the final result of the computation. The Roman numeral CCVIII (represented by 208 in Hindu-Arabic numerals) would be cast on the counter-top using two stones in the *hundreds* space, one stone on the line between the *tens* and the *units* spaces, and three stones in the *units* space. Similarly, the Roman numeral DCXXVIIII (or 629) would be cast using one stone on the line between the *thousands* and the *hundreds* spaces, one stone in the *hundreds* space, two stones in the *tens* space, one stone on the line between the *tens* and the *units* spaces, and four stones in *units* space. The use of a quasi-positional subtractive principle in Roman numerals – so that IIII is represented as IV and VIIII as IX – is a later development used only sparingly in ancient and medieval times.

To add CCVIII + DCXXVIIII, the person doing the calculating (probably a merchant) would first cast stones representing CCVIII and then the additional stones representing DCXXVIIII. These would be regrouped by rearranging the stones in full view of the customer first as D CC C XX VV III IIII and then simplified as D CCC XXX V II (or simply as 837 in our more familiar numerals).

In the early fourteenth century, bankers and merchants were still required by law to use Roman numerals to record business transactions. Since the Gutenberg printing press was not invented until about 100 years later, the majority of the population was illiterate (i.e., not taught to read the printed word). Recording the result of the previous example, DCCCXXXVII, in Roman numerals requires ten symbols, one symbol on the paper for each stone on the counting table. Recording the same result using Hindu-Arabic numerals would require only three symbols. Zero was a difficult concept, one that was not easily adopted. The Hindu-Arabic numeral 500 requires three digits, but would be represented by a single stone on the abacus and by the single letter D using Roman numerals. Although the idea of zero as a placeholder was sometimes understood in medieval times, it simply was not needed in doing computations using an abacus. If results were recorded using Roman numerals, the clear correspondence between the stones on the counting table and the symbols on the paper was readily apparent. Thus, using Roman numerals, the customer would be assured that the merchant or banker was accurately recording the result of the transaction.

The Roman bead-frame calculators found at some archaeological sites are small enough to be held in one hand and have a design similar to the Chinese *Suan Pan*. This evidence suggests that the abacus was taken from Western Europe to the East by Christian migrations. In the late fourth century, Arabs brought the concept of a numeral for zero to the West from the Hindus in India.

References

Ball, W. W. R. (1960). *A short account of the history of mathematics*. New York: Dover. (An unabridged and unaltered republication of the author's fourth edition which first appeared in 1908).

Bergamini, D. (1972). *Mathematics*. New York: Life Science Library.

Bronowski, J. (1973). *The ascent of man*. Boston: Little Brown.

Cajori, F. (1897). *A history of elementary mathematics*. New York: Macmillan.

Cajori, F. (1922). *A history of mathematics* (2nd ed.). New York: Macmillan.

Cajori, F. (1928). *History of mathematical notations* (Notations in elementary mathematics, Vol. 1). La Salle, IL: Open Court.

Dantzig, T. (1922). *Number: The language of science* (4th ed.). New York: Free Press.

Evans, G. R. (1997). Abacus. In S. Helaine (Ed.), *Encyclopaedia of the history of science, technology and medicine in Non-Western cultures*. Dordrecht: Kluwer Academic Publishers.

Eves, H. (1964). *An introduction to the history of mathematics* (Rev. ed.). New York: Holt Rinehart Winston.

Fernandes, L. *Abacus: The art of calculating with beads*. Updated on November 8, 2004. http://www.ee.ryerson.ca:8080/~elf/abacus/. Selected by *Scientific American* as a winner of the 2003 Sci/Tech Web Awards.

Grundlach, B. H. (1969). The history of numbers and numerals. In K. B. John (Ed.), *Historical topics for the mathematics classroom* (pp. 18–36). Washington, DC: National Council of Teachers of Mathematics.

Karpinski, L. C. (1965). *The history of arithmetic*. New York: Russell & Russell.

Pullan, J. M. (1969). *The history of the abacus*. New York: Frederick A. Praeger.

Reynolds, B. E. (1993). The algorists vs. the abacists: An ancient controversy on the use of calculators. *The College Mathematics Journal, 24*(3), 218–223. Washington, DC: The Mathematical Association of America.

Smith, D. E. (1919). *Number stories of long ago*. Washington, DC: National Council of Teachers of Mathematics.

Smith, D. E. (1958). *History of mathematics* (Vol. 2). New York: Dover.

Smith, D. E., & Ginsberg, J. (1971). *Numbers and numerals*. Washington, DC: National Council of Teachers of Mathematics.

Struik, D. J. (1967). *A concise history of mathematics* (3rd Rev. ed.). New York: Dover.

Abortion

Malcolm Potts

Abortion, along with circumcision, is amongst the oldest operations known to human kind. While abortion meets an extraordinarily important need of the individual, society commonly treats it differently from other aspects of medical science. Usually, there is little honor to be gained by improving abortion technologies.

The explanations and beliefs different cultures develop concerning the origin and maturation of pregnancy help determine attitudes to abortion. The *Qu'rān*, for example, describes pregnancy as a process of increasing complexity progressing from, "a drop of seed, in a safe lodging, firmly affixed" to a "lump" with "bones, clothed with flesh", and some Islamic theologians permit abortion early in pregnancy. Most abortions are performed because the woman feels she cannot support the child if born, although unmarried women, especially in non-Western traditional societies, may abort for fear of punishment. In the ancient Ugandan royal household, abortion was carried out on princesses so as not to divide the kingdom.

Abortion is known in practically all cultures from preliterate societies to the most industrialized. Abortionists are often also traditional birth attendants or medicine men. A spectrum of techniques is used which differ in their complexity and in their consequences, and which are greatly influenced by the stage of pregnancy when the procedure is carried out. In non-Western societies most techniques fall into one of three categories: herbal remedies, abdominal massage, and the insertion of foreign bodies into the uterine cavity.

In many contemporary non-Western cultures a variety of brews and potions are concocted to bring on a late menstrual period. Such methods were also widely sold in Western cultures until the reform of the abortion law. The open sale of emmenogogues (medicines to bring on a late period) in Manila, Lima, or Dacca today finds a close parallel in Boston in the nineteenth century United States, or Birmingham, England in the middle of this century. The ▶ Jamu remedies sold every day in Indonesia include a number of emmenogoges. The use of a tea brewed with the spiny nettle (*Urtica magellanica*) by the Aymara Indians of Bolivia living near Lake Titicaca and the juice of hibiscus leaves (*Abelomschus diversifolius*) in the Pacific islands are two examples from among many herbal remedies in preliterate societies.

The use for abortifacient medications is usually limited to the first 6 or 8 weeks after the last menstrual period. Many do not work, but rely on the fact that spontaneous abortion is common and will often be ascribed to a traditional remedy when one has been used. Others are physiologically active, either on uterine muscle or the embryo, although they often need to be used in doses that may be toxic to the woman. In the 1970s and 1980s the Human Reproduction Program of the World Health Organization tested a number of such abortifacients from around the world, and at least one, from Mexico, underwent preliminary screening by a pharmaceutical company. The time of collection, the method of preparation, and details of use may all be critically important in determining the outcome. An alternative technique for studying traditional abortifacients was developed by Moira Gallen in the Philippines, who worked with vendors of traditional abortifacients and then followed up the women who used them. The data suggest some herbal remedies do indeed bring on a late period.

An amalgamation of Western and non-Western cultures has taken place in Brazil where the Western drug Cytotec, an oral form of prostaglandin, is sold illicitly to women with an unintended pregnancy. It is estimated there are one to four million illegally induced abortions in Brazil each year, and each woman has one to three abortions in a lifetime. Cytotec produces bleeding from the uterus which, although it does not always lead to abortion, is usually sufficient to take the woman to the hospital, where the abortion is invariably completed in the operating theater. It is relatively safe but can be very painful. Until restrictions were placed on sales in 1991, 50,000 packets a month were being sold.

The second set of abortion technologies, with a history stretching back to preliterate societies, involves physical trauma to the woman's body. Many cultures associate falls and physical violence with abortion, as did the ancient Hebrews (*Bible*: Exodus 21: 22). The oldest visual representation of an abortion anywhere in the world is on a bas relief in the great temples of Ankor Wat built by King Suryavarman II (AD 1130–1150). Massage abortion remains common from Burma, through Thailand and Malaysia to the Philippines and Indonesia. Traditional birth attendants use their hands, elbows, bare feet, or a wooden mallet (as portrayed on the Ankor reliefs) to pound the uterus and terminate an unwanted pregnancy. Operators begin by asking the woman to empty her bladder and then try to draw the uterus from beneath the pubic bone so they can apply pressure to the abdominal wall. Sometimes these procedures lead to vaginal bleeding and abortion with relative ease; on other occasions the pain may be so severe that the operator has to stop and return some other time. A study in Thailand estimated that 250,000 such massage abortions take place in the villages of Thailand each year. Gynecologists in Malaysia have described how women are sometimes admitted to hospital for what appear to be the symptoms of appendicitis, with fever and rigidity of their abdominal muscles; when the abdomen is open, the uterus is found to be so bruised and damaged that it may be necessary to do a hysterectomy.

This specialized technique, which has to be learnt from generation to generation, is largely limited to Southeast Asia, although the American Indian Crows and Assiniboines used a board, on which two women jumped, placed across the abdomen of a recumbent pregnant woman, and Queensland native Australians used a thick twine wound around the abdomen combined with "punching" the abdominal wall.

The third types of abortion techniques are the most common and are found in all continents. They involve passing a foreign body through the uterine cervix in order to dislodge the placenta and cause an abortion. In traditional societies a twig or root may be used and it may take a day or more for the procedure to work. The major risks are infection and hemorrhage. The Smith Sound Inuit used the thinned down rib of a seal with the point cased in a protective cover of tanned seal skin, which could be withdrawn by a thread when the instrument had been inserted into the uterus. The Fijians fashioned a similar instrument from *losilosi* wood, but without the protective cover for insertion, and the Hawaiians used a wooden dagger-shaped object up to 22 cm long which was perceived as an idol Kapo. In contemporary Latin America and much of urban Africa, the commonest method of inducing abortion is to pass soft urinary catheters, or *sonda*, such as those used by doctors when men have enlarged prostates. Such catheters are readily available, although traditional abortions do not always use adequate sterile techniques and, even under the best of conditions, leaving such a catheter in place can be associated with infection.

Epidemiological studies show beyond all doubt that the safest way of inducing first trimester abortion is through the use of vacuum aspiration, and most legal abortions in the Western world are done using this technique. A small tube, varying in diameter from something slightly larger than a drinking straw to about 1 cm, is passed through the cervix, and attached to a vacuum pump. In the first 3 months of pregnancy such a procedure generally takes about 5 min and is commonly done as an out patient procedure under local anesthesia.

Vacuum aspiration abortion was described in nineteenth century Scotland, but the technique used today was invented in China sometime in the 1950s by Wu and Wu. The method spread across certain parts of the Soviet Union and into Czechoslovakia and some other areas of Eastern Europe. In the 1960s a nonmedically qualified practitioner from California called Harvey Karman invented a piece of handheld vacuum aspiration equipment. Karman got the idea from descriptions of procedure performed in China, Russia, and Eastern Europe, and the flow of ideas has gone full circle with the syringe equipment now being widely used in many non-Western countries, such as Bangladesh, Vietnam, and Sri Lanka.

In the Ankor reliefs the women having abortions are surrounded by the flames of hell. Although abortion was disapproved of in the East, it was still considered a crime against the family, not against the state as it is commonly perceived in the West. Abortion before the felt fetal movements was legal in Britain and all states of the United States in 1800 and illegal in those same places by 1900. With the expansion of colonialism, Western abortion laws were imposed upon all colonized nations of the Third World. The nations of the then British Empire either adopted a form of the 1861 Offenses Against the Person Act of Queen Victoria's

England or a version of the Indian penal code. French colonies enacted the code of Napoleon and even countries that were not colonized, such as Thailand and Japan, adopted some form of restrictive abortion legislation in the nineteenth century derived from Western statutes.

The second half of the twentieth century has seen a reversal of many restrictive laws. The majority of the world's population now lives in countries which have access to safe abortion on request. The technologies used all over the world owe a great deal to non-Western philosophies and inventiveness.

See Also

▶ Childbirth
▶ Ethnobotany
▶ *Jamu*

References

Arilha, M., & Barbosa, R. M. (1993). Cytotec in Brazil: 'At least it doesn't kill. *Reproductive Health Matters, 2*, 41–52.

Devereux, G. (1955). *Abortion in primitive societies*. New York: Julian Press.

Gallen, M. (1982). Abortion in the Philippines: A study of clients and practitioners. *Studies in Family Planning, 13*, 35–44.

Narkavonkit, T. (1979). Abortion in rural Thailand: A survey of practitioners. *Studies in Family Planning, 10*, 223–229.

Wu, Y. T., & Wu, H. C. (1958). Suction curettage for artificial abortion: Preliminary report of 300 cases. *Chinese Journal of Obstetrics, 6*, 26.

Abraham Bar Ḥiyya (Savasorda)

Tony Lévy

Abraham bar ḥiyya, also called Savasorda (latinized from the Arabic *ṣāḥib al-shurṭa* = Chief of the guard), flourished in Barcelona, in Christian Spain, but was probablyeducated in the kingdom (*tā'ifa*) of Saragossa, during the period in which it was ruled by the Arabic dynasty of the Banū Hūd. Thus his scientific education could be related to the well known scientific talents of some of the Banū Hūd kings.

Having mastered the Arabic language and culture, he was a pioneer in the use of the Hebrew language in various fields. He wrote on philosophy, ethics, astronomy, astrology, mathematics, and calendrial calculations. He clearly indicated that his Hebrew compositions were written for Jews living in southern France, who were unacquainted with Arabic culture and unable to read Arabic texts.

Two mathematical compositions by Abraham Bar ḥiyya, and four astronomical ones are known.

Yesodey ha-tevuna u-migdal ha-emuna (The Foundations of Science and the Tower of the Faith) was supposed to be a scientific encyclopedia, of which only the mathematical sections survived. Presumably an adaptation from some unknown Arabic composition, it dealt with basic definitions and knowledge in arithmetic, geometry, and optics.

ḥibbur ha-meshiḥa we ha-īshboret (The Composition on Geometrical Measures) dealt with practical geometry. This book enjoyed a very large diffusion in medieval Europe in its Latin version, the *Liber embadorum*, translated by Plato of Tivoli (1145), who was assisted by the author himself. The importance of this text for the development of practical geometry in Europe has been noted by ancient and modern scholars.

Seferṣṣurat ha-areṣ we-tavnit kaddurey ha-raqi 'a (Book on the Form of the Earth and the Figure of Celestial Spheres), together with *ḥeshbon mahalakhot ha-kokhavim* (Calculations of the Courses of the Stars) and The *Luḥot* (The Astronomical Tables), offered a basic astronomical knowledge founded on Arabic sources such as the works of ▶ al-Farghānī and ▶ al-Battānī.

Sefer ha-'Ibbur (The Book of Intercalation) dealt with calendrial calculations and aimed "to enable the Jews to observe the Holy Days on the correct dates."

Bar ḥiyya can rightly be considered the founder of Hebrew scientific culture and language.

See Also

► al-Battānī

References

Ḥeshbon mahalakhot ha-kokhavim. La obra Sefer Heshbon Mahlekoth ha-Kokabin de R. Abraham bar Ḥiyya ha-Bargeloni. (1959). (J.-M. Millas-Vallicrosa, Ed.). Barcelona, Spain: Consejo Superior de Investigaciones Cientificas.

Ḥibbur ha-meshiḥa we ha-tishboret. Chibbur ha-Meschicha we ha-Tishboret. (1912) (M. Guttmann, Ed). Berlin, Germany.

Lévy, T. (2001). Les débuts de la littérature mathématique hébraïque: la géométrie d'Abraham bar Hiyya (XIe-XIIe siècle). *Micrologus, 9*, 35–64.

Millas-Vallicrosa, J.-M. (1949). La obra enciclopedica de R. Abraham bar Hiyya. *Estudios sobre historia de la ciencia espanola*. Barcelona, Spain: n.p. 219–262.

Sarfatti, G. (1968). *Mathematical terminology in Hebrew scientific literature of the middle ages* (pp. 61–129). Jerusalem, Israel: The Magnes Press (in Hebrew).

Stenschneider, M. (1867). Abraham Judaeus, Savasorda und Ibn Ezra. *Zeitschrift für Mathematik und Physik, 12*, 1–44. Rpt. *Gesammelte Schriften*. Berlin: M. Poppelauer, 1925. 388–406.

Yesodey ha-tevuna u-migdal ha-emuna. (1952). In J.-M. Millas-Vallicrosa (Ed.), *La obra enciclopedica Yesode ha-tebuna u-migdal ha-emuna de R. Abraham bar Ḥiyya ha-Bargeloni*. Madrid, Spain: Consejo Superior de Investigaciones Cientificas.

Abraham Ibn Ezra

Samuel S. Kottek

Abraham Ibn Ezra was born in Toledo, Spain in 1089. In his youth, he studied all the branches of knowledge that Arabic and Jewish gifted (and well to do) youngsters could master, and was mainly known as a poet. Around 1140, he left Spain and wandered through Italy, southern France, and England. Also, legend says that in his old age he traveled to the Holy Land. During his itinerant life, Ibn Ezra met scores of scholars and wrote a number of works, of which his commentary on the Pentateuch and the Prophets in the most widely known.

He was a real polymath, who wrote on Hebrew philology (*Moznei Leshon ha-Kodesh*), translated several works on grammar from Arabic into Hebrew, and wrote on the calendar, mathematics (*Sefer ha-Mispar*, Book of the Number), and philosophy and ethics (*Yesod Mora* on the meaning of the commandments). He is considered one of the Jewish Neoplatonists, in particular regarding his description of the soul. In his view, intellectual perfection is the only way to enjoy a relationship with the divine Providence. As a scientist, Ibn Ezra (also known by the name of Avenezra, sometimes misspelled Avenaris) is mainly known for his works on astronomy (*Sefer ha-ʿIbbur*: *Ta'amei ha-Luḥot*, Book on Intercalation) and for his treatise on mathematics mentioned above. He also composed a number of brief astrological works, most of them still unpublished. It is not known whether Ibn Ezra ever practiced medicine. He certainly showed in his biblical commentary a fair degree of knowledge in medicine and biology.

It has been said that Ibn Ezra wrote over 100 works, which seems rather exaggerated; certainly many fewer have survived. Ibn Ezra was the Paracelsian type of scholar, learning from each new experience, from each encounter with other scholars, living a simple life and despising wealth. It is particularly striking that he wrote only in Hebrew, contrary to nearly all his contemporaries in Spain who wrote in Arabic. This is mainly due to the fact that he wandered throughout Europe and North Africa, using the language that was common to all his coreligionists. He may be considered an ambassador of Spanish scholarship to the Jewish Diaspora at large. He died in 1164.

References

Akabia, A. A. (1957). Sefer ha-'Ibbur le-Rabbi Abraham ibn Ezra: Biurim, he'arot vehagahot (The book of the leap year: Explanations, remarks, and proofs). *Tarbiz, 26*(3), 304–316.

Ben Menaḥem, N. (1958). Iyyunim be-mishnat Rabbi Abraham ibn Ezra (Research in the teachings of Rabbi Abraham ibn Ezra). *Tarbiz, 27*(4), 508–520.

Goldstein, B. R. (1996). Astronomy and astrology in the works of Abraham ibn Ezra. *Arabic Sciences and Philosophy, 6*(1), 9–21.
Gómez Aranda, M. (2001). Aspectos cientificos en el Comentario de Abraham ibn Ezra al libro de Job. *Henoch, 23*(1), 81–96.
Gómez Aranda, M. (2003). *Ibn Ezra, Maimónides, Zacuto. Sefarad científica: la visión judía de la ciencia en la edad media*. Prólogo de Miguel García-Posada. Madrid, Spain: Nivola.
Heller-Wilensky, S. A. (1963). Li-sheelat meḥabero shel Sefer Sha'ar Hashamayim hameyuḥas le-Abraham ibn Ezra (To the question of the author of the book Sha'ar Hashamayim attributed to Abraham ibn Ezra). *Tarbiz, 32*(3), 277–295.
Langermann, Y. T. (1999). *The Jews and the sciences in the Middle Ages*. Aldershot, UK: Ashgate.
Leibowitz, J. O., & Marcus, S. (1984). *Sefer Hanisyonot: The book of medical experiences, attributed to Abraham ibn Ezra*. Jerusalem: Magnes.
Levy, R. (1927). *The astrological works of Abraham ibn Ezra*. Baltimore: Johns Hopkins University Press.
Lévy, T. (2001). Hebrew and Latin versions of an unknown mathematical text by Abraham Ibn Ezra. *Aleph, 1*, 295–305.
Millás-Vallicrosa, J. M. (1938). Avodato shel Rabbi Abraham ibn Ezra beḥokhmat ha-tekhunah (The work of Rabbi Abraham ibn Ezra in astronomical science). *Tarbiz, 9*, 306–322.
Sarton, G. (1931). *Introduction to the history of science* (Vol. II, pp. 187–189). Baltimore: Williams & Wilkins. Part 1.
Sela, S. (2001a). Abraham ibn Ezra's scientific corpus: Basic constituents and general characterization. *Arabic Sciences and Philosophy: A Historical Journal, 11*(1), 91–149.
Sela, S. (2001b). Abraham Ibn Ezra's special strategy in the creation of a Hebrew scientific terminology. *Micrologus, 9*, 65–87.
Sela, S. (2003). *Abraham Ibn Ezra and the rise of Medieval Hebrew science*. Boston: Brill.
Steinschneider, M. (1880). Abraham ibn Ezra. *Zur Geschichte der mathematischen Wissenschaften im XII. Jahrhundert. Supplement to Zeitschrift für Mathematik und Physik, 25*, 59–128.

Abū ʻl-Barakāt

Y. Tzvi Langermann

Abū al-Barakāt al-Baghdādī (d. 1164 or 1165) was one of the most original thinkers of the medieval period. Born a Jew in about 1080, but converted late in life to Islam, Abū ʻl-Barakāt was a prominent physician and natural philosopher who achieved considerable fame during his own lifetime, as his appellation *awḥad al-zamān* (Unique of His Age) attests. His numerous insights into physics and metaphysics have been elucidated by the late Shlomo Pines in a number of brilliant studies, on which this résumé depends in large measure.

Abū ʻl-Barakāt's contributions are all contained in his *chef d'œuvre*, *al-Muʿtabar* (That Which has been Attained by Reflection). Although there may be some doctrinal discrepancies between various passages in the book, which may be due to the fact that the work is actually a collection of notes compiled over a considerable period of time, each section by itself displays a very clear and systematic exposition, surveying earlier opinions on the subject, objections to these, and possible answers to the objections (including the occasional concession that the objection is valid and necessitates a revision of the original idea), followed by Abū ʻl-Barakāt's own opinion. Abū ʻl-Barakāt exhibits a remarkable ability to disentangle issues that had become densely intertwined through centuries of debate, for example the three notions of time, space, and the infinite. Particularly significant are the occasions when the author gives great, occasionally decisive, weight to "common opinion," on the grounds that the issues at hand – the notions of time and space are the most important to fall into this group – involve a priori concepts which must be elucidated by examining how people actually perceive, rather than a posteriori academic analysis.

Some of the ideas which Abū ʻl-Barakāt advances in the course of his discussions prefigure much later notions which proved to be correct: for example, the idea that a constant velocity applied to a moving body causes it to accelerate. Others, by contrast, showed themselves to be wrong: for instance, the idea that every type of body has a characteristic velocity which reaches its maximum when the resistance is zero. (In this way, Abu ʻl-Barakāt answers the objection that bodies moving in a vacuum would have an infinite velocity.) All in all, the work of Abū ʻl-Barakāt and its continuation by his student

Fakhr al-Dīn ▶ al-Rāzī constituted a most serious challenge to the formulations of Ibn Sīnā, which then dominated physical and metaphysical thought in Near East.

All that we possess in the way of medical writings by Abū ʻl-Barakāt are a few prescriptions for remedies. These remain in manuscript and are as yet unstudied.

See Also

▶ Abū'l-Fidāʾ
▶ al-Rāzī
▶ Ibn Sīnā (Avicenna)

References

Abū ʻl-Barakāt. (1938–1940). *al-Muʿtabar (That which has been attained by reflection)* In S. Yaltkaya (Ed.), 3 Vols. Hyderabad, India: Osmania Publication Bureau.

Pines, S. (1979). *Studies in Abu ʻl-Barakāt al-Baghdādī, physics and metaphysics (The collected works of Shlomo Pines)* (Vol. 1). Jerusalem: Magnes Press/E. J. Brill.

Abū Jaʿfar al-Khāzin

Jan P. Hogendijk

Abū Jaʿfar Muḥammad ibn al-ḥusay al-Khāzin was a mathematician and astronomer who lived in the early tenth century AD in Khorasān. Until recently, it was believed that there were two different mathematicians in the same period, namely Abū Jaʿfar al-Khāzin and Abū Jaʿfar Muḥammad ibn al-ḥusayn, but in 1978 Anbouba and Sezgin showed that they are the same person.

In mathematics, Abū Jaʿfar al-Khāzin is mainly known because he was the first to realize that a cubic equation could be solved geometrically by means of conic sections. ▶ Al-Māhānī (ca. AD 850) had shown that an auxiliary problem in Archimedes' *On the Sphere and Cylinder* II: 4, which Archimedes had left unsolved, could be reduced to a cubic equation of the form $x^3 + c = ax^2$. Abū Jaʿfar knew the commentary to Archimedes' work by Eutocius of Ascalon (fifth century AD), in which Eutocius discusses a solution of the same auxiliary problem by means of conic sections. Abū Jaʿfar drew the conclusion that the equation $x^3 + c = ax^2$ could also be solved by means of conic sections. Abū Jaʿfar also studied a number of other mathematical problems. He stated that the equation $x^3 + y^3 = z^3$ did not have a solution in positive integers, but he was unable to give a correct proof. He also worked on the isoperimetric problem, and he wrote a commentary to Book X of Euclid's *Elements*.

In astronomy, Abū Jaʿfar's main work was the ▶ *Zīj alṣafāʾiḥ* (the Astronomical Handbook of Plates). A manuscript of this work has recently been discovered in Srinagar. The work deals with a strange variant of the astrolabe. One such instrument, made in the twelfth century, was still extant in the beginning of this century in Germany, but it has since disappeared. Photographs of this instrument have been published by David King. Abū Jaʿfar developed a homocentric solar model, in which the sun moves in a circle with the earth as its center, in such a way that its motion is uniform with respect to a point which does not coincide with the center of the earth.

See Also

▶ al-Māhānī

References

Anbouba, A. (1978). L 'Algèbre arabe; note annexe: identité d' Abū Jaʿfar al-Khāzin. *Journal for History of Arabic Science, 2*, 98–100.

King, D. A. (1980). New light on the *Zīj al-ṣafāʾiḥ. Centaurus, 23*, 105–117. (Reprint in D. A. King. *Islamic Astronomical Instruments*. London: Variorum, 1987).

Lorch, R. (1986). Abū Jaʿfar al-Khāzin on Isoperimetry and the Archimedean Tradition. *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften, 3*, 150–229.

Samsó, J. (1977). A homocentric solar model by Abū Jaʿfar al-Khāzin. *Journal for History of Arabic Science, 1*, 268–275.

Abū Kāmil

Jacques Sesiano

Abū Kāmil, Shujāʿ ibn Aslam (ca. 850–ca. 930), also known as "the Egyptian Reckoner" (*al-ḥāsib al-miṣrī*) was, according to the encyclopedist Ibn Khaldūn's report on algebra in his *Muqaddima*, chronologically the second greatest algebraist after ► al-Khwārizmī. He was certainly one of the most influential. The peak of his activity seems to have been at the end of the ninth century.

Although at the beginning of his *Kitāb f ī'l-jabr wa'l-muqābala* (Algebra) he refers to al-Khwārizmī's similar work, Abū Kāmil's purpose is radically different, for he is addressing an audience of mathematicians presumed to have a thorough knowledge of Euclid's *Elements*. His *Algebra* consists of four main parts.

1. Like his predecessor, Abū Kāmil begins by explaining how to solve the six standard equations and to deal with algebraic expressions involving an unknown and square roots. The next section (Book II) contains, as in his predecessor's work, six examples of problems and the resolutions of various questions, but the whole is notably more elaborate and geometrical illustrations or proofs are systematically appended. With Book III comes a difference, already hinted at in the introduction to the treatise: the problems now contain quadratic irrationalities, both as solutions and coefficients, and require notable proficiency in computing. Quadratic irrationalities may thus be said to enter definitely the domain of mathematics and no longer be confined to their Euclidean representation as line segments.
2. These extensions found in Book III are put to immediate use in the resolutions of problems involving polygons in which the link between their sides and the radii of a circumscribed circle is reducible to a quadratic equation – since they are all constructible by ruler and compass.
3. The subsequent set of quadratic indeterminate equations and systems is most interesting. The methods presented are similar to those of Diophantus's *Arithmetica*, but there are new cases and the problems are presented in a less particular form. Abū Kāmil surely relied on some Greek material unknown to us.
4. A set of problems which are, broadly speaking, applications of algebra to daily life are directly appended to the former. Some of these, which correspond to highly unrealistic situations, belong more to recreational mathematics. The inclusion of such problems in an algebraic textbook was to become a medieval custom, with both mathematical and didactical motives. The *Algebra* ends with the classical problem of summing the successive powers of 2, which, from the ninth century on, became attached to the 64 cells of the chessboard.

Abū Kāmil's Arabic text is preserved by a single, but excellent, manuscript. The *Algebra* was commented upon several times, in particular in Spain, and the first large mathematical book of Christendom, Johannes Hispalensis's *Liber mahameleth*, is basically a development and improvement of parts *a* and *d*. Despite the *Algebra*'s importance in Spain, no Latin translation was undertaken until the fourteenth century, when Guillelmus (presumably: de Lunis) translated half of it (up to the beginning of part *c*). This translation is better than Mordekhai Finzi's fifteenth century Hebrew one, which, however, covers the whole work. Since these translations were late, Abū Kāmil had no direct influence in the Christian West. Similar material, however, may be found in writings of Leonardo (Fibonacci) of Pisa (fl. 1220).

Abū Kāmil also wrote *Kitāb al-ṭair* (Book of the Birds), a small treatise consisting of an introduction and six problems all dealing with the purchase of different kinds of birds, of which one knows the price per unit, the total number bought and the amount spent (both taken to be 100). Since there are more unknown kinds (three to five) than equations, these linear problems are all indeterminate. Abū Kāmil undertook to determine their number of (positive integral) solutions, which he found to be, respectively, 1, 6, 96 (correct: 98), 304, 0, 2676 (correct: 2,678). Although such problems are frequently met in the medieval world, Abū Kāmil remained seemingly unparalleled in his search for all solutions in various cases.

Kitāb al-misāḥa wa'l-handasa, or *Kitāb misāḥat al-araḍīn* (On Measurement and Geometry) is an elementary treatise on calculating surfaces and volumes of common geometrical figures. Since it is meant for beginners, demonstrations and algebra are left out. Why Abū Kāmil found it necessary to write such an elementary book becomes clear when he describes some of the formulas then in use by official land surveyors in Egypt.

Finally, *Kitāb al-waṣāyābi'l-juḏūr* or *Kitāb al-waṣāyābi'l-jabr wa'l-muqābala* (Estate Sharing Using Unknowns, or Using Algebra) applies mathematics to inheritance problems. Abū Kāmil begins by explaining the requirements of the Muslim laws of inheritance and discussing the opinions of known jurists.

Bibliographic sources inform us that Abū Kāmil also wrote another treatise on algebra, and a further one on the rule of false position.

Note that two of the subjects included by ▶ al-Khwārizmī in his *Algebra* were treated by Abū Kāmil in separate works. From that time onward, algebra textbooks adopted the same form as his.

See Also

- ▶ Algebra in Islamic Mathematics
- ▶ Algebra, Surveyors'
- ▶ Mathematics Practical and Recreational
- ▶ Number Theory in Islamic Mathematics
- ▶ Surveying

References

Kāmil, A. (1986). *The book of algebra (reproduction of the Arabic manuscript)*. Frankfurt, Germany: Institut für Geschichte der arabischislamischen Wissenschaften.

Levey, M. (1966). *The Algebra of Abū Kāmil*. Ed. of the Hebrew translation of part a. Madison, WI: University of Wisconsin.

Lorch, R., & Sesiano, J. (1993). Edition of the Latin translation. In M. Folkerts & J. Hogendijk (Eds.), *Vestigia mathematica: Studies in medieval and early modern mathematics in honor of H. L. L. Busard* (pp. 215–252). Amsterdam, The Netherlands: Rodopi. and 315–452.

Sesiano, J. (1977). Les Méthodes d'analyse indéterminée chez Abū Kāmil (on part c of the *algebra*). *Centaurus, 21*, 89–105.

Sesiano, J. (1996). Le *Kitāb al-Misāḥa* d'Abū Kāmil. *Centaurus, 38*, 1–21.

Suter, H. (1909/1910). Die Abhandlung des Abū Kāmil über das Fünfeck und Zehneck (On part b of the *algebra*). *Bibliotheca Mathematica, 10*, 15–42.

Suter, H. (1910/1911). Das Buch der Seltenheiten der Rechenkunst von Abū Kāmil el-Miṣrī (On the *book of the birds*). *Bibliotheca Mathematica, 11*, 100–120.

Abū Maʿshar

Richard Lemay

Arabic sources such as the *Kitāb al-Fihrist* give the date of Abū Maʿshar al-Balkī's death as 273 of the Hegira, which is AD 886, stating that he was over 100-years old. Since he was of Persian (Afghan) origin these may well be solar years rather than the lunar years of the Muslim calendar. Therefore his age at his death could have been reckoned as "over" 100 years if counted in lunar years in Muslim fashion, or else as 100 solar years. David Pingree claimed to have found the exact date of his birth to be August 10, 787 in a natal horoscope in Abū Maʿshar's *Nativities*. The trouble with this calculation is that Abū Maʿshar himself, in *Mudhākarāt* (Recollections), lamented the fact that he did not know the exact date of his birth and had to rely therefore on a "universal" horoscope he had drawn up. The *Mudhākarāt* then supplies the basic elements of this universal horoscope. Matching these data with Pingree's, it is probably safe to consider the year 171 H/AD 787 as his birth date.

Abū Maʿshar, known in the West as Albumasar, was born in Balkhī in Khurāsān, actually Afghanistan, and seems to have lived there and acquired a reputation as an astrologer much before he came to settle in Baghdad during the reign of the Caliph ▶ al-Maʾmūn (813–833), shortly after 820. He lived in Iraq until the end of his life in 886. He must have traveled, at least up and down the Tigris, since in the *Mudhākarāt* he is shown refusing to embark on the stormy waters of the Tigris. He died in Wasit, a city situated in the Sawād, midway between Baghdad and Basra.

Abū Maʿshar's early years are clouded in confusion because of an error committed by the earliest and most important Arab bibliographer, Ibn al-Nadīm (1970), in his *Kitāb al-Fihrist*. Writing in the late tenth century, nearly a century after Abū Maʿshar's death, al-Nadīm (d. ca. AD 987) apparently confused Abū Maʿshar the astrologer from Balkh with another Abū Maʿshar, called an-Najīh, who lived in Medina but died in Baghdad AD 787, the year of Abū Maʿshar's birth.

Once settled in Baghdad, where he spent the remaining 60 years of his life, Abū Maʿshar seems to have been involved in its cultural activity, but also in its tumultuous civic life at a time when "nationalisms" in the form of the *Shuʿūbiya* (non-Arabs) were raising their aspirations to cultural parity with the dominant Arabs. Abū Maʿshar's reputation as an astrologer, his newly found friendship with ▶ al-Kindī, and the credit he gained through astrological predictions assessing the power of rulers must have opened for him the doors of the political and learned elite of Baghdad. Al-Nadīm relates an episode in which Abū Maʿshar was punished with lashes by the Caliph for a realistic prediction that the Caliph disliked. Both Abū Maʿshar and al-Kindī, using an intricate system of astral conjunctions inherited from the Sassanian tradition, attempted to anticipate the duration of the Arab rule. In his *Risāla* (Epistle) on the duration of the rule of Islam, al-Kindī tried to comfort the ruling Caliph by giving the Arab rule a minimum span of some 693 years, longer than Abū Maʿshar's prediction. In fact Abū Maʿshar gives a total of 693 years, just as al-Kindī did. Still, in combination with the parallel scheme of the two maleficent planets Saturn and Mars affecting the meaning of the conjunctions of Saturn and Jupiter, Abū Maʿshar tended to reduce the duration to some 310 or 330 years only, which would bring the end of Arab rule closer, thus encouraging the aspirations of the *shuʿūbiyya*.

The *Mudākarāt* of Abū Saʿīd further tell us that, along with other astrologers, Abū Maʿshar accompanied the army of al-Muwaffaq in its campaign against the rebellious Zanj. Astrologers were used by both sides during these civic troubles. Abū Maʿshar's credit as an astrologer served him in these circumstances, for he may have been consulted by both sides in the Rebellion. At any rate he died in the city of Wasit, south of Baghdad, a city which had seen the farthest advance of the rebellious Zanj army and had been reconquered only shortly before by al-Muwaffaq.

The *Fihrist* credits Abū Maʿshar with 36 works, to which David Pingree adds six more. The list has remained fairly the same for all later bibliographers. This holds true for the original Arabic works as well as for the numerous translations into Latin, Greek, Hebrew, and medieval Romance languages. The uncertainty is due to a number of factors. Abū Maʿshar may have produced some works in several versions or editions. He has been imitated in a number of ways by later Arab authors, some of whom displayed his name prominently at the beginning of their own work, thus complicating the task of the bibliographer. Above all there is a lack of any systematic survey of Abū Maʿshar's production. In addition to the confusion still affecting the Arabic originals, a number of Abū Maʿshar's works were translated into so many media during the Middle Ages that the task of surveying the authentic remains is enormous. This illustrates the immense popularity enjoyed by Abū Maʿshar in the West.

See Also

▶ Astrology in Islam

References

Primary Sources

Abū Maʿshar. (1488). *Albumasaris Flores astrologiae*. Augsburg, Germany: Erhard Ratdolt.

Abū Maʿshar. (1489a). *Introductorium in astronomiam Albumasaris Abalachi octo continens libros partiales*. Augsburg, Germany: Erhard Ratdolt.

Abū Maʿshar. (1489b). *Albumasar de magnis coniunctionibus et annorum revolutionibus ac earum profectionibus*. Augsburg, Gernmany: Erhard Ratdolt.

Abū Maʿshar. (1968). In D. Pingree (Ed.), *Albumasaris. De revolutionibus nativitatum*. Berlin, Germany: Bibliotheca Scriptorum Graecorum et Romanorum Teubneriana.

Abū Maʿshar. (2000). *On historical astrology: The book of religions and dynasties (on the great conjunctions)* (K. Yamamoto & C. Burnett, Ed. & Trans.). Leiden, The Netherlands: Brill.

Ibn al-Nadīm. (1970). *Kitāb al-Fihrist*, (Vol. II, pp. 656–658) (B. Dodge, Trans.). New York: Columbia University Press.

Secondary Sources

Dunlop, D. M. (1971). The *Mudhākarāt fiʿIlm an-nujūm* (Dialogues on astrology) attributed to Abū Maʿshar al-Balkhī (Albumasar). In C. E. Bosworth (Ed.), *Iran and Islam, in memory of the Late Vladimir Minorsky* (229–246). Edinburgh, UK: Edinburgh University Press.

Lemay, R. (1962). *Abu Maʿshar and Latin Aristotelianism in the twelfth century*. Beirut, Lebanon: American University of Beirut.

Millas Vallicrosa, J.M. (1913–1936). Abū Maʿshar. *Encyclopedia of Islam*. Leiden, The Netherlands: E. J. Brill.

Pingree, D. (1968). *The thousands of Abū Maʿshar*. London: The Warburg Institute.

Pingree, D. (1975). Abū Maʿshar. In C. C. Gillispie (Ed.), *Dictionary of scientific biography*. New York: Charles Scribner's Sons.

Thorndike, L. (1954). Albumasar in Sadan. *Isis, 45*, 22–32.

Abū'l-Fidāʾ

Emilia Calvo

Abū'l-Fidāʾ Īsmāʿīl ibn ʿalī ibn Maḥmūd ibn Muḥammad ibn ʿUmar ibn Shahanshāh ibn Ayyūb ʿImād al-Dīn al-Ayyūbī was a prince, historian, and geographer belonging to the Ayyūbid family. He was born in Damascus, Syria in AD 1273 and soon began his military career against the Crusaders and the Mongols. In AD 1299 he entered the service of the Sultan al-Malik al-Nāṣir and, after 12 years, he was installed as governor of ḥamā. Two years later he received the title of al-Malik al-ṣāliḥ. In AD 1320 he accompanied the Sultan Muḥammad on the pilgrimage to Mecca and was given the title of al-Malik al-Muʾayyad. He died at ḥamā, Syria in AD 1331.

Abū'l-Fidāʾ is the author of some poetic productions, such as the version in verse of al-Māwardī's juridical work *al-Hāwī*. However, his celebrity is based on two works which can be considered basically compilations of earlier works which he elaborated and completed. One of them is the *Mukhtaṣar Taʾrīkh al-bashar* (A Summary on the History of Humanity) written in AD 1315 as a continuation of the *Kāmil fī-l-taʾrīkh* of Ibn al-Athīr. It was divided into two parts: the first was devoted to pre-Islamic Arabia and the second to the history of Islam until AD 1329. It was kept up to date until AD 1403 by other Arabic historians. It was translated into Western languages and became the basis for several historical syntheses by eighteenth-century Orientalists.

Abū'l-Fidāʾ's most important scientific work is *Taqwīm al-buldān* (A Sketch of the Countries) written between AD 1316 and 1321. It consists of a general geography in 28 chapters.

This book includes the problems and results of mathematical and physical geography without touching upon human geography or geographical lexicography. There is a table of the longitudes and latitudes of a number of cities, including the differing results found in the sources, setting up a comparative table for geographical coordinates. Among the sources of the book are geographers such as Ibn Hawqal and Ibn Saʿīd al-Maghribī.

This work was translated into German, Latin, and French between the sixteenth and the nineteenth centuries, making a significant contribution to the development of geography.

References

Gibb, H. A. R. (1960). *Abū l-Fidāʾ* (Encyclopédie de l'Islam 2nd ed., Vol. 1). Leiden, The Netherlands/Paris: E. J. Brill/G. P. Maisonneuve.

Reinaud, J. -T. (1848/1985). *Géographie d'Aboulfëda traduite de l'arabe en français et accompagnée de notes et d'éclaircissements* (Vol. 2). Paris. Rpt.

Frankfurt, Germany: Institut für Geschichte der Arabisch-Islamischen Wissenschaften.
Sarton, G. (1947). *Introduction to the history of science* (Vol. 3). Baltimore, MD: Williams and Wilkins.
Sezgin, F. (1987). *The contribution of the Arabic-Islamic geographers to the formation of the world map*. Frankfurt, Germany: Institut für Geschichte der Arabisch-Islamischen Wissenschaften.
Vernet, J. (1970). *Abū'l-Fidā'* (Dictionary of scientific biography, Vol. 1). New York: Charles Scribner's Sons.

Abū'l-Ṣalt

Julio Samsó

Abū'l-ṣalt is known as Abū'l-ṣalt al-Dānī. He was an Andalusian polymath born in Denia in 1067. In about 1096 he went to Egypt where he lived for 16 years. An unsuccessful attempt to rescue a boat loaded with copper which had sunk in the harbor of Alexandria cost him 3 years in prison, after which he migrated to Mahdiyya (Tunis) where he died in 1134.

He wrote about pharmacology (a treatise on simple drugs, *Kitāb al-adwiya al-mufrada*, translated into Latin by Arnold of Vilanova), music, geometry, Aristotelian physics, and astronomy, and he seems to have been interested in a physical astronomy, different from the Ptolemaic mathematical astronomy which predominated in al-Andalus. His treatise on the use of the astrolabe, *Risāla fī-l-ʿamal bi-l-asṭurlāb*, written while he was in prison, probably introduced into Eastern Islam the characteristic Andalusian and Maghribi device, present in the back of Western instruments, which establishes the relation between the date of the Julian year and the solar longitude. He is also the author of a short treatise on the construction and use of the equatorium, *ṣifat ʿamal ṣafiḥa-j-āmiʿa tuqawwim bi-hā-jamiʿ al-kawākib al-sabʿa* (Description of the Way to Use a General Plate With Which to Calculate the Positions of the Seven Planets) which follows the techniques developed in al-Andalus by Ibn al-Samḥ (d. 1035) and ► Ibn al-Zarqāllu (d. 1100), although it also presents original details which show his ingenuity. He probably reintroduced this instrument in the Islamic East where it had appeared in the tenth century but was later forgotten until it was recovered by al-Kāshī (d. 1429).

See Also

► Ibn al-Zarqāllu

References

Comes, M. (1991). *Ecuatorios Andalusíes. Ibn al-Samḥ al-Zarqāllu y Abū'l Ṣalt* (pp. 139–157). Barcelona, Spain: Instituto de Cooperación con el Mundo Arabe and Universidad de Barcelona. 237–251.
Labarta, A. (1998). Traducción del prólogo del "Libro de medicamentos simples" de Abû-l-Salt de Denia/Ana Labarta. *Dynamis: Acta Hispanica ad Medicinae Scientiarumque Historiam Illustrandam, 18*, 479–487.
Samsó, J. (1992). *Las Ciencias de los Antiguos en al-Andalus* (pp. 313–317). Madrid, Spain: Mapfre.

Abū'l-Wafāʾ

Yvonne Dold-Samplonius

Abū'l-Wafāʾ al-Būzjānī, Muḥammad ibn Muḥammad ibn Yaḥyā ibn Ismāʿīl ibn al-'Abbās, was born in Būzjān (now in Iran) on 10 June 940. After he moved to Baghdad in 959, he wrote important works on arithmetic, trigonometry, and astronomy.

Abū'l-Wafāʾ provided new solutions to many problems in spherical trigonometry and computed trigonometric tables with an accuracy that had not been achieved until his time. He made astronomical observations and assisted at observations in the garden of the palace of Sharaf al-Dawla. Finally, he wrote two astronomical handbooks, the *Wāḍiḥ* ► Zīj and *al-Majisṭī* (*Almagest*). More information about Abū'l-Wafāʾ's tables must be obtained from *zījes* that have incorporated material from his works, such as the *Baghdādī Zīj*, compiled shortly before the year 1285 by Jamāl al-Dīn al-Baghdādī. A solar equation table attributed to Abū'l-Wafāʾ occurs in it.

Several later *zījes* incorporate Abū'l-Wafāʾ's mean motion parameters. Various sine and cotangent values which he gave in the extant part of *al-Majisṭī* are equal to the values found in al-Baghdādī's sine and cotangent tables. Furthermore, al-Baghdādī's table for the equation of daylight was computed by means of inverse linear interpolation in a sine table with accurate values to four sexagesimal places for every 15° of the argument, and Abū'l-Wafāʾ is known to have computed an accurate sine table with just that format.

In *Risāla fī iqāmat al-burhān 'alā 'l-dā'ir min al-falak min qaws al-nahār wa'rtifā' nisf al-nahār wa'rtifā' al-waqt* (On Establishing the Proof of the [rule for finding the] Arc of Revolution from the Day Arc, the Noon Altitude, and the Altitude at the Time), Abū'l-Wafāʾ deals with a fundamental problem of ancient astronomy that of finding the time in terms of solar altitude. He mentions in the introduction that the formula stated by Ḥabash al-Hāsib (fl. 850) is only approximate. Abū'l-Wafāʾ gives three proofs of the formula. The procedure of the first two proofs deals entirely with rectilinear configurations inside the sphere, in spite of the fact that the relation being investigated concerns arcs on the surface of the sphere. This technique was characteristic of Hindu spherical astronomy, as well as that of the Greeks prior to the application of Menelaus' Theorem. The method used in the third proof consists essentially of two applications of the Transversal Theorem. Contrary to Hindu trigonometry and most Islamic astronomers, Abū'l-Wafāʾ was one of the few who defined the trigonometric functions with respect to the unit circle, as is the case nowadays. In *Fī ḥirāfat al-abʿād bain al-masākin* (On the Determination of the Distances Between Localities) Abū'l-Wafāʾ gives two rules for calculating the great circle distance between a pair of points on the earth's surface. He applies both to a worked example: given the terrestrial coordinates of Baghdad and Mecca he calculates the distance between them, a matter of some interest to Iraqi Muslims undertaking the pilgrimage. The first method employs standard medieval spherical trigonometry and can be regarded as a byproduct of a common procedure for calculating the *qibla*, the direction of Muslim prayer. It is called by ► al-Bīrūnī "the method of the *zījes*." The second method is less ordinary and its validity is not obvious. In addition to the tangent function, it employs the versed sine, a term Abū'l-Wafāʾ does not use in the treatise studied above, but which appears frequently in the literature. The origin of this second rule might stem from the so-called *analemma method*, a common and useful ancient technique for solving spherical astronomical problems. The general idea was to project or rotate elements of the given solid configuration down into a single plane, where the desired magnitude appeared in its true size. The resulting plane configuration was then solved by constructions to scale or by plane trigonometry. Aside from the trigonometry, the text is of interest as an intact example of medieval computational mathematics. Numbers are represented in Arabic alphabetical sexagesimals throughout. The results of the multiplications suggest that all operations were carried out in sexagesimal arithmetic, with none of the very common intermediate transformations into decimal integers. Trigonometric functions and their inverses are carried out to four sexagesimal places. Al-ḥubūbī challenged Abū'l-Wafāʾ to produce and prove a rule for calculating the area of a triangle in terms of its sides. In his *Jawāb Abī al-Wafāʾ Muḥ ibn Muḥal-Būzjānī ʿammā sa'alahu al-Faqīh Abū ʿAlī al-ḥasan ibn ḥārith al-ḥub ūbī fī misāḥat al-muthallathāt* (Answer of Abū'l-Wafāʾ to the Question Put to Him by the Jurist Abū 'Alī al-ḥasan al-Hubūbī on Measuring the Triangle), Abū'l-Wafāʾ gives three such rules. None of these is identical with "Heron's Rule," but all are equivalent to it. The earliest work on finger reckoning that has survived is Abū'l-Wafāʾ's *Fīmāyahtāju ilaihi l-kuttāb wa-l-ummāl min 'ilm al-ḥisāb* (On What Scribes and Officials

Need from the Science of Arithmetic). As the name implies, it was written for state officials, and therefore gives an insight into tenth-century life in Islam from the administrative point of view. Three more works demonstrate Abū'l-Wafāʾ's interest in practical mathematics: *Fīmā yahtāju ilaihi as-sāniʿmin aʿmāl al-handasīya* (On the Geometrical Constructions Necessary for the Craftsman), written after 990; *al-Mudkhal al-ḥifzī ilā ṣināʿat al-arithmāṭiqī* (Introduction to Arithmetical Constructions); and *Risāla al-shamsīya fī l-fawāʾid al-ḥisābīya* (On the Benefit of Arithmetic).

On What Scribes and Officials Need, written between 961 and 976, enjoyed widespread fame. The first three parts, "On Ratio," "On Multiplication and Division," and "Mensuration," are purely mathematical. The other four contain solutions of practical problems with regard to taxes, problems related to harvest, exchange of money units, conversion of payment in kind to cash, problems related to mail, weight units, and five problems concerning wells. In this compendium Abū'l-Wafāʾ systematically sets forth the methods of calculation used by merchants, by clerks in the departments of finance, and by land surveyors in their daily work; he also introduces refinements of commonly used methods and criticizes some for being incorrect. Considering the habits of the readers for whom the textbook was written, Abū'l-Wafāʾ completely avoids the use of numerals. Numbers are written in words, and their calculations are performed mentally. To remember the results of intermediary steps, calculators bent their finger joints in conventional ways which enabled them to indicate whole numbers from 1 to 9,999. This same device was repeated to indicate numbers from 10,000 onward. All procedures, often quite complex, are only described by words. This treatise on practical arithmetic provides the model for all the treatises on the subject from the tenth to the sixteenth centuries.

He is cited as a source or an authority, but more often can only be discerned underneath. In the *Geometrical Constructions Necessary for the Craftsman* Abū'l-Wafāʾ discusses a host of interesting geometrical constructions and proofs. He constructs a regular pentagon, a regular octagon, and a regular decagon. The construction of the regular pentagon with a "rusty" compass is especially noteworthy. Such constructions are found in the writings of the ancient Hindus and Greeks, but Abū'l-Wafāʾ was the first to solve a large number of problems using this compass with fixed opening.

Renaissance Europe had a great interest in these constructions. The possible practical applications (such as making decorative patterns) may have been an additional motivation for studying things like a regular (or perhaps equilateral) pentagon inscribed in a square. However, the importance of such applications should not be overestimated. In proposing his original and elegant constructions, Abū'l-Wafāʾ simultaneously proved the inaccuracy of some practical methods used by the craftsmen.

To honor Abū'l-Wafāʾ, a crater on the moon was named after him. He died in Baghdad in 997 or 998.

See Also

▶ Algebra, Surveyors'
▶ Ḥabash al-Ḥāsib
▶ Mathematics Practical and Recreational
▶ Qibla and Islamic Prayer Times

References

Abū'l-Wafāʾ al-Būzjānī. (1979). In: S. A. al-ʿĀlī (Ed.). *Knowledge of geometry necessary for the craftsman*. Baghdad, Iraq: University of Baghdad Centre for the Revival of the Arabic Scientific Heritage, (in Arabic).

Aghayani Chavoshi, J. (2000). Le pentagone régulier chez Abu al-Wafa, Dürer et Léonard de Vinci. *Scienza e storia N, 13*, 79–86.

Ehrenkreutz, A. S. (1962). The Kurr system in Medieval Iraq. *Journal of the Economic and Social History of the Orient, 5*, 309–314.

Kennedy, E. S. (1984). Applied mathematics in the tenth century: Abū'l-Wafāʾ calculates the distance Baghdad-Mecca. *Historia Mathematica, 11*, 192–206.

Kennedy, E. S., & Mawaldi, M. (1979). Abū'l-Wafāʾ and the Heron Theorems. *Journal of the History of Arabic Science, 3*, 19–30.

Nadir, N. (1960). Abū'l-Wafāʾ on the solar altitude. *The Mathematics Teacher, 53*, 460–463.

Saidan, A. S. (1973). *The arithmetic of Abū al-Wafāʾ al-Būzajānī*. Amman, Jordan: al-Lajnah al-Urdunnīyah lil-Taʿrīb wa-al-Nasr wa-al-Tarjamah.
Saidan, A. S. (1974). The arithmetic of Abū'l-Wafāʾ. *Isis, 65*, 367–375.
Youschkcvitch, A. P. (1975). Abū'l Wafāʾ. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 1, pp. 39–43). New York: Charles Scribner's Sons.

Acoustics at Chichen Itza

Frans A. Bilsen
Delft University of Technology, Delft, The Netherlands

A Chirp Echo from El Castillo Pyramid

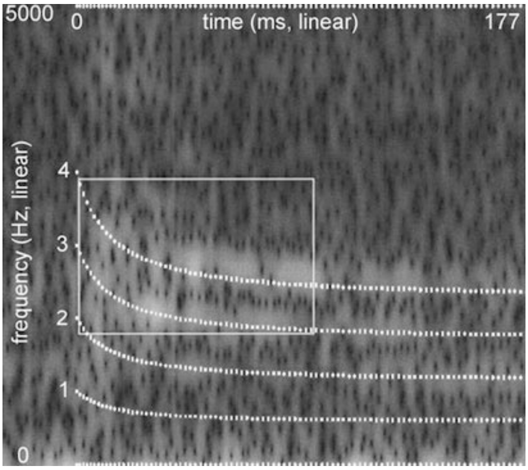
At Chichen Itza in Mexico, there is a Mayan ruin with a pyramid named El Castillo that produces an echo in response to a handclap. According to some authors, it sounds like the chirp of a quetzal bird. It was felt by Lubman and others that the periodic structure of the central staircase (see Fig. 1) is responsible for the chirp-like sound of the echo (Lubman, 1998a, b). Declercq, Degrieck, Briers, & Leroy (2004) performed a spectral analysis of the echo sound as recorded by Lubman and tried to find an explanation by applying optical diffraction theory to the periodic structure of the steps of the pyramid. Bilsen (2006), on the other hand, proposed an explanation based on auditory pitch theory, by considering the detailed time pattern of sound reflections from the steps of the staircase.

In Fig. 2, the gray-scaled background constitutes the sonogram of the chirp echo as reproduced from Fig. 8 of Declercq et al. (2004). Time is plotted horizontally on a linear scale (total span 200 ms), and frequency is plotted vertically on a linear scale from 0 to 5,000 Hz. Note that the lighter areas in this sonogram suggest the presence of spectral energy at the second, third, and fourth "harmonic" of a gliding fundamental frequency. These gliding harmonics are indicated by the dotted lines as predicted by the theory of repetition pitch.

Repetition Pitch Theory

A sound like a handclap contains spectral energy smeared over a wide range of frequencies. We consider the idealized case of a short pulse with a white spectrum (compare white light). When

Acoustics at Chichen Itza, Fig. 1 The El Castillo pyramid at the Mayan ruin at Chichen Itza in Mexico



Acoustics at Chichen Itza, Fig. 2 Gray-scaled sonogram after Declercq et al. (2004, Fig. 8) of the chirp echo recorded by Lubman (1998b). Time is plotted horizontally; frequency is plotted vertically. *White dotted lines* represent the 1st, 2nd, 3rd, and 4th "harmonic" following repetition pitch theory (see text below)

such a sound is mixed with the (delayed) repetition of itself, a compound signal is obtained having a rippled spectrum with peaks and valleys at equal distances in frequency (compare interference in optics). Specifically, the power spectrum of a white signal with one added repetition is a cosine function of frequency (see continuous bold-faced lines in Fig. 3) with spectral maxima at multiples of a "fundamental" f_0 corresponding to the reciprocal value of the delay time τ.

With such a signal, a listener generally perceives a pitch, repetition pitch (RP), corresponding to the fundamental (which, by the way, need not necessarily be present in the physical signal). Extensive psychophysical experiments in the past have shown that, in principle, RP can be predicted correctly by alternative theories, specifically (1) by neural signal processing described as autocorrelation on the temporal fine structure of the cochlear signal (Bilsen & Ritsma, 1969/1970), (2) by internal-spectrum matching as imagined in Fig. 3 (Bilsen, 1977), or (3) by correlation-like processing performed on the harmonics resolved in the cochlea (e.g., Yost, Patterson, & Sheft, 1996; see also Hartmann, 1997, pp. 361–376).

The Chirp Echo Modeled as a Gliding Repetition Pitch

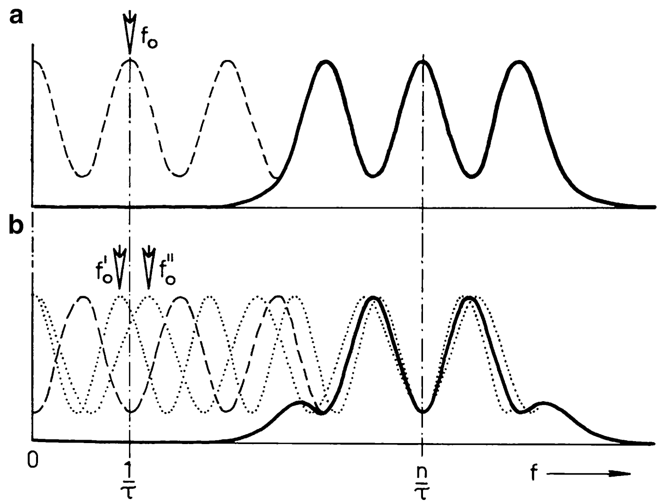
Adopting the data of pyramid dimensions, handclap, and sound recording positions, from Declercq et al. (2004), the drawing of Fig. 4 was obtained (Bilsen, 2006, Fig. 2). The steps of the staircase are numbered $n = -7$ to 84, with $n = 0$ being the step at ear (microphone) height. Dimensions are given in meters. Paired reflections (repetitions) from successive steps are considered as pairs of pulses with inherent delay τ_n, equal to the sound path differences $\{S(n + 1) - S(n)\}$ divided by the speed of sound. From the reciprocal values, $1/\tau_n$, a theoretical sonogram (see Fig. 5) is calculated, showing a cosine shape along the vertical (frequency) dimension and a gliding "fundamental" together with its "harmonics" (maxima) in the horizontal (time) dimension.

For easy comparison with the sonogram of the recorded chirp echo (see Fig. 2), dotted lines are superimposed on the sonogram (total span 200 ms) so that the 177-ms span of the model (91 dots) coincides as well as possible with the extent of the lighter areas of the sonogram in the horizontal direction. Each dotted line represents one of the first four harmonics numbered 1 through 4, with each dot representing the instantaneous value of an RP harmonic. The calculated fundamental glides from 796 to 471 Hz within a time span of 177 ms. Horizontal dotted lines at 0 Hz and 5 kHz coincide with the frequency scale of the sonogram. It can be concluded that the dotted lines fit nicely to the lighter regions in the sonogram, which proves the adequacy of RP theory.

By informal listening to a synthesized RP glide following the above model, basic similarity with the chirp recorded by Lubman was observed. This confirms also the perceptual relevance of the present considerations (http://fabilsen.home.xs4all.nl).

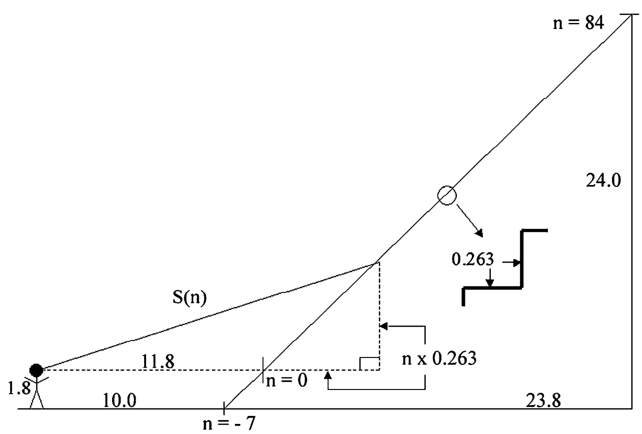
Chichen Itza Compared to Chantilly

In 1693, Christiaan Huygens standing at the foot of the majestic staircase in the garden of the castle



Acoustics at Chichen Itza, Fig. 3 Here it is imagined how the brain might "calculate" a repetition pitch corresponding to the (absent) fundamental frequency f_0 by making a best harmonic fit to the spectral maxima present in a signal. (**a**) Harmonic case (delayed signal added) with harmonically related spectral maxima at $\boldsymbol{n/\tau}$ for $n = 3$, 4, and 5. (**b**) Ambiguous case (delayed signal subtracted) with spectral maxima for $n = 3½$ and 4½ giving rise to two alternative pitches f_0' or f_0''

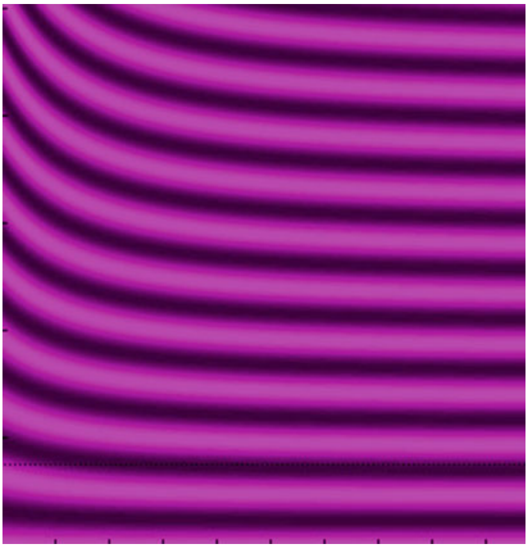
Acoustics at Chichen Itza, Fig. 4 Schematics of El Castillo pyramid with source/receiver position and step dimensions in meters. Steps are numbered $n = -7$ to 84 (Note: n different from n in Fig. 3) (After Bilsen, 2006, Fig. 2)



of Chantilly in France (see Fig. 6) made the following observation (translated rather literally by the present author from old French) (Huygens, 1693[1905]):

> When one is standing between the staircase and the fountain, one hears from the side of the staircase a resonance that possesses a certain musical pitch that continues, as long as the fountain spouts. One did not know where this tone originated from or improbable explanations were given, which stimulated me to search for a better one. Soon I found that it originated from the reflection of the noise from the fountain against the steps of the staircase. Because like every sound, or rather noise, reiterated in equal small intervals produces a musical tone, and like the length of an organ pipe determines its own pitch by its length because the air pulsations arrive regularly within small time intervals used by the undulations to do the length of the pipe twice in case it is closed at the end, so I imagined that each, even the smallest, noise coming from the fountain, being reflected against the steps of the staircase, must arrive at the ear from each step as much later as the step is remote, and

this by time differences just equal to those used by the undulations to travel to and fro the width of one step. Having measured that width equal to 17 in., I made a roll of paper that had this length, and I found the same pitch that one heard at the foot of the staircase.

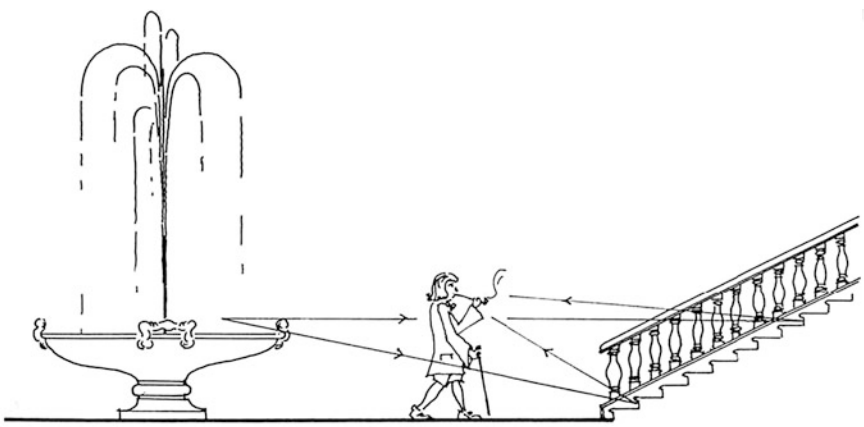


Acoustics at Chichen Itza, Fig. 5 Theoretical sonogram following repetition pitch theory and the El Castillo dimensions of Fig. 4. Frequency is plotted vertically; time is plotted horizontally on linear scales

Having established that the pitch was heard only when the fountain was working, he returned in winter when snow obscured the shape of the steps and he confirmed the absence of the pitch although the fountain was switched on. It is really a great experiment, tackling and controlling separately the two main physical factors responsible for the specific pitch.

Of course, Huygens did not posses our present knowledge of auditory theory, nor did he have knowledge of the psychophysical properties of repetition pitch. But having to do with many regular repetitions instead of only one, he could immediately draw an analogy with the musical tones from organ pipes. Thus, acoustically rather than physiologically, his explanation was adequate.

Huygens' observations were confirmed at later occasions by handclapping. Due to the rather large distance of the fountain or handclap position from the staircase, the smaller extent of the staircase, and the near horizontality of reflections, acoustic registrations show a regular reflection pattern in time, resulting in a rather stationary repetition pitch of 370 Hz equivalent.



Acoustics at Chichen Itza, Fig. 6 Christiaan Huygens at Chantilly as imagined by F. M. M. Bilsen (After Bilsen & Ritsma, 1969/1970, Fig. 1) (Note that, in reality, the fountain or handclap position is at greater distance from the staircase)

References

Bilsen, F. A. (1977). Pitch of noise signals: Evidence for a "central spectrum". *Journal of the Acoustical Society of America, 61*, 150–161.

Bilsen, F. A. (2006). Repetition pitch glide from the step pyramid at Chichen Itza. *Journal of the Acoustical Society of America, 120*, 594–596.

Bilsen, F. A., & Ritsma, R. J. (1969/1970). Repetition pitch and its implication for hearing theory. *Acustica, 22*, 63–73.

Declercq, N. F., Degrieck, J., Briers, R., & Leroy, O. (2004). A theoretical study of special acoustic effects caused by the staircase of the EL Castillo pyramid at the Mayan ruins of Chichen Itza in Mexico. *Journal of the Acoustical Society of America, 116*, 3328–3335.

Hartmann, W. M. (1997). *Signals, sound, and sensation*. Woodbury, NY: AIP Press.

Huygens, C. (1693). En envoiant le problème d'Alhazen en France. In *Correspondance No. 2840*, *Oeuvres Complètes*, Tome X. Correspondance 1691–1695. Martinus Nijhoff, Den Haag 1905.http://www.dbnl.org/tekst/huyg003oeuv10_01/huyg003oeuv10_01_0186.php#z2840

Lubman, D. (1998a). Archaeological acoustic study of chirped echo from the Mayan pyramid at Chichen Itza. *Journal of the Acoustical Society of America, 104*, 1763.

Lubman, D. (1998b). http://www.ocasa.org/MayanPyramid.htm

Yost, W. A., Patterson, R. D., & Sheft, S. (1996). A time domain description for the pitch strength of iterated rippled noise. *Journal of the Acoustical Society of America, 99*, 1066–1078.

Acoustics in Chinese Culture

Chen Cheng-Yih

A sound is perceived in terms of its pitch, loudness, and tone quality characteristics. The Chinese term for pitch is *yīn lǜ* or simply *lǜ*. Early mentions of pitch in connection to its function in ode singing, in musicology, and in the standardization of measures and weights are found in the *Yú Shū* (*The Book of Yú*). The Chinese used the terms *qīng* (clear) and *zhuó* (muddy) to describe, respectively, the high and low pitches. In remonstrating the decision of the High King Jǐng of Zhōu to have the Wǔ-Yì bell melted down and converted into the Dà-līn bell of lower pitch, minister Shan Mū Gōng stated in 522 BCE:

The ear functions harmoniously within a certain range of high and low pitches. The determination of this pitch-range should not be left for individuals. For this reason bells constructed by our ancient kings never exceeded their corresponding size in *jūn* (unit) and weight in *dàn* (unit). This is where the specifications of measures and weights for pitches originated.

This statement, recorded in the *Guó Yǔ* (Discourses on States), reveals that the early Chinese were aware of the existence of an audible pitch range.

A description on the development of the 12 pitches preserved in bells from antiquity is provided by music master Zhōu Jiū. He says that the reason that ranges and degrees can be established for pitch is due to Shén Gǔ of antiquity, who investigated and determined the *zhōng shēng* (middle tone) as the reference. The degrees of the pitches and tuned bells are the standards observed by all officials. From the *zhōng shēng*, one first establishes 3 pitches, then levels them out evenly into 6 pitches, and finally brings them to completion in 12 pitches. This is the *dāo* of nature.

This suggests that the 12-pitch system was derived from "trichords". An early example of a trichord is provided by three jade stone-chimes unearthed from a pit of the Yin ruins (ca. thirteenth century BCE) at Anyang; they not only are capable of producing tones but also have their pitch names engraved on the stones.

Early evidence for pitch standardization mentioned in the Chinese text is provided by the common notes found among the unearthed musical instruments. The most significant archaeological evidence is provided by the pitch pipes unearthed in 1986 from a Chǔ tomb (M21) of the Warring States period located at the present Yǔtáishān in Jiāngling, Hūběi province. These pitch pipes, made of nodeless ▶ bamboo (open ends) with different lengths and diameters, are the earliest specimens currently available. Though broken, four of the pitch pipes still had readable inscriptions, providing not only the names of the pitches, but also explicit statements on assigning pitches through the usage of the character *dìng* (literally to fix or determine). From the measured frequencies of the unearthed Marquis Yǐ set-bells, one obtains for the Huáng-zhōng pitch a measured frequency of 410.1 vibs s^{-1} in the fifth century BCE.

In Chinese, the louder sound is called *dà* and the softer one *xì*. The modern Chinese term for loudness in acoustics is *yīn-liàng*. An early discussion on loudness is found in the *Guó Yu* on the arrangement of instrument in an orchestra, in which harmony and balance are considered essential.

An obvious question on loudness is its role in audibility. Lǎo Zǐ made some interesting observations which seem to have some bearing on the threshold of hearing. We have from the *Dào Dé Jīng* (Canon of the Virtue of Dào) the statement: That which is listened to but not heard is called *xī*. The term *xī*, as it is defined here, relates to the term *xī-shēng*, which Needham translates as "tenuous note".

At the time of Lǎo Zǐ, concepts such as frequency and intensity had not yet been developed. Lǎo Zǐ could not have distinguished the audibility of *xī-shēng* in relation to its frequency and intensity. But he probably was aware that most *xī-shēng* are low-pitch sounds and that their audibility depends sensitively on loudness. Thus, when he said that the loud sound contains *xī-shēng*, he was probably referring to the audibility of those *inaudible* low-pitch sounds at a louder level.

Tone quality is the perception of sound in relation to the dynamic structure of the sound. The Chinese term for tone quality is *yīn-zhì* and in classic usage simply *yīn*. The early Chinese acousticians identified tone quality with the sound-producing material and began to classify sounds in accordance with such materials. Eight distinct tone qualities known simply as *bā-yīn* (eight tones) are identified with eight such sound-producing materials.

Early mention of the "eight tones" is found in the *Yú Shū* and *Zhǒ Zhuàn*. Other than being responsible for instituting music with the two sets of six pitches, the Grand Music Masters (*Dà-Shī*) were also responsible for making sure that all music was composed in pentatonic intonations: *gōng*, *shāng*, *jué*, *zhî*, and *yǔ*, and that all music was performed in eight tones: *jīn* (metal), *shí* (stone), *tǔ* (clay), *gé* (skin), *sī* (silk), *mù* (wood), *páo* (gourd), and *zhū* (bamboo).

Each of these sound-producing materials represents a basic tone quality. In 1936, Schaeffner commented that the *bā-yīn* was "probably the oldest extant classification of musical instruments in any civilization." Needham and Robinson compared the *bā-yīn* classification with the Greco-Roman classification of musical instruments, namely wind, stringed, and percussion instruments, and concluded that the Greco-Roman classification was more scientific. The point that needs to be emphasized here is that the *bā-yīn* classification was based on tone qualities and not on musical instruments, even though there is an intimate connection between the two. It is important to note that each complex tone has its own unique characteristic harmonic spectrum and wave form. There does not yet exist a satisfactory system for classifying tone quality. The fivefold classification of ideophones, membramophones, chordophones, electrophones, and aerophones is again a classification based on musical instruments.

In addition to the tone quality of sound due to the sound-producing materials, the ancient Chinese were also interested in the variation in tone quality coming from the configuration of musical instruments and the different ways of playing musical instruments. Twelve sounds are specified in the *Zhōu Lǐ* to identify tone qualities with the configurations of the musical instruments. According to the *Lü-Shì Chūn-Qiū* of 239 BCE, the techniques of exploiting timbre with overtones had reached a high level of art in *qín* (half-tube zither) playing. Indeed, in the playing the ancient lute (*gu qin*) with no frets and markings, each note could be played with a variety of subtleties in touch.

The Physical Nature of Sound

As described in the *Kăo Gōng Jì* (The Artificers' Record), sound is produced by vibrations, and there is a relationship between the thickness of the vibrating walls and the pitch of the sound produced by the vibration.

In Chinese classic usage, the character *ji* means rapid (or fast) and *shū* means slow. Thus, sound produced by rapid vibration is called *yīn jí* (or *shēng jí*) and by slow vibration *yīn shū* (or *shēng shū*). Such technical terms are found in the description of acoustics of bells, stone-chimes, and drums in the *Kăo Gōng Ji*. It is important to appreciate the relation between this terminology and the terminology for pitch. The terms *qīng* and *zhuó* for high and low pitches represent the perceptive description of sound in relation to the rate of vibration, while the terms *yīn jí* and *yīn shū* represent the physical description of sound in relation to the rate of vibration.

An explicit statement on the direct relation between the physical and perceptive descriptions of sound is found in the *Guăn Zĭ* (The Book of Master Guăn), in which it is stated that the sound of rapid vibration has a high pitch.

According to the *Kăo Gōng Jì*, Chinese bell-makers examined the audibility of a bell's sound at a distance and discovered that the audible distance of a strike tone depends on the interplay of the diameter and the length of the bell. Such an experimental investigation on the dependence of the audible distance of a bell's sound on the dimensions of the bell was a significant step toward a scientific inquiry into the physical nature of sound propagation. The early Chinese probably looked to the propagation of a disturbance in water as a mental image for the propagation of sound. This is suggested by the hydraulic terms, *qīng* (clear) and *zhuó* (muddy). Thus, the analogy between the expanding pattern of ripples on water and the propagation of sound in the air probably also began early in Chinese civilization. However, no extant record with explicit mention of this mental connection between waves in water and in air is available earlier than the work of Wáng Chōng of the first century AD.

An important physical phenomenon of sound that was discovered early in Chinese civilization is resonance. In the *Zhuāng Zĭ* (The Book of Master Zhuāng), there is a passage attributed to Lŭ Jù of Western Zhōu, in which he says that the striking of the *gōng* note of one zither causes the *gōng* note of the other zither to vibrate, and that the same is true of the *juē* note, because the notes are of the same pitch.

The resonance phenomenon of Lŭ Jù achieved wide recognition in ancient times. The principle of resonance was later summarized in the statement "*shēng-bĭ zē-yìng*." This contains two key technical terms, *bĭ* and *yìng*. The term *bĭ*, which literally means "comparison," is coined to represent "matching in pitch," a condition for resonance first pointed out by Lŭ Jù, and the term *yìng*, which literally means "respond," is coined to emphasize the sympathetic aspects of the vibrations in resonance. These technical terms became common in subsequent accounts of resonance in sound.

References

Chen, C. Y. (1987). The generation of chromatic scales in the Chinese bronze set-bells of the 5th century. In C. Y. Chen (Ed.), *Science and technology in Chinese civilization* (pp. 155–197). Singapore, Singapore: World Scientific.

Chen, C. Y. (1994). The significance of the Marquis Yĭ set-bells on the history of acoustics. In C. Y. Chen (Ed.), *Two-tone set bells of Marquis Yi* (pp. 145–244). Singapore, Singapore: World Scientific.

Chen, C. Y. (1996). *Early Chinese work in natural science: A re-examination of the physics of motion, acoustics, astronomy and scientific thoughts*. Hong Kong: Hong Kong University Press.

Li, C. Y. (1981). *Zhōng-Guó Gŭ-Dài Yīn-Yuè Shĭ Găo (notes on the history of music in ancient China)*. Beijing, China: Yin-Yue Publisher.

Needham, J. (1962). *Science and civilisation in China. Vol. 4, part I, sec. 26* (pp. 126–228). Cambridge: Cambridge University Press.

Schaeffner, A. (1936). *Origine des Instruments de Musique*. Paris: Payot.

Tán, W. S. (1988). Jiānglíng Yŭtáishān 21-Hào Chŭ-Mŭ Lü-Guăn Qiăn-Lŭn. (A discussion of the pitch-pipes of the M21 Chŭ-Tomb of Yŭtáíshān in Jiānglíng). *Cultural Relics, 4*, 39–42.

Acupuncture

Yun-tao Ma

Terminology

1. *Zhen Jiu* (针灸)/acupuncture/acumoxology. The term "acupuncture," meaning "using needles to pierce" (*Webster's College Dictionary*), is translated from the Chinese term *Zhen Jiu*, in which *Zhen* means "using needling to pierce" and *Jiu* refers to burning Moxa (Moxa refers to dried, pressed leaves of Mugwort (*Artemisia vulgaris*) burned on or above the skin to stimulate an acupuncture point or serve as a counterirritant) on the acupoints. ► Moxibustion refers to the application of heat stimulation with a moxa roll or cone on the point or affected site instead of using a needle. In Chinese, the term *Zhen Jiu* is often used as one concept, so, a new term *acumoxology* has been used to translate the original meaning of *Zhen Jiu*. The term "acumoxology" will be used if the text refers to both burning moxa and needling.
2. *Jing Luo* (经络)/meridian/channel/vessels. The English words meridian, channel, or vessel have been used to translate the Chinese term *Jing Luo*. Historically the concept of *Jing Luo* was related to arterial vessels; in this text the term vessel is used for the Chinese term *Jing Luo* instead of meridian or channel.
3. Chinese classic literature. There are often different English translations for the titles of the same Chinese classics. In this article, all Chinese classics are spelt first with Chinese Pinying and then by an English translation, as, for example, ► Huangdi Neijing (Yellow Emperor's Inner Canon). If the same title appears again in the text, only the Chinese Pinyin transliteration is used.

Sociohistorical Evolution of Acumoxology

Acupuncture is an ancient healing practice which appeared in different civilizations. Documents indicate that needling treatments were found in ancient Egypt, Greece, India, Japan, and China. Nevertheless, only the Chinese have nurtured this healing practice into a systemic medical modality which consists of clinical experiences accumulated for thousands of years and the theories gradually developed to explain these experiences. All branches of Traditional Chinese Medicine (TCM), herbology, tuina, (Tuina utilizes soft tissue manipulation, acupoints, external herbal medicines, therapeutic exercise, and structural realignment methods to treat a wide variety of musculoskeletal and internal organ disorders) and Qigong (Qigong is a Chinese healing art using a series of gentle focused exercises for mind and body) have absorbed some concepts from classic acumoxology.

Chinese archeological records suggest that stone needles (*bian shi*), the earliest tools for acupuncture, were invented to treat diseases during 8000–4000 BCE of the Neolithic Age. Later, bone, ► bamboo, bronze, and other metals like iron, silver, and gold were used to make needles. Today most of the clinical needles are made of stainless steel. *Mai Shu* (The Book of Vessels), the earliest document of acumoxology, appeared between the fourth and third centuries BCE. The first TCM classic *Huangdi Neijing* (Yellow Emperor's Inner Canon) discussed vessel theories, clinical principles of acumoxology, needling methods, and needling tools. However, *Huangdi Neijing* is neither systemic nor rigorously structured. It is a collection of medical treatises by authors of different times possibly from the period of Warring States (475–221 BCE) to the Han Dynasty (206 BCE–AD 220). The first book specifically devoted to acumoxology was *Huang Di Ming Tang Jing* (The Yellow Emperor's Canon of Bright Hall) in the Han Dynasty. Another book, *Jiu Fang* (Prescriptions for Moxibustion), came out in the period of Three

Kingdoms (AD 220–280). Thus all the basic elements – the theories, acupoint system, methods of needling and moxibustion, and treatable diseases – were organized into a system of acumoxology.

The Ministry of Health of the Tang Dynasty (AD 618–907) designated acumoxology as one of the five medical specialties and appointed medical doctors to teach and practice acumoxology in a royal institute. The government of the Song Dynasty (AD 960–1264) published an official document of acumoxology, *Tong Ren Shu Xue Zhen Jiu Tu Jing* (Standard Atlas of Acupoints on Life-Sized Bronze Human Statue for Acumoxology), in AD 1026. This document clarified the location and indications of 354 acupoints and assigned them into 14 vessels. This is the first standardization of acumoxology in history. After the Song dynasty, a notable theoretical development in acumoxology includes prescriptions of acupoints according to the time of the day and seasons (*Zi Wu Liu Zhu*) or differential diagnoses (Differential diagnosis is the determination of which one of two or more diseases or conditions a patient is suffering from, by systematically comparing and contrasting their clinical findings) (*Bian Zhen Lun Zhi*) and a variety of needling manipulation techniques. Acumoxology as a medical practice declined after the Ming Dynasty (AD 1368–1643), especially when the Chinese agricultural culture confronted the Western industrial and scientific culture ever since the middle of the nineteenth century.

After the founding of the People's Republic of China (1949), application of modern science to traditional medicine was politically advocated and financially supported by the new government. Some of the best scientists and clinicians trained in Western science were encouraged to study and modernize traditional medicine. In 1972, successful cases in acupuncture anesthesia were reported in the US (American interest was triggered in 1972 by a rumor that New York Times reporter James Reston had received acupuncture anesthesia for an appendectomy while visiting China during President Nixon's historic visit. Actually, he had had standard anesthesia and received acupuncture for postoperative cramps); this increased interest in acupuncture in both professional circles and for the public. Acupuncture became the most studied subject of all alternative medical modalities internationally. Enormous quantities of research data have been obtained from laboratories and clinics in many countries and have justified the scientific basis of acumoxology. Because of this intensive research, the trend to biomedicalize acumoxology and integrate it into mainstream medicine began in both China and the West.

Historical Development of Acumoxologic Theories

How Acupoints Were Discovered

Ancient Chinese doctors believed that a vital force, *qi*, flowed inside the vessels of the human body. They felt the quality of qi pulsation at multiple pulsing points on the body and used this to diagnose diseases. They also needled these pulsing points to treat diseases. These points became the earliest acupoints. As clinical experience accumulated, effective but nonpulsing acupoints were discovered and recorded.

The Origin of Vessel Theories

Early acumoxologic theories were formed from empirical facts. For example, ancient doctors found that needling certain pulsing loci on the dorsum of the foot and medial part of the lower leg was more effective than other points in treating pain or other symptoms of the genitals, lower abdomen, and lumbar areas. Thus they drew lines to connect the effective needling points with the parts of the body that were most affected by the needling, making a visible representation which connected all the points and related body parts together. In this example the pulsing points on the dorsum, the medial leg, the genital area, the lumbar area, and up to the tongue were connected. They believed that these symptoms were related to the imbalance of the "liver," and thus the "liver vessel" was gradually formulated. However, different doctors at different times formulated different "liver vessel" maps.

The Historical Integration of the Various Vessel Theories into a Single System

► Huangdi Neijing (Yellow Emperor's Inner Canon) integrated the various channel theories into one system. However, inconsistencies in this book reveal that the authors had differing medical experience from different historical periods. In the years that followed the appearance of the *Huangdi Neijing*, acumoxology continued to evolve by incorporating more theories, and an ever-increasing number of acupoints and channels, into the existing system. When clinical realities did not fit into an existing theory, the facts were often modified to ensure the continuance of the theory. New theories coexisted with old ones. Thus classical acupuncture as we know it today is made up of theories and clinical experiences that are valuable, but they are mixed with fallacious concepts and imperfect explanations.

Daoist Philosophy Guided Both Theories and Clinical Practice

"The universe and humans are one" (*Tian Ren He Yi*) is the central thinking model of Daoism. Its ► Yinyang (Yinyang is a Daoist symbol of the interplay of forces in the universe. In Chinese philosophy, yin and yang represent the two primal cosmic forces in the universe. Yin (moon) is the receptive, passive, cold female force. Yang (sun) is masculine, representing movement and heat. The Yinyang symbol represents the idealized balance of the forces; they demonstrate equilibrium in the universe) and *Wuxing* (The theory of the five phases looks at five interrelated forces that have specific relationships to one another. Each of the elements has corresponding organs, emotions, colors, tastes, tissues, human sounds, and countless other correspondences. For example, an Earth person likes late summer, singing and sweet tastes) (five phases: metal, wood, water, fire, and earth) models have been applied to the human body, its anatomy, pathophysiology, and acumoxology. All 14 vessels are classified into Yin and Yang vessels and within each vessel the important acupoints below elbow and knee are ascribed to five phases such as fire point, water point, etc. When treating diseases, the nature of Yin or Yang vessels and the phases of the points are synthesized to form the prescription according to the principle of Yinyang balance.

The "Pearls" of Classic Acumoxology Theory

Since the 1960s, international scholars and scientists have conducted research, but they still cannot verify the vessel entities. Both historical documents and clinical trials clearly show that the most valuable discovery in acumoxology theory is the interrelatedness between the parts of the body surface, and between the parts of the body surface and the internal organs. These are the immortal "pearls" of classic acupuncture. The classic 14 vessels are just tentative theories used by ancient medical sages to explain this interrelatedness of human body.

The Internationalization of Acumoxology

During the Tang Dynasty (AD 618–906), Korean and Japanese students were sent to China to study medicine and other subjects. Acumoxology, massage, and herbal medicine were first taught in a Korean medical school in AD 692. In Japan, specialized faculty taught acumoxology as part of a 7-year course in the Imperial medical school established by the emperor in AD 702.

Jesuit missionaries introduced acupuncture to Europe in 1683. Acupuncture was taught in French hospitals and was practiced by some doctors in Germany, The Netherlands and England. Acupuncture therapy has remained in European countries since the eighteenth century. An American doctor, William M. Lee, learned acupuncture from a British doctor and published his paper on using acupuncture for rheumatism in 1836. Sir William Osler, in his *The Principles and Practice of Medicine* (8th ed., 1909), suggested acupuncture therapy for low back pain. Acupuncture was reintroduced into the US in 1972 from China after diplomatic normalization between the two countries.

Since the 1950s, doctors of the former Soviet Union and Eastern European countries have studied acupuncture from China and they still practice acupuncture in hospitals today.

In 1975, three international acupuncture training centers were set up to train worldwide healthcare professionals in China. The World Health Organization (WHO) has offered enormous support to spread acupuncture therapy in developing countries. In 1989, WHO approved the *Standard International Acupuncture Nomenclature* which has been used worldwide. In 1994 and 1999, WHO issued the *Standard for Clinical Acupuncture Research* and *Guidelines on Basic Training and Safety in Acupuncture*.

Medical Differences Between Acumoxology and Chinese Herbal Medicine

There is a difference between acumoxology and Chinese herbal medicine, although they have absorbed theories from each other. First, acumoxology developed its special *Jing Luo* (vessel) theories, while Chinese herbal medicine applies *Zang Xiang* (Visceral concepts) theories. Second, the same acupoints can be applied to different symptoms, while herbs, more or less, have specific therapeutic indications. Third, the method of differential diagnosis is essential in herbal medicine while it is not necessary in acumoxology.

Medical Differences Between Acupuncture and Moxibustion

Acupuncture needling inoculates minor lesions inside the soft tissues including nerve tissue. This needling-induced lesion stimulates neuroimmune response involving the cardiovascular and endocrine systems. Fresh cells will replace this needle-induced lesion within 2–5 days. Most ► moxibustion has the same physiological effect as needling does, but no lesion is introduced into the tissue. Traditional pus-making moxibustion (*hua nong jiu*) burns the skin and makes huge superficial lesions which produce a longer effect.

Medical Differences Between Acupuncture and Western Conventional Medicine

In general, acumoxology therapy does not target any particular cause(s) of a symptom(s) or disease(s); it just activates the self-healing potential of the built-in biological survival mechanisms to normalize the physiologic processes and let the body heal. Acumoxology treats the whole body and produces no side effects, but the efficacy is achieved within a physiologically healable limit. Western conventional medicine tries to eliminate or correct the causations of the diseases by manipulating the chemistry and biological structure of the body first. The body then recovers from the impairment of both the disease and the medical intervention. This strategy may be accompanied by some side effects.

Biomedicalization of Classic Acumoxology

The medical value of acupuncture has been recognized internationally, especially in cases in which Western medicine has been unable to cause healing, but it has been challenged for its scientific justification in both Western and Eastern countries as modern sciences predominate in every field. Since the 1960s, acupuncture has been the most researched subject of traditional folk medicine in both China and the West, from the molecular to the organismic level, using new technologies in anatomy, neuroscience and immunology laboratories and evidence-based, double blind, statistical methods in clinics. Sufficient data have verified that acumoxology shares the same biomedical basis with Western medicine, and also indicate that acupuncture can be understood, taught, and practiced in biomedical concepts. Historically acupuncture has been acculturated many times when it was adopted by different host cultures. Thus, during this new acculturation, the biomedicalization of classic acumoxology becomes both possible and necessary. In September 2004, two new biomedically oriented textbooks were published. *Acumoxology Course for International Students* was published in China and *Biomedical Acupuncture for Pain Management*: *An Integrative Approach* was published in the United States. The two textbooks emphasize the new developments and new trends in acumoxology while maintaining its traditional medical values and philosophy. The fact that they were published simultaneously represents the biomedicalization of acumoxology in both China and the West.

What Diseases Can Acupuncture Treat?/How Effective Is Acupuncture Therapy?

Both clinical and laboratory data suggest that acupuncture and moxibustion are physiological therapies which result in self-healing, which is coordinated by the nervous system and mediated by the immune, endocrine, and cardiovascular systems. In 1979 WHO suggested a list of disorders and conditions for which acupuncture is effective, including neurological, musculoskeletal, respiratory, gastrointestinal, mouth, and eye problems. Nevertheless, WHO also made the statement that "this list was not based on controlled clinical research and cannot be considered authoritative nor does it reflect WHO's view in any way." This uncertainty can be clarified as we understand the physiological basis of acupuncture. Acupuncture does not target any specific symptoms or diseases but just normalizes physiologic processes to activate self-healing. The results of this self-healing depend on (1) the healability of the symptoms, and (2) self-healing capacity maintained by the patients. Thus, the same symptoms can be cured in some patients, or can be partially relieved in other patients but do not respond to acupuncture at all in a few patients. The information of healability may be obtained from medical examination. To estimate the self-healing capacity, readers may refer to the textbook *Biomedical Acupuncture for Pain Management*: *An Integrative Approach*.

Limitations of Acumoxology Therapy

As acumoxology normalizes physiological processes to activate self-healing, it works better for conditions resulting from physiological abnormalities. For example, if low back pain is caused by inflammation of soft tissues, acumoxology will cure it in most patients. If the low back pain is caused by a tumor of the spinal cord, acumoxology may provide only temporary pain relief. The former condition is an *acupuncture* remedy, while the latter is an *acupuncture-aided treatment*. In cases of acupuncture remedy, faster and more stable results can be obtained if conditions are treated at their early stage.

Questions Remaining

Today we understand acumoxology in terms of its physiological basis even better than some medical procedures used in conventional medicine, but, as in any field of science, more new questions arise after old mysteries have been clarified. There are many unanswered puzzles in acumoxology. For examples, what is the biological basis of the interrelatedness between different parts of human body as classic *Jing Luo* (Vessel) phenomena demonstrate? What symptoms or disorders are more amenable to acupuncture remedy or acupuncture-aided treatment? How are diseases related to particular acupoints? What acupoints should be selected for particular symptoms? How does needle manipulation influence the results? Clarification of these and other questions will improve clinical results of acumoxology.

See Also

- ▶ Five Phases (Wuxing)
- ▶ Medicine in China
- ▶ Yinyang

References

Deng Lian-yue, & Huang Long-xiang (Ed.). (2004). *国际针灸学教程，邓良月，黄龙祥主编，华夏出版社，北京 (acumoxology course for international students)*. Beijing, China: Huaxia Publisher, (in Chinese).

Long-xiang, Huang. (2000). *中国针灸学术史大纲，黄龙祥，华夏出版社，北京 (historical development of acupuncture)*. Beijing, China: Huaxia Publisher, (in Chinese).

Yun-tao Ma, Ma, Mila Ma, & Zang Hee Cho. (2005). *Biomedical acupuncture for pain management: An integrative approach*. St Louis, MO: Elsevier Churchill Livingstone. (http://www.BioMedAcupuncture.com)

Acyuta Piṣāraṭi

Manu V. Devadevan
Archive India Institute, Bhubaneswar, Odisha, India

Acyuta Piṣāraṭi (ca. 1550–1621) was an astronomer from the south Indian state of Kerala. He came from the village of Tṛkkaṇṭiyūr near Tirūr in southern Malabar. Born in an *aṃpalavāsi* (temple servant) caste, he belonged to a long and illustrious line of mathematicians and astronomers that commenced with Saṅgamagrāma Mādhavan (ca. 1340–1425) in the fourteenth century and continued up to Kṛṣṇadāsan (1786–1812) in the nineteenth. He was a student of the redoubtable Jyeṣṭhadevan (ca. 1500–1610) and was teacher to the great grammarian and devotional poet Melpattūr Nārāyaṇa Bhaṭṭatiri of the *Nārāyaṇīyaṃ* fame. His patrons included Ravi Varma, the chief of Veṭṭaṃ near Ponnāni, and the Taṃprākkaḷs of the Āḻvāñcēri family.

Acyuta Piṣāraṭi studied medicine, poetics, and grammar and wrote the *Praveśaka*, an introduction to Sanskrit grammar. But his fame rests on the contributions he made to the development of astronomy. In the *Sputanirṇaya* written before 1593, he showed that the Moon moves on its own orbit that differs marginally from the ecliptic used to measure its longitude. He proposed a correction to the calculation – which is called the "reduction to the ecliptic" – and further elaborated it in his *Rāśigolasphuṭanīti*: Multiply the tabular cosine and sine of the difference between the Moon and the node and the product by the tabular versine of the Moon's maximum latitude. Divide this by the tabular cosine of the latitude for the given moment and divide the quotient further by the tabular radius. In modern terms, when λ is the correction required, α the difference in longitude between the node and a planet, β the maximum latitude, θ the actual latitude, and r the tabular radius, we have

$$\text{Sin}\ \lambda = \frac{\text{Sin}\ \alpha \times \text{Cos}\ \alpha \times \text{Versine}\ \beta}{\text{Cos}\ \theta \times r}$$

$$r\ \text{Sin}\ \lambda = \frac{r\text{Sin}\,\alpha \times r\text{Cos}\,\alpha \times r\text{Versine}\,\beta}{r\text{Cos}\,\theta \times r}$$

$$\text{Sin}\ \lambda = \frac{r^3\text{Sin}\ \alpha \times \text{Cos}\ \alpha\,(1 - \text{Cos}\ \beta)}{r^2\text{Cos}\ \theta \times r}$$

$$= \frac{\text{Sin}\ \alpha \times \text{Cos}\ \alpha\,(1 - \text{Cos}\ \beta)}{\text{Cos}\ \theta}$$

As Sin λ tends to be more or less equal to λ for small values of λ, we have

$$\lambda = \frac{\text{Sin}\ \alpha \times \text{Cos}\ \alpha\,(1 - \text{Cos}\ \beta)}{\text{Cos}\ \theta}$$

It is striking that Acyuta Piṣāraṭi was a contemporary of the Danish astronomer Tycho Brahe (1546–1601) who proposed the reduction to the ecliptic for the first time in Europe in his book *Astronomiae Instauratae Progymnasmata*, published posthumously in 1602.

The *Sputanirṇaya* became an influential work among astronomers in Kerala in the seventeenth and eighteenth centuries. No less than nine works were composed during this period to elaborate upon Acyuta Piṣāraṭi's formulations.

Acyuta Piṣāraṭi was a champion of new methods in astronomy. In the *Uparāgakriyākrama*, he presented innovative methods for computing eclipses. The *Karaṇottama*, which deals among other things with gnomonical shadow (*chhāyā*) and the complementary situation of the Sun and the Moon (*vyatīpāta*), also draws attention by its novel computational methods. This work deploys the *dṛggaṇita* system of mathematics developed by Saṅgamagrāma Mādhavan's student Vaṭaśśeri Parameśvaran (ca. 1360–1460). Acyuta Piṣāraṭi claims in this work that he was only trying to make known in writing what was preserved secretly (*gopyatvena*) by masters in the line of Parameśvaran and others (*parameśvarādi parīkṣaka paraṃparayā*). Piṣāraṭi also excelled in astrology. He wrote the *Jātakābharaṇapaddhati*. His *Horāsāroccaya* was based on Śrīpati's *Jātakapaddhati*. His other works include terse tracts on astronomy, like the *Chāyāṣṭaka* on the Moon's gnomonic shadow, and a commentary on Saṅgamagrāma Mādhavan's *Veṇvāroha*. It is likely that he also wrote the anonymous *Uparāgaviṃśati*.

It will not be an overstatement to say that Acyuta Piṣāraṭi was the last great astronomer of premodern Kerala. Although his successors refined the existing theories at different times, never again was so original a contribution as the reduction to the ecliptic made in the region before the arrival of modern education.

See Also

- ▶ Astronomy in Medieval India
- ▶ Mādhava of Saṅgamagrāma

References

Iyer, S. V. (1952–1953). Acyuta Piṣāroṭi: His date and works. *The Journal of Oriental Research Madras, 22*, 40–46.

Joseph, G. G. (2009). *A passage to infinity: Medieval Indian mathematics from Kerala and its impact*. New Delhi: Sage.

Raja, K. K. (1995). *Astronomy and mathematics in Kerala*. Madras: The Adyar Library and Research Centre.

Agriculture in Africa

Paul Richards

According to the philosopher Hegel, Africa was the inert mass around which the history of consciousness pivoted in its journey from East to West. Even today one still encounters the view that sub-Saharan Africa is exceptionally backward in science and technology, and has no indigenous intellectual history worth the name. Judged by the conventional standards of modernity, e.g., statistics on literacy and education, Africa does indeed seem a "backward" continent; but against this we must consider the crucial part played by the African savannas in the story of human evolution; human intellectual development was shaped by challenges set by the African environment. The legacy is still perhaps apparent in the continent's exceptional linguistic diversity and an enduring facility among its peoples for coping with severe environmental challenge. Until recently, however, African indigenous knowledge of environmental resources has failed to register in conventional histories of science and technology, due in large part to the distinctive resource endowments and consequent agrarian history of large parts of the continent.

Population density, historically, has been low over much of sub-Saharan Africa, and was depressed further by the slave trade and the wars and epidemics associated with colonial conquest. This has meant an emphasis (contrary to the trend of agrarian history in Asia) on land-management strategies that efficiently deploy scarce labor, but in settings ill-suited to plough agriculture or mechanization (contrary to experience in Europe and North America). In place of labor-intensive leveling, drainage, and installation of irrigation, for example, African cultivators typically have sought to make use of diverse soil and land conditions as they find them. This requires emphasis on what might be termed "mix-and-match" approaches, e.g., maintaining different animal species in the pastoral herd, selecting a range of crop types adapted to different soil and land conditions, using different crop types in the same field (inter-cropping), or by ingenious dovetailing of a complex and varied portfolio of productive activities (hunting and gathering, shifting cultivation, tree-crop cultivation).

This emphasis on versatility above specialization has been of particular importance in those extensive tropical regions in sub-Saharan Africa blighted by insect-borne disease (notably malaria and sleeping sickness), climatic irregularities, poor soils, and lack of irrigation opportunities. Here, characteristically, human groups tend to invest heavily in the social "software" of agrarian relations rather than the "hardware" of technology and land improvement. Groups facing periodic drought may prefer to devote attention to the cooperative social relations that sustain an "optimal foraging strategy" rather than tie up large amounts of labor in costly land improvements such as irrigation systems. In an outright disaster social investments are portable, but land improvement is fixed and may have to be abandoned.

The knowledge and mental attitudes that support versatility among hazard-prone resource users do not lend themselves readily to the writing of conventional history of technology. Historians whose ideas have been formed against a background of more steadily evolving agrarian technological traditions in Europe and Asia have been at times tempted to conclude that African agriculture is deficient in technical expertise. Local knowledge tends to be regarded as makeshift and perhaps even irrational. Shifting cultivators and pastoralists, more anxious to meet the next challenge than celebrate past achievements, may have unwittingly reinforced these misperceptions. For Mende rice farmers in Sierra Leone several "traditional" techniques are colonial innovations - the local notion of tradition is simply "something that works." Sometimes, sensing potential damage to a good practical skill from wordy rationalization, African resource users may even seek to deny that they know anything useful about the topic under discussion. Outsiders end up perceiving a technological void where none exists.

Many schemes were set up during the colonial period to assist African farmers to climb across these imagined gaps in what was thought to be a fixed ladder of agro-technological progress. Colonial reformers concentrated at first on European innovations such as sickle and plough, only to be beaten back by African preferences for panicle selection in harvesting as a means to maintain the varietal distinctiveness of planting materials, or for the hand hoe as a superior means to maintain soil physical quality under difficult tropical climatic conditions. Later, it was supposed that Asia was the proper yardstick against which to measure the backwardness of African agrarian technology, and first steps were taken to transform African agriculture according to Asian experience. This culminated in efforts in the 1970s and 1980s to replicate the Asian Green Revolution in Africa, using fertilizer-responsive high-yield crop types under intensive management. Asia-to-Africa technology transfer repeatedly foundered on the issue of labor. Innovations for Asian farmers needed to be labor-absorbing, but for African farmers (not threatened, historically, to anything like the same extent by population pressure on land) labor-efficiency was often the criterion of greatest relevance.

During the colonial period in Africa a significant minority of long-serving agricultural officers came to appreciate that rural people did in fact have a considerable fund of valid practical knowledge of agriculture and the environment. This coincided with the rise of scientific ecology and related disciplines during the 1930s and 1940s; foresters, economic botanists, soil scientists, and veterinary officers were particularly active in recording African indigenous knowledge of agriculture and the environment, and in drawing parallels between these local concepts and emergent ideas in ecology and related disciplines. Perhaps the single most striking of these instances is the letter to the scientific journal *Nature* in 1936 by the Tanganyika-based soil scientist Milne, proposing the concept of the soil catena as a regularly recurring chain of soil types controlled by topography. African soils tended to be very old, and showed the influence of underlying rock types much less than in Europe. The concept of soil catena, by emphasizing topography and downplaying the role of geology, provided a much better guide to the way the soils had formed, and to how African farmers typically used their soils. Throughout the tropical zone, but especially where seasonal variations in rainfall distribution are most marked, farmers secure food supplies during the preharvest hungry season and spread their labor burdens by systematically planting up and down slopes, carefully matching different crops or crop types to the different soils within the catenary sequence. The catena rapidly became established as a basic organizing concept in tropical soil science throughout the world; Milne's letter to *Nature* makes clear its African roots by using the Sukuma terms employed by local farmers to categorize the different soils within the chain.

This is in stark contrast to earlier official thinking about land systems on the other side of the continent, in Sierra Leone. After famine in 1919, caused not by local agricultural incompetence but the loss of harvest labor resulting from the influenza that tracked colonial troops to their homes from the battlefields of Europe, the colonial governor Wilkinson sought (as he thought) to transform Sierra Leonean rice farmers from being shifting cultivators farming rain-fed up lands into permanent cultivators of irrigated valley-bottom lands along Asian lines. Moving local farmers from the tops to the bottoms of their valley slopes was for Wilkinson a shift of epochal proportions, through which the "ignorant" African would be able to catch up a 1,000 years of agrarian technological history in a matter of a few years. The official of the Madras Department of ► Agriculture in India employed by the Government of Sierra Leone to set things in motion requested to be sent home after nearly 2 years working with local farmers, on the grounds there was little if anything he could teach them that they did not know already, and that in any case they obtained better yields from similar resource endowments than farmers in Madras. However, the belief that there was something decisive about a shift from upland to valley-bottom farming survived into the modern period, and received a new boost from the example of the Green Revolution in the 1960s. This insistent categorical contrast on "uplands" and "wetlands" remains in stark contrast to local farmers' knowledge and practice in which seed types and labor resources are invested up and down catenary sequences, and across the upland-wetland divide, according to circumstances. Standing on the boundary between the rain-fed and water-logged soil types in their farms, Sierra Leonean peasants repudiate any gap between themselves and more technologically advanced farmers in Asia, and see instead only an opportunity for flexible adjustment to changing conditions. Recently, mathematicians have begun to provide formal tools with which to grasp the fuzzy logic that underpins this kind of cognitive flexibility, typical of African indigenous knowledge of environmental resources.

Rice farming on the western coast of West Africa is of considerable antiquity, and based on the domestication of the African species of rice (*Oryza glaberrima*). Due to contacts arising from the slave trade we have quite rich documentary sources concerning indigenous agricultural knowledge for this part of Africa at an early date, including a number of accounts from the seventeenth and eighteenth centuries specifying the way in which farmers matched planting materials to different soils, so spreading labor peaks and minimizing preharvest hunger. Today, rice farmers in the region continue to research this relationship whenever they encounter new material (e.g., accidental introductions, or new types that arise as spontaneous crosses). This knowledge of and interest in management of crop genetic resources is widespread in Africa, and is perhaps the single most important aspect of the legacy of indigenous agrotechnological knowledge on the continent. Today it is threatened by social dislocation (including the effects of warfare) and agricultural modernization (including the spread of modern cultivars and labor-efficient harvesting technology).

African contributions to crop biodiversity management have been undervalued in the past, with some exceptions, because several of Africa's indigenous food crops are not widely known elsewhere (e.g., *Digitaria* millet in West Africa, *teff* in Ethiopia, and finger millet in eastern and central Africa). Vavilov recognized the Ethiopian Highlands as a major center of crop biodiversity, but a number of important crops originating in Africa are scattered more widely (e.g., African rice, white yam, sorghum, and oil palm). Greater recognition is still needed for the historical role played by Africa's farming populations in identifying, shaping, and conserving these genetic resources. In this context it is interesting to note the systematic efforts made by Thomas Jefferson in the 1790s to establish African rice in the United States. Jefferson was convinced that the hardy dryland cultivars selected and maintained by West African farmers would help reduce some of the health problems associated with rice farming in the coastal zone of South Carolina, and had a cask of upland rice imported from the coast of what is today the Republic of Guinea for distribution among inland planters in South Carolina and Georgia. Earlier, South Carolina rice planters had shown a preference for slaves from the coastal rice-growing regions of West Africa, and it is possible that the tidal-pumped wetland rice cultivation systems of the tidewater zone drew upon African technological expertise in this field. Historical examples such as these help correct the erroneous notion that the transfer of agricultural knowledge and technology between Africa and the rest of the world has been a one-way process.

During a period of aggressive modernization of African agriculture following the end of colonial rule the work of documenting and understanding African systems of resource knowledge and management, begun by ecologically oriented technologists in the colonial period, was kept alive only by a handful of enthusiasts. Special mention should be made of African pioneers such as George Benneh in Ghana and Uzo Igbozurike in Nigeria. However, interest in local knowledge systems expanded enormously in the 1980s and 1990s, after the failure of many "high-tech" schemes to promote rapid change in African agriculture. A number of agricultural and other scientists now see indigenous knowledge as a resource for orthodox science (farmer experimentation attracts particular attention). Recent studies have highlighted the specialist knowledge of Africa's women farmers, pointed to the complex ways in which indigenous technical knowledge of the environment is bound up with social relationships of production and consumption, and drawn attention to local knowledge in biodiversity conservation. The ratification of an international convention on biodiversity, adopted by the United Nations' Rio de Janiero Conference on Environment and Development in 1992, gives indigenous agricultural knowledge a new visibility, and status in international law. Questions of ownership and preservation of Africa's abundant legacy of indigenous knowledge now attract attention, though some concern has been expressed that this might serve to ossify such knowledge, and reduce its practical utility.

See Also

▶ Colonialism and Science
▶ East and West
▶ Environment and Nature in Africa
▶ Ethnobotany
▶ Food Technology in Africa
▶ Knowledge Systems: Local Knowledge

References

Carney, J. A. (2002). *Black rice: The African origins of white rice cultivation*. Cambridge, MA: Harvard University Press.

Igbozurike, U. (1977). *Agriculture at the crossroads*. Ile-Ife, Nigeria: University of of lfe Press.

Milne, G. (1936). Normal erosion as a factor in soil profile development. *Nature, 138*, 548–549.

Richards, P. (1985). *Indigenous agricultural revolution*. London: Hutchinson.

Agriculture in China

Francesca Bray

China is a vast country covering roughly the area of Europe. Because much of it is steep mountains or fragile grasslands, only about 10 % of China's total area is suitable for farming (see *Online resources* for some useful maps). However, intensive patterns of land use, increasingly refined over the centuries, sustained high levels of population and production throughout much of the imperial period. The modernization of farming in the West has characteristically involved increasing the size of farms or managerial units while substituting machines or other industrial products for human labor. In China the process was reversed: farms and equipment became smaller and inputs of human skills intensified. There is a fierce debate among historians as to how this long-term trend should be interpreted. Some see it as a "technologically blocked" system, incompatible with the emergence of capitalism, in which farming families had to work ever harder for smaller returns. Others argue that the farming system of China and the rural manufactures and commercial networks that grew up around it constituted a flexible and dynamic economic system which not only generated internal prosperity, but played a key role in stimulating and shaping the emerging global economy of the modern world (see BOX). The unusual quantity of agricultural treatises and economic or policy documents that have come down to us from the imperial era help fuel and complicate this important debate as to whether "modernity" is a Western or a worldwide phenomenon. In either case, the current social and environmental critiques of contemporary "productivism" and of the problems generated by industrial agriculture suggest the value of looking more carefully at such alternative paths to development as the progressive intensification of land-use typical of Chinese agriculture.

China has several different farming regions, ranging from the chilly plains of the Northeast where the main food crops are soybeans, sorghum, spring wheat, and corn, to the lush tropical gardens of Hainan Island where the year-round growing season allows constant cropping, including two crops of rice (Bray, 1984, pp. 9–27; http://www.1uptravel.com/worldmaps/china39.html). Broadly speaking, however, China has two distinct farming traditions that correspond to climatic zones. North China has sparse and irregular rain that falls mostly in the summer; the winters are long and cold. The uplands of the interior are formed of thick deposits of fertile loess; over the millennia the Yellow River has eaten away at the primary loess and deposited it as silt on the alluvial plains downstream. The main constraints on agricultural productivity in the Northern region are the relatively short growing season (between 5 and 8 months) and the lack of water. It is seldom possible to grow more than one crop a year. The typical crops are those which do well with little water: millets, wheat, sorghum, cotton, and beans.

From the Yangzi plains south, the climate is semitropical. Rainfall is much heavier and spread throughout the year. As a result much of the natural soil fertility has been leached away, but irrigated rice fields counteract this effect. They build up their own fertile microecology that allows the same field to produce two or even three harvests a year, depending on the latitude. The growing season ranges from 9 months to year round. Rice is the staple, grown everywhere in the Southern zone: other important crops are winter wheat, maize, sweet potato, sugar, tea, and cotton along the Yangzi.

The distinction between a Northern and a Southern tradition has its roots in prehistoric times. The earliest Chinese farming villages date from the sixth millennium BCE, much later than those of the Fertile Crescent. Archaeologists used to consider that farming diffused throughout the Old World from that single center; the current evidence suggests however that within China itself there were at least two independent centers of plant domestication. At the 5000 BCE Neolithic site of Banpo, in the loesslands of Northwest China, the dryland crop of Setaria millet was grown (Bray, 1984, p. 434). The village of Hemudu, built in the marshes near the mouth of the Yangzi at the same period, grew large quantities of wet rice (Bray, 1984, p. 481). Though some archaeologists believe they have now discovered evidence of domesticated rice in sites in Central and Southern China dating back as far as 10000 BCE (An, 1999), most of the early evidence for farming in China is no earlier than Banpo or Hemudu.

Land was a scarce resource from very early times. Unlike the pattern of development in the West, where capital was invested in draft animals, equipment, and machines to substitute for labor, in China the historical trend was towards increasing the productivity of land through the application of skilled labor and cheap small-scale inputs. With one or two rare exceptions, economies of scale did not apply. The roots of this relationship between land, population, and labor developed very early in China's history.

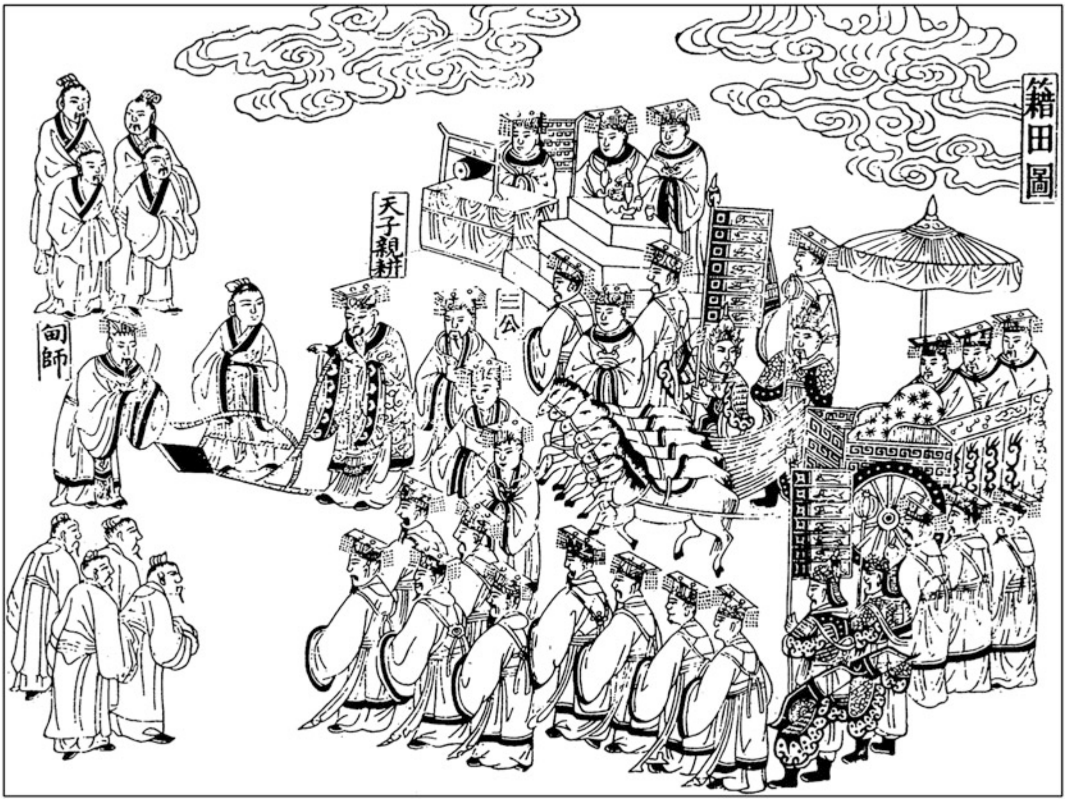
From the sixth to the fourth centuries BCE, several states battled for control of all China; the states with most men to fight and most grain to feed them emerged as victors. A fiscal policy based on peasant contributions of grain, textiles, and services became the norm. A strong state was one with a large population of skilled farmers. As a political philosopher of the third century BCE put it: "Therefore it is said:" Where a hundred men farm and one is idle, the state will attain supremacy; where ten men farm and one is idle, the state will be strong; where half farms and half is idle, the state will be in peril." This is why those, who govern the country well, wish the people to take to agriculture' (*Shangjun shu*, trans. Duyvendak, 1928, p. 191). This remained the basic view of Chinese statesmen through the unification of the empire in 221 BCE right up to the end of the Maoist era. For over 2,000 years officials encouraged farming and took an active role in developing and diffusing knowledge and techniques. They fostered labor-intensive peasant farming and tried to control the accumulation of land in the hands of the rich. Successive medieval regimes confiscated land from the wealthy and redistributed it to peasants to ensure that it provided a livelihood for as many people as possible.

In part this intensity of land use was made possible by the particularities of Chinese farming systems. No arable land was wasted. There were few pastures in China proper. The main sources of animal protein were pigs, poultry and fish, and draft animals (oxen and mules in the North, water buffalo in the South) grazed on rough land (Fig. 1). The practice of fallowing seems to have died out as early as 2,000 years ago in parts of North China. Crop rotations alternated soil-enriching crops like beans with cereals; all human and animal waste was composted and returned to the fields. Medieval states in the North allocated approximately 6 acre of land to support a family. Land was even more intensively used in the South. By the seventeenth century, some fields in the South produced two crops of

Agriculture in China, Fig. 1 Water buffalo and herdboy. The sound of the herdboy's flute echoing up some distant valley was a common element in Chinese poetry, but here the agronomist Wang Zhen (see below) is illustrating the flute as one of the indispensable implements of a rice-farming household. Wang Zhen, *Nongshu*, Ming edition of 1530, 13/7a

rice and another of tobacco or vegetables each year. In the early twentieth century families in the most densely populated regions lived off under a tenth of an acre of rice land.

The tax system meant that improving agriculture was a key concern in Chinese state policy from the very beginning (Wong, 1997, p. 90), and many of the most important works on agriculture were written by members of the official elite in their capacity as civil servants (Fig. 2). Imperial compilations and works by civil servants aimed at a readership of local officials who would pass on the information to the farmers under their jurisdiction. They tended to stress practical details of husbandry, including innovations that could be introduced, and they emphasized subsistence production. Other works, written by landowners who



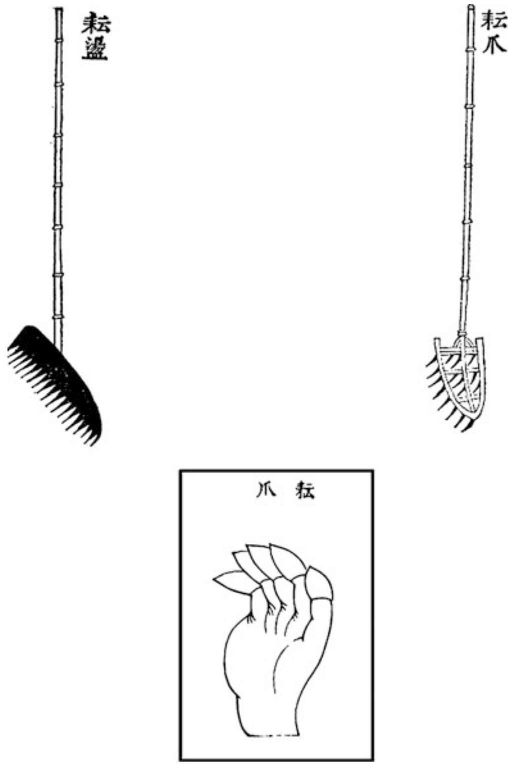
Agriculture in China, Fig. 2 Wang Zhen wrote his agricultural treatise of 1313 after service as magistrate in both Northern and Southern provinces; he hoped his work would help disseminate advanced technology and improved techniques. He begins with a section on the importance of official encouragement of farming. This included not only practical but also symbolic measures such as the New Year imperial plowing ceremony, where the emperor plowed a ceremonial furrow before the Temple of the God of the Soil in order to ensure good harvests throughout the empire. In this highly stylized rendering, an emperor of ancient times is shown holding the strut of a plow to the *left* of the picture (Wang Zhen, *Nongshu*, 7/4a–b)

ran their own farms, were written for fellow landowners; these works usually included discussions of labor, prices and estate management (Bray, 1984, pp. 47–80) (Fig. 3).

The earliest extant agricultural treatise belongs to the second category. It is entitled *Qimin yaoshu* (Essential Techniques for the Peasantry); the author, Jia Sixie, completed its ten volumes in around AD 535 (Bray, 1984, pp. 55–58). It describes the agriculture of the dry regions of the Yellow River plains. Perhaps its most striking features are the detailed descriptions of how careful and repeated tillage techniques (different depths of plowing, sowing with a seed-drill, harrowing and hoeing, all techniques requiring the use of several oxen or mules) were used to conserve soil moisture in a dry climate, and crop rotations were used to increase fertility. We can reconstruct much of the equipment mentioned by Jia from somewhat earlier tomb paintings, as well as archaeological discoveries of huge state iron foundries from the first century AD, that mass-produced cast iron plowshares, moldboards, and the iron shoes of seed-drills. Together with Jia's numerous citations from earlier Northern works, this evidence confirms that the *Qimin yaoshu* represented the culmination of a long Northern tradition of productive estate farming that was dependent on large acreages and heavy capital investment in equipment and draft animals. It was a form of centralized estate farming that peasant farmers

A

Agriculture in China, Fig. 3 The harvest feast held by a landlord (shown seated *right* in front of his family altar) for his tenant farmers (*Bianmin tuzuan*, 1593 edition, 1/8a)

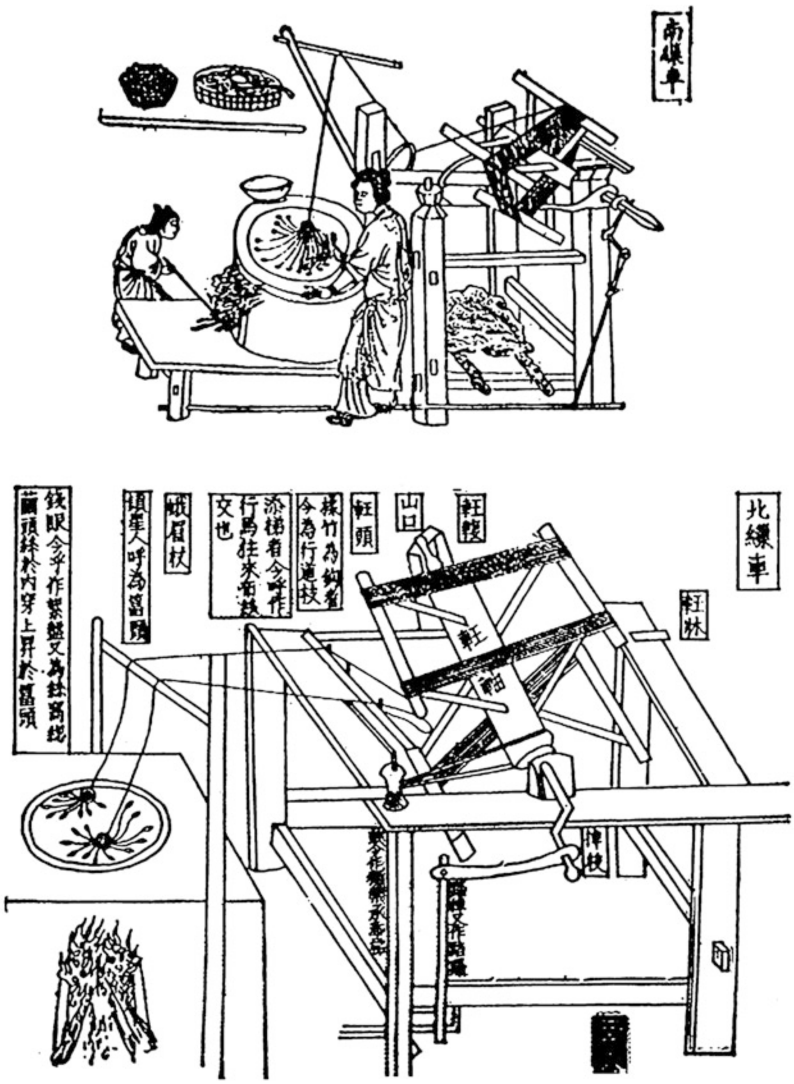


Agriculture in China, Fig. 4 Varieties of tools for weeding rice fields depicted by Wang Zhen. On the *top left* is a simple rake. The hinged rake at the *right* was a new invention from the lower Yangzi which Wang described with great enthusiasm, hoping that it would relieve farmers of much back-breaking work going through the young rice on their hands and knees. The "weeding claws" at the bottom were made of ▶ bamboo and helped farmers grub up weeds at the roots (*Nongshu* 13/27–29)

could not afford or compete with (Bray, 1984, pp. 587–97). The *Qimin yaoshu* was the last of the great works focused on the Northern system.

Repeated wars and invasions ravaged the Northern plains in medieval times. In the eleventh century the loss of the North to the Khitan finally established the Yangzi region as the political and economic center of Song dynasty China. The estates of the Northern aristocrats disintegrated, and as under-equipped peasant farmers did their best to scratch a living from a few acres of dry soil, the North became a backward region compared to the fruitful South. Migrants flooded into the Southern provinces from the North, and the state sought to encourage more productive agriculture by every possible means. Irrigation works were improved, seeds were handed out, information distributed, and cheap loans and tax breaks offered – the scope was similar to the Green Revolution of the 1970s, as was the impact on production (Bray, 1986; Elvin, 1973). One particularly fruitful venture was the introduction of quick-ripening rices from Vietnam that allowed rice farmers to double crop their fields, alternating winter wheat or barley with rice.

Several important agricultural works were published during the Song, but the landmark of the period dates from the Yuan (Mongol) dynasty. In 1313 Wang Zhen published a *Nongshu* (Treatise on Agriculture) several hundred pages long. His aim was to describe local innovations so that they could be adopted elsewhere (Bray, 1984, pp. 59–64). He included detailed woodblock illustrations of farming tools (Fig. 4), machinery (Figs. 5 and 6),



Agriculture in China, Fig. 5 Silk-reeling machines typical of Northern China (*below*) and the Yangzi region (*above*). Rural women produced almost all the silk thread and much of the silk cloth in circulation at the time when Wang Zhen was writing, but later silk weaving moved into suburban workshops where most of the workers were men (*Nongshu* 22/26a–27b)

irrigation equipment (Figs. 7 and 8), and various types of terraced or dyked fields that permitted the extension of farming into mountainous or marshy lands (Figs. 9 and 10). The treatise depicts a system of family farming in which poor peasants with little capital invested intensively in labor, skills, and low-cost inputs. This was the farming system that formed the basis for the commoditization and expansion of the rural economy in succeeding centuries (Bray, 2000, pp. 25–41).

Wang Zhen's *Treatise* was the paradigm for later works, including imperial compilations and the magisterial *Nongzheng quanshu* (Complete Treatise on Agricultural Administration) by the statesman Xu Guangqi, completed in 1639. Xu was a polymath and Christian convert who served for some years as Grand Secretary of China. The *Nongzheng quanshu* advocates a balance between the production of essentials (cereals for food and fiber crops for textiles) necessary for the health of the central state, and cash crops and handicrafts that would ensure a prosperous rural economy. Xu was also preoccupied with population pressure and the need to expand the arable area and improve yields; he devotes long sections of his treatise to land reclamation and improved irrigation techniques, to his own experiments

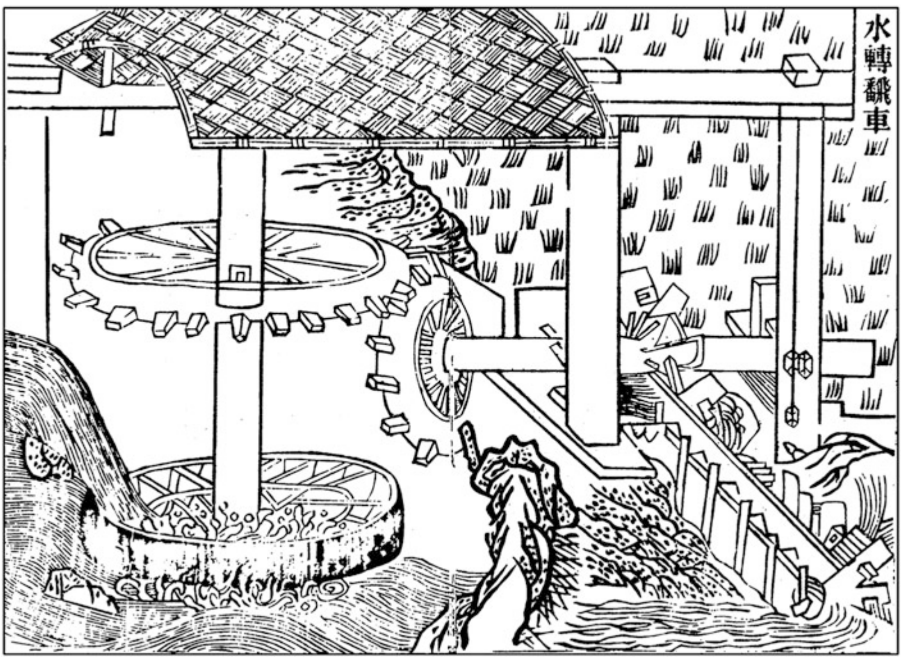
Agriculture in China, Fig. 6 Spinning wheel for making cotton yarn. When Wang Zhen was writing in the early fourteenth century, cotton was just beginning to replace other vegetable fibers as the most common everyday cloth, and Wang provides copious documentation about the techniques and equipment involved. *Nongshu* 25/6b

with manures and commercial fertilizers such as lime and bean cake, and to crops like sweet potatoes that can be grown on poor land (Bray & Métailié, 2001).

Landowners wrote a number of other works in the Southern tradition. In striking contrast to the *Qimin yaoshu*, however, the landowners themselves farmed only a few acres and rented the rest out to tenants. The main criteria for selecting a suitable tenant were his skills and experience, and his assiduity at work; capital assets were not a consideration as they would have been for a contemporaneous English capitalist landowner. The main difference between landowner and tenant lay in the ownership of land; it did not extend to differences in the scale of the farm, or in the range and size of equipment (Bray, 1986, pp. 113–119). In this highly intensive and skilled farming system there were no economies of scale, and anyone who owned more than an acre of rice land would seek a tenant to farm the surplus. If levels of agricultural expertise were reckoned simply by the complexity of farm machinery or by levels of capital investment, then the farming methods of the eighteenth and nineteenth centuries might be reckoned a decline from those of 800 years earlier, for as average farm size diminished many peasants abandoned animal-drawn implements in favor of hand tools. However, if we look at the productivity of land, we see a different picture. Improvements in water control, in fertilizing (Fig. 11), in the spacing of plants and the breeding of varieties enabled China's peasant farmers to increase the total output of crops at a rate that kept up with population growth until about 1800 (Li, 1998a, 1998b; Perkins, 1969). This intensive small-scale farming also supported a diversified rural economy of small industries and handicrafts that fed into national and international trade networks (Bray, 2000; Daniels, 1996; Gardella, 1994; Marks, 1998; Mazumdar, 1998; Pomeranz, 2000; Rawski, 1972) (Figs. 12 and 13).

The great inventions of Chinese agriculture are anonymous, the collective achievements of peasants recorded by servants of the state. Many important innovations occurred in the densely populated heartlands where pressure on land was most intense. There has been a tendency for Chinese historians past and present to assume that political and technical superiority went together, and that the Chinese taught civilization to the barbarians. However, several features crucial to Chinese high farming came not from the center but from the periphery. The technique of transplanting rice, fundamental for the development of intensive wet farming, was practiced by Thai-speaking populations in the Canton and Tonkin regions when they were conquered by China 2,000 years ago (Bray, 1984, p. 279). Terraced fields probably spread northwards into China from Vietnam and Yunnan, reaching the Yangzi region by the fourteenth century (Bray, 1984, pp. 123–26). Tea was introduced from Tibet and Western Sichuan some time before the eighth century (Smith, 1991). The techniques of cotton cultivation and processing were introduced to the Lower Yangzi from Hainan Island around the thirteenth century (Kuhn, 1988).

Agriculture in China, Fig. 7 Chain pump operated by two men. These light, portable pumps could be made quite easily by local carpenters and they would be moved from field to field as each needed irrigating or draining (Wang Zhen, *Nongshu* 19/7a–b)



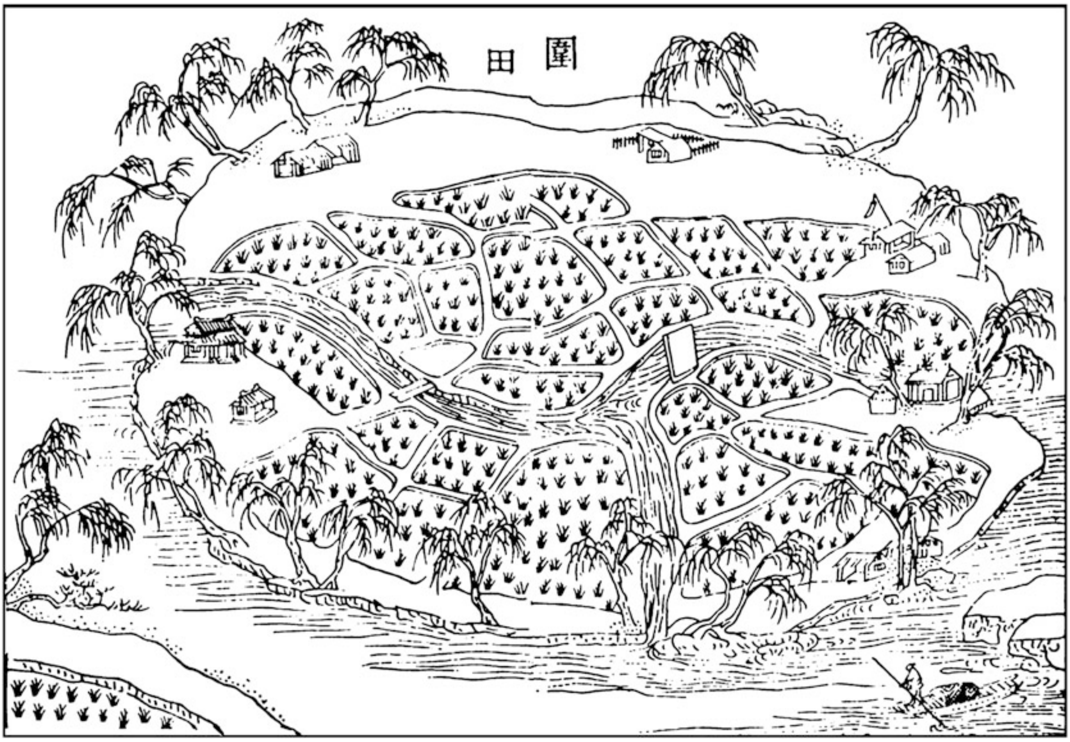
Agriculture in China, Fig. 8 Water-driven chain pump. Water mills were an essential element in medieval Chinese industry, as they were in Europe, and Wang Zhen also illustrates water mills of the kind used to power millstones, the bellows for metal foundries, and multiple trip hammers for fulling cloth or mixing clay for potteries (*Nongshu* 19/11a–b)

Agriculture in China, Fig. 9 A large sluice across a river, with irrigation channels leading off into padi fields (*Nongshu* 19/2a–b)

Although there was no indigenous development of experimental agricultural science or engineering, Western agronomists found much to admire in traditional Chinese farming in the early twentieth century, particularly its careful husbandry and sustainability. Also traditional agronomic strengths such as crop breeding, have allied fruitfully with modern science. For example, Chinese geneticists used their vast range of local rice varieties to develop the first semi-dwarf high-yielding *indica* strains in the 1960s, several years before "miracle rices" were released by the International Rice Research Institute in the Philippines (Harlan, 1980).

Extra: Chinese Agriculture and the "Great Debate"

Until recently comparative historians of economics or of science and technology tended to treat non-Western civilizations like China (or the Islamic world, or the Mayan empire) as *failed* or *blocked systems*. The most interesting question to ask about them was: Why did they fail to follow the European pattern of historical progress to industrialization, capitalism and modernity? Even Joseph Needham, who dramatically documented so many fundamental contributions of Chinese civilization to early science and technology, believed that China's creativity and ingenuity ground to a halt in about 1400. Needham was inclined to blame this on the mindset of the governing elite ("bureaucratic feudalism"). In 1973 Mark Elvin published a highly influential study in which he argued that the problem lay primarily with the technologies and organization of production, beginning with farming and the associated system of household manufactures. Unlike in early modern Europe, Chinese landlords and merchants saw no reason to invest in new technology in order to increase production or profits because smallholder farmers and household manufacturers, who were already highly productive, were always able to raise output a little more by increasing the family's inputs of labor. Elvin argued that by about 1400 or 1500 this system of small-scale commodity production had reached a point of technical stagnation and diminishing returns to labor, an "involutionary"



Agriculture in China, Fig. 10 A polder (protective dyke) surrounding a block of rice fields reclaimed from swamp or the shallows of a river. Drainage channels run through the middle, and houses nestle among the willow trees planted along the high surrounding dykes (This illustration from 1742 is based on an original in Wang Zhen's *Nongshu*. *Shoushi tongkao*, 1742 edition, 14/5b)

system or "high-level equilibrium trap" that precluded indigenous transformation and encouraged overpopulation, impoverishment and the devastation of the environment. Only the forced confrontation with the modern Western powers in the nineteenth century offered China the opportunity to break out of this trap (Elvin, 1973). In the mid-1980s Philip Huang began to elaborate on Elvin's analysis and on Chayanov's theories of peasant self-exploitation through the lens of farm management and market participation, to lay out a theory of late imperial China's "growth without development" (Huang, 1985, 1990; see also Goldstone, 1996).

Since the late 1990s a revisionist trend has come to prominence, stimulated by scholarship that has reconsidered the roots, nature and trajectories of the Industrial Revolution in the West. Jan de Vries' concept of "industrious revolution" suggests close parallels between early modern Europe, China and Japan. de Vries (1994) argues that between roughly 1550 and 1850 households in northwestern Europe steadily increased their working hours and allocated more of their labor to specialized production for the market. This was not "involution," however, for they freed time for this work by purchasing some goods that they had previously made for themselves. The profits they made by their sales allowed them to purchase more consumer goods. Though they sacrificed some leisure hours, this brought them higher living standards. Historians and social theorists including André Gunder Frank (1998), Bin Wong (1997, 2003), and Ken Pomeranz (2000, 2003) have argued that this was also true of much of China through the late imperial period.

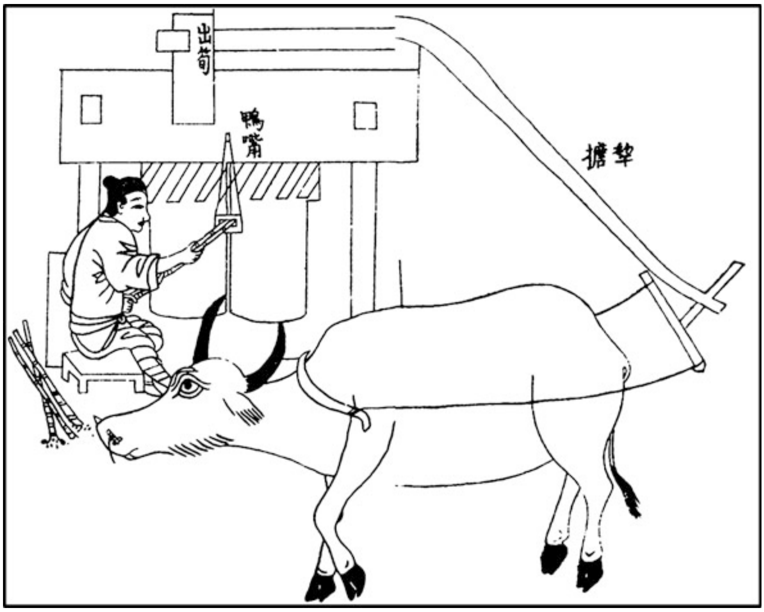
A slightly different angle is taken by historians whose research suggests that sometimes increased farming output was achieved without additional labor. There were a range of

A

Agriculture in China, Fig. 11 Fertilizing the rice seedlings in the nursery bed before transplanting (*Gengzhi tu*, Yongzheng imperial edition of 1742, 1/8b)

improvements in farming technology that did not involve labor-saving machinery per se yet made it possible to raise farming output without increasing labor inputs (Bray, 1986; Li, 1998a, 1998b; Shiba, 1998). The steady expansion of inter-regional or international trading networks allowed growing numbers of rural households to specialize in commercial production while buying food and other necessities on the market (Daniels, 1996; Gardella, 1994; Marks, 1998; Mazumdar, 1998), and government policies for monitoring and regulating grain distribution and prices helped reduce the risks of such market dependence (Hamilton & Chang, 2003; Marks, 1998; Wong, 1997). Local specialization was another factor that could raise output without necessarily leading to involution.

The revisionist historians stress that until at least 1800 China was the world's chief producer and exporter of manufactured goods. It was trading from a position of strength: from the sixteenth well into the eighteenth century, three quarters of



Agriculture in China, Fig. 12 Sugar mill with vertical rollers, depicted in Song Yingxing's technical treatise on crafts and industries *Tiangong kaiwu* of *1637*. This type of mill had apparently come into use in the chief sugar-exporting regions of China, namely the Southeastern provinces of Fujian and Guangdong, shortly before Song wrote his book. Song describes a variety of sugars, some for internal trade and some for export to Europe (*Tiangong kaiwu*, 1637 edition, 6/2a–b)

Agriculture in China, Fig. 13 Picking cotton. A group of young women is hard at work, while a granny and a little boy, helpfully carrying a wicker basket round his neck, look on. This is from a short illustrated work written by the Provincial Governor of Zhili (the Beijing region) in order to encourage rural women to take up cotton production. Wood block print of 1808 based on the original painting of ca. 1765 (*Shouyi guangxun*: 1/14b–15aBox) all the silver produced in the world ended up in China (Atwell, 1998; Brook, 1998; Flynn, Frost, & Latham, 1999). Not only was China a key actor in generating the economic configurations of world trade that catalyzed the rise of the modern West (Arrighi, Hui, Hung, & Selden, 2003: Frank, 1998), but life expectancy and living standards of rural households in around 1800 compared favorably with those in the most advanced regions of Western Europe at the time (Pomeranz, 2003). Hamilton and Chang (2003) go so far as to claim that from as early as 1500 China should be thought of as a mass-consumption society. Moreover, many of the revisionist scholars argue, early modern China's political, social and economic institutions were not inherently incompatible with or antagonistic to industrial capitalism, nor even to today's global capitalism: the legacy of the late imperial era is clearly visible in China's national and international reflorescence today (Arrighi et al., 2003; Hamilton & Chang, 2003).

The debate continues to rage, and given the patchy nature of the data both for Europe and for China it is likely to continue to seethe for some time. Often we find strong disagreements over the interpretation of the same data. In his magisterial new study of China's environmental history, for example, Elvin (2004) presents levels of deforestation in 1800 as proof that population growth and path-driven technologies had trapped China into a situation where it was probably more environmentally degraded than northwest Europe at the same time, while Pomeranz (2003) represents what he sees as roughly similar levels of deforestation in France and China around 1800 as a triumph of the Chinese political economy and its sustainable resource use.

The critical rethinking of the long-term logics of economic and technological development which we see in the revisionist scholars' work clearly owes much to the questioning of "master narratives" in postcolonial theory and critical studies of science and technology. Social and environmental critiques of productivism, together with new models of productive efficiency that emphasize decentralization, smaller scale and flexibility, provide a broader intellectual context for these new perspectives on the achievements or shortcomings of the imperial Chinese agrarian economy, as does China's meteoric rise as an economic and industrial powerhouse since the economic reforms of 1979.

See Also

▶ Food Technology in China

References

An Zhimin. (1999). *Origin of Chinese rice cultivation and its spread east* (W. Tsao, Trans., B. Gordon, Ed.). http://www.carleton.ca/~bgordon/Rice/papers/zhimin99.htm.

Arrighi, G., Hui, P. K., Hung, H. F., & Selden, M. (2003). Historical capitalism, east and west. In G. Arrighi et al. (Eds.), *The resurgence of east Asia: 500, 150 and 50 year perspectives* (pp. 259–333). London: Routledge.

Atwell, W. S. (1998). Ming China and the emerging world economy. C. 1470–1650. In D. Twitchett & S. Mote (Eds.), *The Cambridge history of China. Vol. 8(2): The Ming dynasty* (pp. 376–416). Cambridge, UK: Cambridge University Press.

Bray, F. (1984). Agriculture. Vol. VI pt. 2, In J. Needham (Ed.), Science and civilisation in China. Cambridge, UK: Cambridge University Press.

Bray, F. (1986). *The rice economies: Technology and development in Asian societies*. Oxford, UK: Basil Blackwell. Rpt. in Berkeley: University of California Press, 1994.

Bray, F. (2000). *Technology and society in Ming China (1368–1644)*. Washington, DC: Society for the History of Technology and the American Historical Association.

Bray, F., & Métailié, G. (2001). Who was the author of the *Nongzheng quanshu*? In C. Jami, P. Engelfriet, & G. Blue (Eds.), *Statecraft and intellectual renewal in late Ming China: The cross-cultural synthesis of Xu Guangqi (1562–1633)* (pp. 322–359). Leiden, The Netherlands: Brill.

Brook, T. (1998). *The confusions of pleasure: Commerce and culture in Ming China*. Berkeley, CA: University of California Press.

Buck, J. L. (1937). *Land utilization in China*. Shanghai, China: Commercial Press.

Daniels, C. (1996). Agro-industries: Sugarcane technology. In J. Needham (Ed.), *Biology and biological technology, Vol. VI, pt. 3. Science and civilisation in China*. Cambridge: Cambridge University Press.

de Vries, J. (1994). The industrial revolution and the industrious revolution. *Journal of Economic History, 54*(2), 249–270.

Duyvendak, J. L. L. (Ed.). (1928). *The book of Lord Shang; a classic of the Chinese school of law*. London: Probsthain.
Elvin, M. (1973). *The pattern of the Chinese past*. London: Methuen.
Elvin, M. (2004). *The retreat of the elephants: An environmental history of China*. New Haven, CT: Yale University Press.
Flynn, D. O., Frost, L., & Latham, A. J. H. (1999). *Pacific centuries: Pacific and pacific rim history since the sixteenth century*. London: Routledge.
Frank, A. G. (1998). *ReOrient: Global economy in the Asian age*. Berkeley, CA: University of California Press.
Gardella, R. P. (1994). *Harvesting mountains: Fujian and the Chinese Tea trade, 1757–1937*. Berkeley, CA: University of California Press.
Arrighi, G., Hamashita, T., & Selden, M. (Eds.). (2003). *The resurgence of east Asia: 500, 150 and 50 year perspectives*. London: Routledge.
Goldstone, J. (1996). Gender, work and culture: Why the industrial revolution came early to England but late to China. *Sociological Perspectives, 39*(1), 1–21.
Grist, D. H. (1975). *Rice* (5th ed.). London: Longman.
Hamilton, G. G., & Chang, W.-A. (2003). The importance of commerce in the organization of China's late imperial economy. In G. Arrighi et al. (Eds.), *The resurgence of East Asia: 500, 150 and 50 year perspectives* (pp. 173–213). London: Routledge.
Harlan, J. R. (1980). Plant breeding and genetics. In L. A. Orleans (Ed.), *Science in contemporary China* (pp. 295–312). Stanford, CA: Stanford University Press.
Huang, P. C. C. (1985). *The peasant economy and social change in North China*. Stanford, CA: Stanford University Press.
Huang, P. C. C. (1990). *The peasant family and rural development in the Yangzi Delta, 1350–1988*. Stanford, CA: Stanford University Press.
King, F. H. (1926). *Farmers of forty centuries, or permanent agriculture in china, Korea and Japan*. London: Jonathan Cape. Rpt. in Emmaus, Pennsylvania: Rodale Press, 1972.
Kuhn, D. (1988). *Textile technology, Vol. V pt. 9. Science and civilisation in China*. Cambridge: Cambridge University Press.
Li, B. (1998a). Changes in climate, land, and human efforts: The production of wet-field rice in Jiangnan during the Ming and Qing dynasties. In M. Elvin & L. Ts'ui-jung (Eds.), *Sediments of time: Environment and society in Chinese history* (pp. 447–486). Cambridge: Cambridge University Press.
Li, B. (1998b). *Agricultural development in Jiangnan, 1620–1850*. New York: St Martin's Press.
Elvin and Mark, Liu Ts'ui-jung. (Ed.). (1998). *Sediments of time: Environment and Society in Chinese History*. Cambridge, MA: Cambridge University Press.
Marks, R. B. (1998a). *Tigers, rice, silk, and silt: Environment and economy in late imperial South China*. Cambridge, MA: Cambridge University Press.
Marks, R. B. (1998b). It never used to snow': Climatic variability and harvest yields in late-imperial South China, 1650–1850. In M. Elvin & L. Ts'ui-jung (Eds.), *Sediments of time: Environment and society in Chinese history* (pp. 411–446). Cambridge: Cambridge University Press.
Mazumdar, S. (1998). *Sugar and society in China: Peasants, technology, and the world market*. Harvard: Harvard University Asia Center.
Perdue, P. (1987). *Exhausting the Earth: State and peasant in Hunan, 1500–1850*. Cambridge, MA: Harvard University Press.
Perkins, D. H. (1969). *Agricultural development in China 1368–1968*. Edinburgh, UK: Edinburgh University Press.
Pomeranz, K. (2000). *The great divergence: Europe, China and the making of the modern world economy*. Princeton, NJ: Princeton University Press.
Pomeranz, K. (2003). Political economy and ecology on the eve of industrialization: Europe, China, and the global conjuncture. *The American Historical Review, 107*(2), 425–446.
Rawski, E. S. (1972). *Agricultural change and the peasant economy of South China*. Cambridge, MA: Harvard University Press.
Shiba, Y. (1998). Environment versus water control: The case of the southern Hangzhou Bay area from the mid-Tang through the Qing. In Elvin and Liu (Ed.), (pp. 135–164).
Smith, P. J. (1991). *Taxing heaven's storehouse: Horses, bureaucrats, and the destruction of the Sichuan tea industry* (Harvard-Yenching Institute Monograph Series). Cambridge, MA: Harvard University Press.
Sun, E.-T. Z., & Sun, S.-C. (1966). Trans. *T'ien-kung k'ai-wu: Chinese technology in the seventeenth century*. University Park, PA: Pennsylvania State University Press.
Wong, R. B. (1997). *China transformed: Historical change and the limits of European experience*. Ithaca, NY: Cornell University Press.
Wong, R. (2003). The search for European differences and domination in the early modern world: A view from Asia. *The American Historical Review, 107*(2), 447–469.

Chinese Sources

Bianmin tuzuan (Collection of pictures for the convenience of the people) 便民圖纂, 1st ed. 1502, attr. Guang Fan鄺璠. Modern annotated edition with facsimile of 1593 woodblock illustrations, edited Shi Shenghan石聲漢 and Kang Chengyi 康成懿, 1959. Rpt. in Beijing, Agriculture Press, 1982.
Chaosheng王潮生, (Ed.) (1995). Wang *Zhongguo gudai gengzhi tu* 中國古代耕織圖(Farming and weaving pictures in ancient China). Beijing, China: China Agriculture Press,
Gengzhi tu 耕織圖. (1995). (Ploughing and weaving illustrated), a series of scroll paintings and poems

presented by Lou Chou樓璹 to the emperor in 1145; repeatedly reproduced in woodblock editions and stone engravings over the centuries, see Wang Chaosheng.

Shi Shenghan石聲漢 & Kang Chengyi康成懿, (Eds.). (1982). *Bianmin tuzuan便民圖纂* (Collection of pictures for the convenience of the people), attr. Guang Fan鄺璠. Beijing, China: Agriculture Press, (ms completed 1959).

*Nongshu*農書 (Agricultural treatise), Wang Zhen 王楨, preface 1313. The edition cited here, which includes the earliest surviving illustrations from 1530, is Wang Yuhu 1981.

Nongzheng quanshu 農政全書 (The complete treatise on agricultural administration), Xu Guangqi 徐光啟, ed. Chen Zilong陳子龍 et al., 1639. The edition cited is Shi Shenghan 1979.

*Qimin yaoshu*齊民要書 (Essential techniques for the peasantry), Jia Sixie賈思勰, c. 635; the edition cited is Shi Shenghan 1957.

Shi Shenghan石聲漢, (Ed.) (1957). *Qimin yaoshu jinshi 齊民要書今釋* (A modern translation of *Qimin yaoshu*). Beijing, China: Kexue Press, 4 vols.

Shi Shenghan石聲漢, (Ed.) (1979). *Nongzheng quanshu 農政全書* (The complete treatise on agricultural administration). Shanghai, China: Guji Press, 3 vols.

Shoushi tongkao 授時通考. (1742). (Works and days), comp. E'ertai鄂爾泰, presented to the throne.

Shouyi guangxun 授衣廣訓. (1960). (Expanded instructions on producing clothing). Woodblock edn. of *Mianhua tu*棉花圖 (Pictures of cotton), Fang Guancheng方觀承, presented to the Qianlong emperor in 1765 with additional poems and comments. Woodblocks carved under the direction of Dong Gao董誥 and presented to the Jiaqing emperor in 1808. Facsimile ed. *Zhongguo gudai banhua congkan*中國古代版畫叢刊, vol. 4. Beijing, China: Zhonghua Press.

*Tiangong kaiwu*天工開物 (The exploitation of the works of nature), Song Yingxing宋應星, 1st ed. 1637. Ed. cited: Shanghai, China: Commercial Press, *Guoxue jiben congshu jianbian*國學基本叢書簡編 series, 1936.

Yuhu 王毓瑚, (Ed.) (1981). Wang *Wang Zhen Nongshu*王楨農書 (The Agricultural Treatise of Wang Zhen). Beijing, China: Nongye Press, (manuscript completed 1966).

Some Online Resources

Another useful online source for maps of China and its contemporary provinces, with good information about regional history, contemporary economics, climate, agriculture, cuisine, etc., is the Web site of the *South China Morning Post*, the Hong Kong English-language newspaper: http://china.scmp.com/map/

China Facts and Figures provides useful statistics on contemporary agriculture in its section on "Economy"; the English-language Web site for 2003 is http://www.china.org.cn/english/eng-shuzi2003/

For brief accounts of Chinese history from its origins up to 1988, try http://www-chaos.umd.edu/history/toc.html

http://depts.washington.edu/chinaciv/ is the Web site of the *Visual Sourcebook of Chinese Civilization*, prepared by the social historian of China Patricia Buckley Ebrey, with the assistance of Joyce Chow, Lenore Hietkamp, Kevin Jensen, Robert Lin, Helen Schneider, Cyndie-Lee Wang, Kim Wishart, Cong Zhang and Lan Zhang. The project was funded by the National Endowment for the Humanities, the Freeman Foundation and the Chiang Ching-Kuo Foundation. The Web site provides useful historical timelines and geographical background, and it presents the main periods of Chinese history from the Neolithic up to the present by selecting two key themes (such as tombs, or calligraphy, or weapons) for each period. The illustrations (maps, photographs and art works) are excellent. As good background for the history of agriculture in China, under "Geography," "Land" (http://depts.washington.edu/chinaciv/geo/land.htm) you will find a series of maps showing topography, climate, etc. If you follow through to "China proper" and then to "Outer China," among the photographs you will see images of the farming landscapes typical of China's regions, and of typical crop plants and farming techniques (plowing, transplanting rice with a machine, picking tea, herding).

On contemporary economic issues concerning Chinese agriculture, see the UC Davis site http://aic.ucdavis.edu/research1/chinaeconomics.html

The Food and Agriculture Organization (FAO) webpage on China http://www.fao.org/countryprofiles/index.asp?lang=en&ISO3=CHN is an excellent source for a wide range of studies and statistics on contemporary agricultural issues in the People's Republic of China, including themes like sustainable development. It also offers a useful set of interactive maps which include maps showing elevation, slope, precipitation, length of growing period and major environmental constraints as well as more conventional maps of political boundaries, population, communications, etc.

Agriculture in India

R. K. Arora
New Delhi, India

The Harappan culture related to the earliest agricultural settlements in the Indian subcontinent is dated between 2300 and 1700 BCE. The crops of the Harappan period were chiefly of West Asian origin. They included wheat, barley, and peas.

Of indigenous Indian origin were rice, tree cotton, and probably sesame. Rice first appeared in Gujarat and Bihar, not in the center of the Harappan culture in the Indus Valley. There is some rather doubtful evidence that African crops were also grown by the Harappans. There is a record of sorghum (*jowar*) from Sind and *Pennisetum* (*bajra*) from Gujarat. The earliest record of the African cereal, *Eleusine coracana* (*ragi*) is from Mysore, about 1899 BCE. The Southeast Asian crops of importance to India are sugar-cane and banana, and they both appear in the early literary record. Crops of American origin include maize, grain amaranths, and potato. The dating of the introduction of maize is uncertain, the characteristics and distribution of some forms being such as to lend support to the view that they reached India in pre-Columbian times. Crops of the Indian subcontinent have influenced the agricultural development of ancient Egyptian, Assyrian, Sumerian, and Hittite civilizations through their early spread to these regions of the Old World. The Buddhists took several Indian crops and plants to Southeast Asian countries, and there was much early exchange of plant material with Africa. The Arabs distributed crops such as cotton, jute, and rice to the Mediterranean region in the eighth to tenth centuries AD. There was also a reciprocal exchange of several New World domesticates.

Agriculture Today

India is characterized by a wide variety of climates, soils, and topographies. It is rich in biodiversity and a seat of origin and diversification for several crop plants such as rice, millets, pigeon pea, okra, eggplant, loofah, gourds, pumpkin, ginger, turmeric, citrus, banana, tamarind, coconut, and black pepper. Because India is ethnically diverse, traditional agriculture is still practiced in many places. There are about 100 million operational holdings, and the country has over 20 % of the world's farming population.

India has different ecosystems such as irrigated, rain fed, lowland, upland, semideep/deep water, and wasteland. Agriculture is primarily rain fed (rain dependent); it supports 40 % of the human population, 60 % of cattle, and contributes 44 % to the total food production. Owing to differences in latitude, altitude, variation in rainfall, temperature and edaphic diversity, great variety exists in crops and cropping patterns.

There are two important growing seasons in India: the *Kharif* or the summer season, especially important for rice; and the *Rabi* or the winter season in which major crop grown is wheat. The *Kharif* crop is primarily rain dependent, and the *Rabi* is relatively more reliant on irrigation. The *Kharif*/rainy season cropping patterns include major crops such as rice, sorghum, pearl millet, maize, groundnut, and cotton. The *Rabi*/winter season cropping patterns include important crops like wheat, barley and to some extent oats, sorghum, and gram/chickpea. Mixed cropping is also practiced, especially during the kharif season. Pulses, grain legumes, and oilseeds are grown with maize, sorghum, and pearl millet. Brassica and safflower are grown mixed with gram or even with wheat. Under subsistence farming, on small holdings, mixed cropping provides food security and is consumption oriented.

India is the major producer of a number of agricultural commodities including rice, groundnut, sugar-cane, and tea. Food grains constitute roughly two-thirds of the total agricultural output. These consist of cereals, principally rice, wheat, maize, sorghum, and minor millets. India is the second largest producer of vegetables next to China. Mango accounts for almost half of the area and over a third of production; banana is the second largest and is followed by citrus, apple, guava, pineapple, grape, and papaya. Of nonfood cash crops, the most important are oilseeds especially groundnut, short staple cotton, jute, sugar-cane, and tea.

Owing to improvements in recent years there has been widening of inter-regional disparities in agricultural production and productivity. Regions such as the north and north-west and the delta regions of peninsular India have prospered under assured irrigation, but dryland and semiarid regions have not done so well.

References

Arora, R. K. (1992). Plant diversity in the Indian gene centre. In R. S. Paroda & R. K. Arora (Eds.), *Plant genetic resources: Conservation and management* (pp. 25–54). New Delhi, India: International Board for Plant Genetic Resources.

Forty years of agricultural research and education in India. (1989). New Delhi, India: Indian Council of Agricultural Research.

Handbook of agriculture. (1992). New Delhi, India: Indian Council of Agricultural Research.

India. *Regional surveys of the world*. (1993). *The Far East and Australasia*. 24th ed. London: Europa Publications. 275–335.

Agriculture in Indonesia

Harro Maat
Knowledge, Technology and Innovation Group, Department of Social Sciences, Wageningen University and Research Centre, Wageningen, The Netherlands

The map of Indonesia suggests a high diversity in types of agriculture. The archipelago has countless different islands that stretch out over thousands of kilometers from east to west, above and below the equator. It has a rich biodiversity and the techniques the people developed to benefit from the natural environment have distinct features on each of the islands. Despite all this diversity, some clear patterns can be detected, based on three major factors. The first is the monsoon climate that divides the year into a dry and wet season with an overall high precipitation of roughly 1,700–3,000 mm in the lowlands and to over 6,000 mm in the mountainous regions. The combination of high rainfall and, for tropical conditions, not excessively high temperatures throughout the year creates a favorable climate for many different crops. The geology and elevation of the landscape is a second factor. The islands are positioned on the edges of different tectonic plates, resulting in vast mountain areas with a high number of (active) volcanoes. The eruption of volcanic ashes and the erosion of volcanic rock can create fertile ground for agriculture. In cases where volcanic sediment makes favorable soil conditions, people have used the topography to exploit this natural fertility. Such conditions are typically found on Java and Bali and some other smaller islands or parts of bigger islands. The bunded rice field (*sawah)* is a catchment for eroded sediments brought along by water from rivers and streams coming from the mountains. The Indonesian people constructed *sawahs* wherever possible but mostly in the lowlands on Java and on the hillsides, forming the now famous terraced landscapes of Bali. In most of the other main islands, these favorable conditions are found much less often. The availability of rice as a staple crop is a third determining factor. Rice was and is the main food crop in the entire archipelago. The only exceptions are the eastern areas, mainly the Moluccas and Western New Guinea, where sago, a starchy substance, was processed from the soft interior of palms, primarily the species *Metroxylon sagu*. It is likely that these communities survived for long periods of time solely on a combination of arboricultural techniques supplemented with hunting. This implies a reliance on the rainforest without additional agricultural techniques for (semi-) permanent crop production (Ellen, 2004). In all other places, the domestication and cultivation of rice formed the core around which many agricultural techniques developed.

The climatic and geological conditions predominantly found on Java and Bali have resulted in a domestication process of rice that is specific for this region. Asian rice (*Oryza sativa*) has two main subspecies (or varietal groups): *indica* and *japonica*. The latter varieties typically grow in more temperate climates but are also found in tropical areas. In Indonesia a morphologically distinct group of these tropical japonicas has developed, commonly known as javanica or bulu in the local language (Vaughan, Lu, & Tomooka, 2008). The most visible characteristic of the bulus are seeds with long awns (bristle on top of seed). Characteristics that mattered most for farmers are lower sensitivity of these varieties for drought, variation in day length, intensity of sunlight, and transplanting time. These latter characteristics also make these varieties have a longer growth duration, the time between sowing and ripening. The yield potential of indica varieties is better on poorer soils, but this was not an issue for the better soils of Java, Bali, and similar places. The characteristics of the bulus allowed farmers to be more flexible in sowing, transplanting, and harvesting of rice, resulting in an overall high labor productivity. Moreover, there was a wide range of bulu varieties available to farmers. Rice, an inbreeding crop, usually produces very few natural crosses but outcrossing is relatively high in the bulu group. Farmers selected the spontaneous crosses and observed their performance in a mix and match strategy to optimize yields under different field conditions. In fields with less advantageous soil and water conditions, as mostly found on mountain slopes, indica varieties were preferred. Early colonial writers acknowledged the varietal diversity of rice on Java and other islands, but only in the early twentieth century did agronomists recognize bulus as a different subspecies and came to understand its role in farm cultivation strategies and techniques (Maat, 2001). The dominance of bulu varieties on Java and similar places gradually disappeared in the twentieth century. Improved irrigation infrastructure introduced by Dutch engineers facilitated two rice crops per year. As a result, indica varieties, having a shorter growth duration, came to dominate (Van der Eng, 1994). Colonial rice breeders tried to maintain some of the favorable characteristics of bulus through crossbreeding with indica varieties. One of the successful lines of these crosses was taken up in the 1960s by the International Rice Research Institute to develop the fertilizer-responsive variety IR8 that was massively introduced in Indonesia in the early years of the green revolution. The productivity levels realized for rice in the twentieth century using science-based technologies thus built on a much longer process of intensification set in motion by the Indonesian farmers.

The combination of specific rice varieties and climatic and geological conditions that dominated Java and Bali over, most likely, several millennia played a major role in the economic prosperity and contributed to a high population density in these islands. Although archaeological evidence of early times is sparse, inscriptions from about the ninth century testify the presence of large and prosperous communities across the islands (Wisseman Christie, 2004). The preference for bulu varieties makes clear that the high labor productivity in agriculture in these areas is not merely an effect of a fortuitous natural environment but involves tested strategies and techniques to optimize intensive wetland rice cultivation with various other forms of crop production in the wet monsoon season and the dry season. The control of land by local communities was left untouched by state formation that came together with the introduction of Hindu and Buddhism, followed later by Islam, creating social structures that favored the intensification of agriculture. The presence of different religions testifies frequent interactions with mainland Southeast Asia, India, and other regions. Intensive regional trade relations and global connections since early colonial settlements implied the introduction of new agricultural crops and the distribution of crops and crop varieties across the Indonesian islands. From about 1,500, rice was no longer the single source of carbohydrates (Boomgaard, 2003). Communities could thus further grow as the new crops allowed them to expand their agricultural activities on soils less suited for rice. Colonial trade relations also were an incentive to produce crops that were initially produced solely for distant markets but became fully integrated in the local economy and diet. Coffee, introduced on Java by the Dutch in the early eighteenth century, is just one example.

The wealth of the Javanese and Balinese states and subsequent emphasis of colonial administrations resulted in a much wider availability of sources about agriculture on these islands compared to other places. This correlates with an overall bias in early colonial history that depicts the farming systems on Java and Bali as most advanced and exemplary for a development trajectory other islands inevitably had to follow. In these evolutionary projections, the sago cultures in the east are typically portrayed as most primitive. In between are agricultural practices known as shifting cultivation and semipermanent forms of agroforestry. These types of farming dominate in the mountainous and forested areas of Sumatra, Kalimantan (Indonesian Borneo), and Sulawesi. They require a variety of different techniques, mainly felling, clearing, and burning of a piece of forest for the cultivation of annual crops. Farming these fields for one up to three harvests is typically combined with planting perennial shrubs and trees, collecting forest products, and hunting. This is either practiced in a cyclical pattern by mobile communities or in more sedentary forms that combine the cultivation of permanent fields with clearing additional pieces of forest for temporary or permanent use. Except for the eastern sago cultures, rice is the main staple and the first crop to be sown after clearing. Similar to more permanent rain-fed upland fields (*tegal*), other crops are grown in between or immediately after the rice crop and later crop introductions further diversified these systems. The representation of the various forms of agroforestry as more primitive and necessarily to be replaced by permanent agriculture on the basis of *sawah* rice fields is partly a colonial projection of developments on Java where shifting cultivation was commonly found but rapidly declined over recent centuries. Moreover, a late and overall low presence of administrators and researchers on Sumatra, Kalimantan, and Sulawesi resulted in low and superficial information about these farming systems. More profound and nuanced understandings emerged from recent anthropological and historical research (Dove, 1985a; Henley, 2011). However, the negative bias against shifting cultivation must be understood primarily from colonial economic and political interests on these islands that continued in similar forms in the policies of Indonesia after independence (Dove, 1985b).

The introduction of cash crops for global markets, set in motion by early colonial explorations, rapidly expanded after the 1860s and profoundly changed the agricultural landscape on various Indonesian islands. The colonials introduced large estates, managed by European private companies and made productive with large numbers of contract laborers. Indonesia became a major supplier of agricultural produce for international markets. In the first half of the twentieth century, Java dominated the international market for the antimalarial quinine and had a highly productive cane sugar sector. Sumatra tobacco became a brand name in Europe and oil palm and rubber estates supplied the Western industries. The late colonial plantations were in many respects foreign introductions. Earlier, larger plantation-like farms were present on Java and some other islands, mainly for coffee, tea, spices, and sugarcane, but those were mostly managed through contracts with local rulers who arranged community farm labor for the delivery of the products. The modern estates were run by European capital investments, and imported tools and machinery. Laborers were recruited from other islands and outside Indonesia. In Sumatra, Kalimantan, and Sulawesi, these enterprises stood in sharp contrast with the shifting cultivation practices of the local farmers, leading to continuous tension and frequent conflicts. A zone of intensive plantation production is the northern region of Sumatra. There, the land hunger of the European enterprises and differences between colonial and local land rights were the source of an ongoing struggle over land ownership and borders (Pelzer, 1978). Likewise, the recruitment of tens of thousands of laborers from outside Sumatra, working on the estate lands and processing the products for low wages under harsh conditions, not only implied a long-fought battle over labor conditions but also confronted the colonial administration with issues over settlements for the workers, land rights, health, and social order (Stoler, 1985).

It is no surprise that the soils in the forested regions of Sumatra, Kalimantan, and Sulawesi are suited for tree crops like rubber and oil palm or shrubs producing pepper or fibers. With markets in reach, local farmers eagerly adopted these crops as an additional and often main source of income. This leads to an extensive smallholder production of these industrial crops in subsequent decades. Unlike the estate monocropping, farmers integrated the cash crops in their shifting cultivation practices. The technique had several advantages, for example, a reduced disease pressure, leading to low production costs and good-quality produce. Moreover, the variety of crops grown in the local systems made the farmers much less vulnerable to price fluctuations of cash crops. This, for example, resulted in a prosperous smallholder rubber production on Borneo (Dove, 1993). The competition with plantation production and the rivalry over land and forest products, the latter resulting out of colonial forest management and timber production, motivated a negative assessment of the shifting cultivation practices. In addition, the large inflow of contract laborers and the growth of urban trade centers like Medan (Sumatra) resulted in a growing dependency on rice imports. This was a general concern for the colonial administration, coming to a climax in the late 1910s when access to overseas markets became vulnerable due to World War 1 and harvest failure in the immediate postwar seasons. The plantation companies and the colonial government, assuming that farmers on Sumatra were ignorant about growing rice properly, experimented with mechanized rice schemes and set up a migration program to transfer Javanese farmers to Sumatra, expecting they would bring their intensive rice-growing systems with them (Maat, 2014). The ill-informed colonial policies thus worked against rather than stimulated the skillful practices of the farmers and their capacity to include new crops, techniques, and methods into their farming systems.

There are no records of early local scientific accounts of agriculture, although connections with India and mainland Asia, witnessed by the Hindu and Buddhist influences, in combination with early state formation, may have produced systemized knowledge of agriculture by administrators. The earliest written records of agriculture were part of botanical investigations from naturalists who were recruited by the Dutch East India Company (VOC). The emerging colonial state and scientific explorations from the early nineteenth century resulted in a growing number of descriptions of many different parts of the archipelago. The reports include detailed accounts of crops, crop varieties, cultivation practices, and related cultural events and festivities. By the late nineteenth century, specialized agricultural research became institutionalized in private experiment stations, the botanic garden in Bogor, and further developed from the first decade of the twentieth century under the colonial Department of Agriculture (Boomgaard, 2006; Maat, 2001). With few exceptions, all these studies were written in Dutch. Although much of the investigations were targeted at cash crops, there was also a substantial set of studies into Indonesian agricultural technologies and practices. In particular the colonial agricultural extension service that employed Dutch and Indonesian agricultural experts produced a substantial number of studies of the farming techniques, tools, and production methods in different regions. A substantial number of these agronomists challenged the common view of a backward and irrational farming community, showing that local strategies and techniques made sense given the environments in which the farmers worked. Their argument to experiment with innovations that build on the local techniques rather than introducing Western examples resonated well with similar criticism on the introduction of Western technological models in the late twentieth century (Maat, 2011). The recent concerns about the environmental impact of agriculture, climate change, and dependency on fossil fuels may foster a renewed attention for the techniques and methods farmers have employed and improved over the ages in the variety of ecological settings the Indonesian archipelago has to offer.

References

Boomgaard, P. (2003). In the shadow of rice: Roots and tubers in Indonesian history, 1500–1950. *Agricultural History, 77*(4), 582–610.

Boomgaard, P. (2006). The making and unmaking of tropical science: Dutch research on Indonesia, 1600–2000. *Bijdragen tot de Taal-, Land- en Volkenkunde, 162*(2/3), 191–217.

Dove, M. R. (1985a). *Swidden agriculture in Indonesia; the subsistence strategies of the Kalimantan Kantu*. Berlin/New York/Amsterdam: Mouton Publishers.

Dove, M. R. (1985b). The agroecological mythology of the Javanese and the political economy of Indonesia. *Indonesia, 39*, 1–36.

Dove, M. R. (1993). Smallholder rubber and swidden agriculture in Borneo: A sustainable adaptation to the ecology and economy of the tropical forest. *Economic Botany, 47*(2), 136–147.
Ellen, R. (2004). The distribution of *Metroxylon sagu* and the historical diffusion of a complex traditional technology. In P. Boomgaard & D. Henley (Eds.), *Smallholders and stockbreeders. Histories of foodcrop and livestock farming in southeast Asia* (pp. 69–105). Leiden: KITLV Press.
Henley, D. (2011). Swidden farming as an agent of environmental change: Ecological myth and historical reality in Indonesia. *Environmental History, 17*, 525–554.
Maat, H. (2001). *Science cultivating practice: A history of agricultural science in the Netherlands and its colonies, 1863–1986*. Dordrecht/Boston: Kluwer Academic Publishers.
Maat, H. (2011). The history and future of agricultural experiments. *NJAS-Wageningen Journal of Life Sciences, 57*, 187–195.
Maat, H. (2014). Commodities and anti-commodities: Rice on Sumatra 1915–1925. In E. Fields Black, F. Bray, D. Schäfer, & P. Coclanis (Eds.), *Rice: A global history*. Cambridge: Cambridge University Press.
Pelzer, K. J. (1978). *Planter and peasant: Colonial policy and the agrarian struggle in east Sumatra 1863–1947*. The Hague: Martinus Nijhoff.
Stoler, A. L. (1985). *Capitalism and confrontation in Sumatra's plantation belt, 1870–1979*. New Haven: Yale University Press.
Van der Eng, P. (1994). Development of seed-fertilizer technology in Indonesian rice agriculture. *Agricultural History, 68*, 20–53.
Vaughan, D. A., Lu, B. R., & Tomooka, N. (2008). The evolving story of rice evolution. *Plant Science, 174*, 394–408.
Wisseman Christie, J. (2004). The agricultural economies of early Java and Bali. In P. Boomgaard & D. Henley (Eds.), *Smallholders and stockbreeders. Histories of foodcrop and livestock farming in southeast Asia* (pp. 47–67). Leiden: KITLV Press.

Agriculture in Japan

Mutsuyasu Ito
Higashi-Koigakubo, Kokubunji, Tokyo, Japan

The land in Japan has distinctive characteristics which make it suitable for plant production, being influenced by favorable ecological conditions. Because of this, intensive agriculture with paddy rice has been the basis of most economic activity over the last 2,000 years, and the people stayed predominantly agricultural until recently. However, Japan has since been transformed into a heavily industrialized society with a remarkably rapid growth of its economy after the Second World War. Now the Japanese have almost abandoned their traditional food culture, which depends on rice plus other supplemental grain foods, diverse vegetables, mountain plants, and sea products. They have instead been paying large amounts of money in order to incorporate Westernized fatty and protein-rich foods from all over the world into their cuisine. Rice consumption has decreased dramatically in the last half century, and the daily intake of nutritious foods such as meat, milk, and other dairy products has increased remarkably, leading to a high demand for luxury foods. Within the Japanese agricultural sector, only rice is produced to the level of national self-sufficiency, while only 50 % of the products derived from animals – themselves raised by concentrates (feed grains) which are nearly 100 % imported – is supplied domestically (Table 1).

The early postwar effort to increase the production of food to meet national requirements actually led to a serious problem from around 1960, when the Japanese economy as a whole began to boom and agriculture began to decline. Rice cultivation narrowly survives with increased abandonment of agricultural fields and deterioration of sub-natural environments which the Japanese people had created over the past 2,000 years. The present situation with Japanese agriculture is the degradation of the rich, green nature of the country that people had long admired as *Mizuho-no-kuni* (the land of vigorously growing rice plants).

Influential Trends of Geography and Climate in Japanese Islands for Farming

Japan is a typical island country expanding along the far eastern edge of the temperate Asian

Mutsuyasu Ito retired.

A

Agriculture in Japan, Table 1 Domestic supply, importation, and domestic demand of various foodstuffs in Japan[a]

Products	(A) 2012[a] Domestic supply (in 1,000 t)	Imported (in 1,000 t)	Self-sufficiency (%)	(B) 1962[a] Domestic supply (in 1,000 t)	Imported (in 1,000 t)	Self-sufficiency (%)	Increasing ratio of demand in 1962–2012 (A/B)
Rice	8,692	848	91.1	13,009	182	98.6	0.72
Wheat	858	6,578	11.5	1,631	2,490	39.6	1.80
Barley	172	1,896	8.3	1,726	0	100.0	1.20
Soybean	236	2,727	8.0	336	1,284	20.7	1.83
Vegetables	11,974	3,302	78.4	12,245	16	99.9	1.25
Fruits	3,027	5,007	37.7	3,387	245	93.3	2.21
Milk	7,608	4,191	64.5	2,526	357	87.6	4.09
Beef[b]	514	722	41.6	153	4	97.5	7.87
Pork[b]	1,295	1,141	53.2	322	0	100.0	7.57
Broiler[c]	1,457	736	66.4	155	0	100.0	14.15
Hen's egg[d]	2,507	123	95.3	981	0	100.0	2.68

[a]Demand and supply table of agricultural products; Ministry of Agriculture, Forestry and Fishery, Japan
[b]In carcass weight
[c]In fresh body weight
[d]In sold amount

continent. The Japanese archipelago covers a vast sea area including 6,852 islands that extend from subtropical Ishigaki (24°N, 124°E) to the northernmost point of Hokkaidō at Wakkanai (46°N, 142°E). It shows diverse landscapes and meteorological conditions, but most of the area has a temperate, oceanic climate. The total land area is less than 380,000 km^2 (only one-thirtieth of the territory of China), and the four main islands of Hokkaidō, Honshū, Shikoku, and Kyūshū are dominated by steep mountains that often reach to 1,000 m or even more above sea level. Because of mountainous nature of the islands, the amount of flat land suitable for cultivating crops is less than 15 % of the total area of land (Table 2).

In spite of its more or less cold winter, Japan benefits from a longer warm season and yearlong rainfall mostly above 1,000 mm per year (Fig. 1), both of which are indeed useful for high-yielding crop cultivation, particularly for paddy rice. However, the climatic condition also accelerates harmful weed generation that disturbs pure stand formation of cultivated crops. The generally warm, moist climate (almost similar to tropical forests during summer seasons), which provides high organic produce, has led to vegetation with forests spreading throughout the archipelago. These geographical features present Japanese farmers with a difficulty in scale economy of their farming and force them to do continual hard work in almost all the seasons to improve yield potential per unit area.

Delayed Start of Paddy Rice Agriculture and Its Remarkable Growth from the Very Beginning

In spite of its rich potential for crop production, the actual start of paddy rice cultivation did not occur until several thousand years after its origin in the Yangtze River basin in the nearby Asian continent. Around 2,400 years ago, when the Jōmon Period (ca. 10, 000 BCE – 400 BCE; this period was dominated by hunting and gathering characterized with straw-rope patterned [=jōmon] pottery) was declining, the arrival of new immigrants from the continent brought techniques for paddy rice cultivation with their own cultivars. As the Yayoi Period (ca. 400 BCE–ca. 300 CE, so-called from the place in Tōkyō where the new type potteries were first unearthed) started, it replaced the lifestyle based on hunting and gathering with one based on the cultivation of

Agriculture in Japan, Table 2 An abstract of land size, vegetation, and agricultural land use in Japan

Item	Area (km^2)	Ratio (%)
(A) Total land size of Japan[a]	377,960	100.0
Hokkaidō	83,457	22.1
Honshū[d]	231,121	61.1
Shikoku	18,793	5.0
Kyūshū	42,194	11.2
Okinawa (Ryūkyū Islands)	2,277	0.6
(B) Total arable lands[b]	45,490	12.0
Those used for paddy rice[b]	24,690	6.5
(C) Forests[b]	244,616	64.7
(D) Grasslands[c]	22,337	5.9

[a]Statistics Japan (2014)
[b]Agricultural statistics (2013)
[c]Mostly seminatural grasslands. Green census, Japan (1983)
[d]In general, Honshū (=Main Province) is geographically divided into five regions, i.e., Tōhoku, Kantō, Chūbu, Kinki, and Chūgoku (see Fig. 1)

rice supplemented with various crops. Because irrigation techniques had been rather primitive and not as sophisticated as in China when the rice culture was introduced, swampy areas along mountain streams and basins were primarily used for cultivation. Indeed, wooden farm implements such as hoes and spades were already very popular for working with improved japonica-type rice varieties together with preparing and transplanting skills of rice seedlings (a lot of transplanted rice stubbles were traced at various archeological sites of the Yayoi Period). It looks as if Japanese agriculture had been consistently staying at an intensive and labor-consuming nature since its origin.

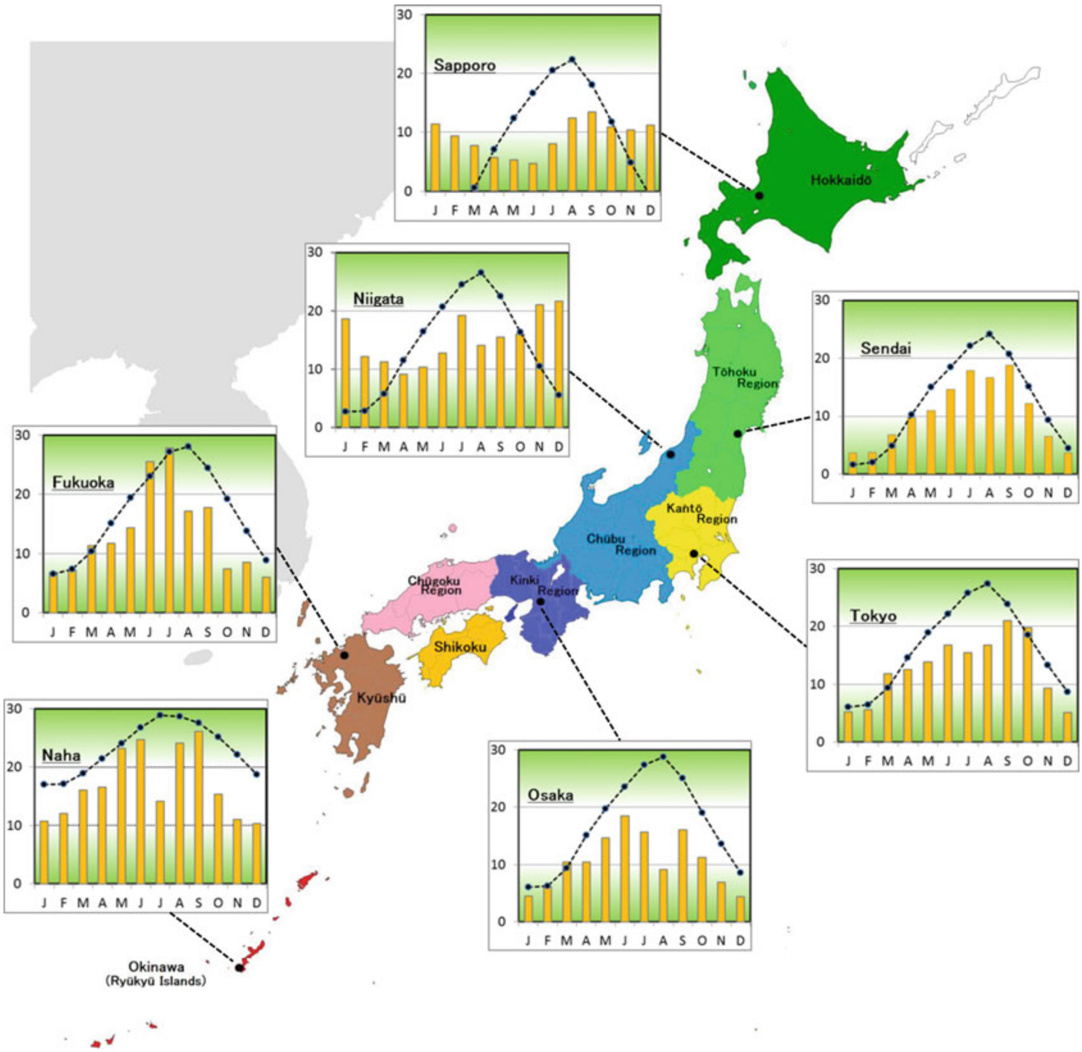
Soon after the introduction of paddy rice in northern Kyūshū around the fourth or fifth century BCE, paddy rice production and its associated technology began to spread eastward into Shikoku Island and Kinki region (the southern Honshū near present Ōsaka) where the Yamato Court later gained supremacy over all of Japan. At least 2,000 years ago, they arrived in the Kanto region (areas around today's Tōkyō) and subsequently moved toward north into the Tōhoku (northern Honshū) region. Large Yayoi remains of paddy fields discovered at Taruyanagi in Aomori Prefecture at the northernmost end of Honshū (42°N) demonstrate that the diffusion of rice cultivation was very rapid and took only several hundred years at most, despite a large distance and different climates between northern Kyūshū and northernmost Honshū. Through experiments, Sato (1992) has endeavored to show that domestically improved thermosensitive cultivars, which ripened quicker and earlier, were probably responsible for this rapid progress of rice cultivation in cooler areas.

A

Development of Farming System in Ancient and Medieval Ages

Although the traces of upland rice and other miscellaneous grain cultivation were detected in various archeological sites of late Jōmon Periods, the beginning of the Yayoi Period should be thought of as the real dawn of agriculture in Japan. Because of the surplus production of introduced paddy rice agriculture, it soon brought about social arrangements with class distinctions. Remains at the Yoshinogari archeological site in northern Kyūshū demonstrate that the agrarian society of that time tightly created the construction of circular trenches protecting against their enemies and had a state-like political structure in which social stratification became clearly visible (Fig. 2). A Chinese history book in the second century CE noted long-lasting disturbances among tiny tribal countries in western Japan struggling for supremacy among their districts.

A much higher technology for agriculture developed in the subsequent Kofun Period (ca. 300–700 CE; Kofun refers to ancient tomb mounds prepared for central and local rulers). Social and technological progress came with the introduction of advanced iron implements (those hoes, plows, and spades led to deeper soil tillage), maintained waterways, reservoirs, canals, and the orderly planting of rice, all of which resulted in higher yields and the further expansion of arable land. These developments were probably accompanied by a change from using stone knives to clip off the progressively developed panicles of



Agriculture in Japan, Fig. 1 Regions and climates of Japanese Archipelago – seasonal changes of mean air temperature (°C, –●–) and precipitation (×10 mm, ▬) in various locations from Hokkaidō to Okinawa. Average of past 30 years from 1981 to 2010 was shown (Statistics of Japan 2014, Ministry of Internal Affairs and Communications). Months below 0 °C were excluded in the case of Sapporo (Outline map is delivered from the website of CraftMAP. http://www.craftmap.box-i.net/)

genetically diverse rice population to using sickles to harvest the aboveground parts of genetically identical crops with their heads attached.

Through these developments, the Yamato Court finally held supremacy over rival countries and was able to carry out social, economic, and political reforms known as the Taika Reform (Taika is the name of the era between 645 and 650 CE, which was first recorded in Japan) that promoted a centralized state similar to that in the ancient empire of China. In 701, the legal system, known as Ritsuryō (Criminal and Civil Laws), was established to govern the whole country except for Hokkaidō (which was not yet Japanese territory). Under the Ritsuryō system, canal improvements, reclamation of new paddy fields, and rezoning of regular-size fields were all planned by the central government in an effort to significantly increase agricultural production. However, the Japanese people did not develop

Agriculture in Japan, Fig. 2 Yoshinogari Archeological Site in Saga Prefecture, North Kyūshū. The site was first excavated around 1990, and a wide area of state-like settlements that developed in the Yayoi Period became apparent through a series of investigations

customs for raising livestock and poultry for consumption because Buddhism became the official religion in the eighth century. Since then, they depended greatly on rice as their main food and supplemented it with various other grains and plants with the occasional addition of fishes. These characteristics of farming and cuisine that date back to the period of consolidating central power in the archipelago continued over the centuries until the beginning of the modern age.

Although the best yields of rice in the Nara Period (710–794) were supposed to be less than 1,000 kg per hectare (Furushima 1947; just one-sixth of the present yield in Japan), that figure was surprisingly high when compared to yields of wheat in England during the same period (Evans 1975). The introduction of rice was also advantageous for efficient food supply at the time because it required basically no fallowing of fields when they were regularly fertilized and properly maintained. Thus the paddy rice farming which originated at early Yayoi Period led to a steady increase of population size, in parallel with steady development of cultivation techniques and further expansion of paddy rice fields. In the Nara Period, the official record noted more than five million citizens in Japanese territory (Kitō 2000; cf., about 70,000 people were estimated to live in the latest Jōmon Period [Habu 2004]).

Governmental power under the Ritsuryō system, however, began to collapse in the middle of the Heian Period (794–1192), as private territories of powerful aristocrats, temples, shrines, and clans emerged as *shōen* (manors). As central rule became weaker and weaker because of the social changes in the late Heian Period, officials in district branches and wealthy farmers began to arm themselves, and their influential leaders formed bands of warriors known as *samurai*. After a long struggle between samurai bands in various areas, the remaining two most powerful bands – Genji and Heishi – fought for national supremacy in the twelfth century. The war finished with the Genji in power and the beginning of the Kamakura Period (1192–1333) in which Japan became to be ruled by a samurai government (the first shogunate). In this feudal period, a relationship developed between lords and vassals from the samurai class, in which the latter usually engaged in agriculture and managed their farmlands as well as providing military service for wartime.

The establishment of manors and the intensification of agriculture in each locality resulted in a further rise of agricultural output that led to a second boom in land reclamation for paddy fields, and surplus agricultural products were gradually commercialized to create markets in various regions. Attempts at double-cropping in paddy fields first emerged in the Kamakura Period, probably trying to raise additional winter harvests in lean years at the beginning. Later it was established in wider areas (particularly in western Japan) as a peculiar rotational cultivation system with rice for the main crop plus wheat, barley, or rape for the winter crop, which was not so popular in other East Asian areas.

The increasing economic strength of various lower classes, however, weakened the central power of the samurai government and drew Japan into a period of civil wars in the latter part of the Muromachi Period (the reign of second shogunate Muromachi, 1338–1573). Dominant feudal powers in various regions began fighting each other in an era known as the Sengoku Period (1467–1598; Sengoku refers to warring states). During that time, improving agricultural production and expanding arable land were the greatest concerns for powerful territorial lords (Sengoku Daimyō; *daimyō* originally meant "great paddy-field-owners") because of the possibility of imminent warfare. They took careful control of paddy fields in their territories and expanded areas even in hilly diluvial plains by using the construction skills they had earned through their preparation for civil war.

Unique Development of Farming During Edo Period in the Premodern Age

After taking over the entire country, Hideyoshi Toyotomi implemented a cadastral survey (Kenchi) known as Taikō-Kenchi (Hideyoshi was known by the title of Taikō) from 1582 to 1598. The survey involved measuring each paddy field, ranking their productivity to assess the tax base, and registering of individual landowners. It established the Kokudaka (productivity, *koku* being a unit of measurement for rice) system in which arable lands were legally graded in terms of average productivity. This brought an end to the system of direct rule by feudal lords and determined land tenureship for small-scale farmers based on nuclear families. Ieyasu Tokugawa defeated the Toyotomi family in the Battle of Sekigahara (1600) and completed the process of unifying Japan by establishing a new shogunate. Under the Tokugawa family, Japan in the Edo Period (1603–1868) flourished in the Sakoku (seclusion from other countries) policy, and each of the surviving Sengoku Daimyō was regulated by the Shōgun (military general) Government established in Edo (present-day Tōkyō).

Because the daimyō could no longer acquire more territory because of the strict Tokugawa regulations, the only way that they could expand their power was to reclaim land or to improve their fields to get better yields (mainly of rice). This led to improved irrigation systems within the big river basins and diluvial tablelands that could not previously be well controlled and utilized; they also improved technology for crop cultivation. The average rice yield was recorded as nearly 2,000 kg per hectare in the later period. Hence, political stability and technical innovations in agriculture brought another population burst in this premodern age, resulting in the dramatic increase in a shorter period from ca. 10 million people counted in late Sengoku to more than 30 million in the middle of Edo Period (Kitō 2000). However, this increase soon reached the ceiling in social stagnation.

Despite the overall developments in agriculture, however, the farmers who got their own lands through the Taikō-Kenchi were strictly restricted to move or even to choose another livelihood under the tightened feudal system. Furthermore, a great deal of their harvested rice was collected by the daimyō as a tax (*nengu*) which left the farmers with relatively little rice and therefore, a spartan existence, particularly in earlier Edo Period. Under such a severe regime, and because of it, many farmers made remarkable improvements in technology for raising field crops other than rice, especially for those which were cultivated on upland. Winter harvests from double-cropped paddy fields were also valuable fruits for farmers as they were often excluded from the nengu.

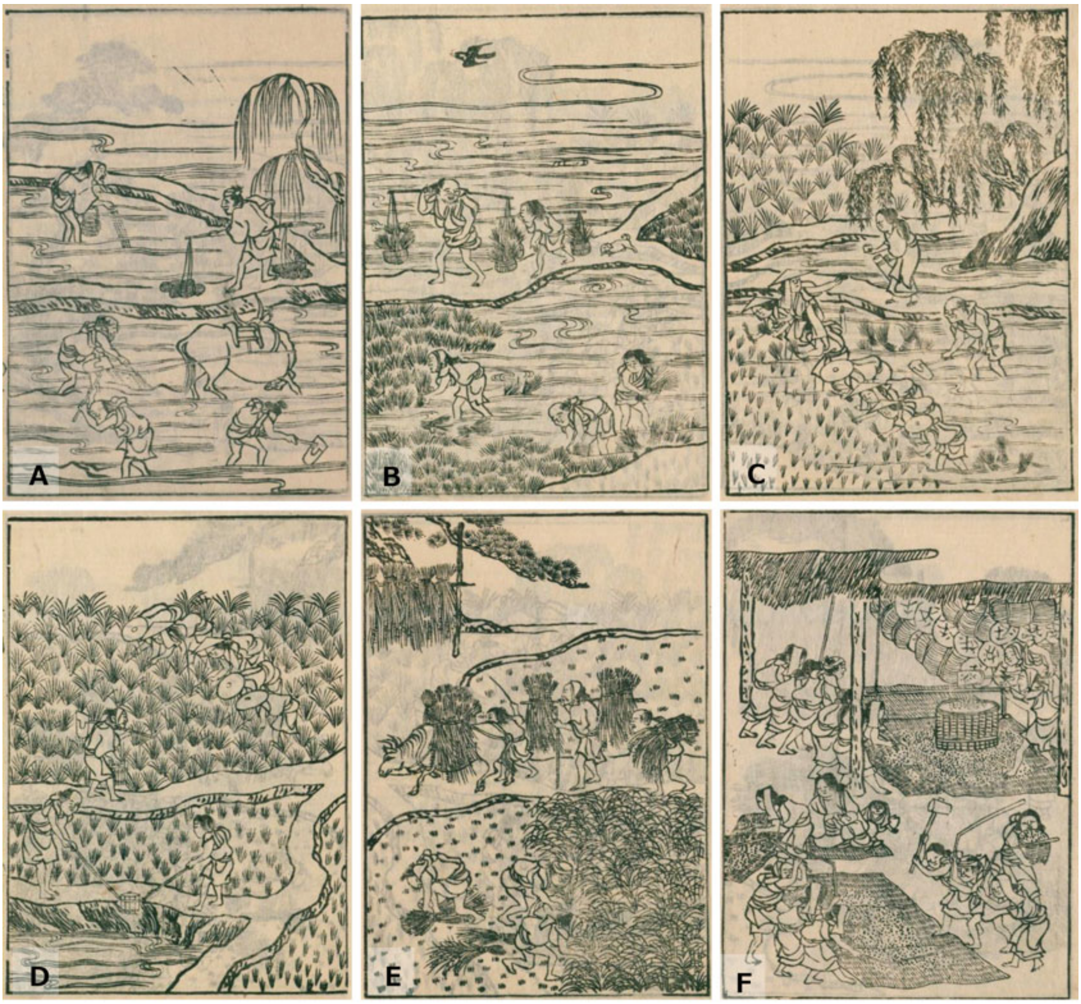
The use of human manure as a fertilizer was an important development at this time; it was used for higher production in intensively managed paddy and upland fields. In fact, all of human feces and urine were carefully collected and stored for fermentation by each farmer. From Edo or some other big cities as Ōsaka and Kyōto, most of the “night soil” was transported to nearby rural areas where cash crop cultivation was flourishing. It may be said that the Edo people who lived more than 200 years ago had almost completed the thorough use of resources and the technological improvements in recycling that are informative even for today’s societies.

In the Edo Period, many books called *nōsho* (writings on agriculture) were written in various areas, and some of them were published in xylography and distributed widely. Publications to describe agricultural technology and various local cultivars contributed to further technological improvements and examination of traditional cultivars. Among others, the most notable work in the first half of Edo Period was *Nōgyō Zensho* (Complete Writings on Agriculture, 1697) by the lordless samurai Yasusada Miyazaki (1623–1697) in northern Kyūshū. This book provided practical instructions based on the author’s comprehensive knowledge acquired over the years, while the basic style of the book followed the famous Chinese *Nóngzhèng Quánshū* (Complete Book on the Administration of Farming, 1639) which was written by Xú Guāngqǐ late in the Ming Dynasty. Miyazaki had long regretted that the life of farmers required hard labor and low incomes because of their paucity of knowledge about the principles of agriculture (Fig. 3), so he published information about the available scientific principles and technology that was easily put to use anywhere in the country. In a sense, an original agricultural science, rooted in the traditional culture of Japan, came into existence by this work. His book greatly influenced agriculture throughout the Edo Period, and it was reprinted repeatedly over 150 years, almost until the end of Edo Period.

The Tokugawa shogunate built many roads which originated in Edo or Ōsaka in the seventeenth century. Various sea routes for shipping were also established, so an integrated system of transportation throughout all of Japan was progressively built with progressive development of a market economy in the latter Edo Period. In this situation, Nagatsune Ōkura (1768–1860), one of the most famous scholars of agriculture late in the Edo Period, wrote many volumes on agriculture and particularly made efforts to publish various textbooks about cash crops. He also prepared manuals on agricultural equipment and wrote about plant protection. The application of this knowledge and those techniques resulted in the prosperous cultivation of rapeseed, cotton, and other industrial crops in the Kinki region and the rise of the processing industry near Ōsaka that increased the amount of merchandise available for distribution.

Despite the remarkable growth in productivity, farming throughout the Edo Period still depended on human power, and the merit of scale was hardly found. Although plowing with draft animals was practiced to some degree in and around the Kinki region, it did not spread throughout the country, partly because the traditional long-soled plows they used were less efficient than hoes for deep tillage in paddy fields to get a higher yield with a higher level of fertilizer use. Hence, the labor-intensive cultivation continued to dominate and relied on specialized hoes and spades just handled by man power. In his *nōsho* (An Investigation of Usefulness of Various Agricultural Tools), Nagatsune Ōkura illustrated a diverse range of hoes modified for various purposes or soil conditions (Fig. 4). The intensive farming system without any convenient machinery had lasted until quite recently, just supplemented by step-by-step fine tuning of hand-operated tools.

Another example of prosperous development of Japanese farming was found in sericulture in the late Edo Period. A lot of novel techniques were invented by farmers in various places of silk production (a nōsho on sericulture written by devoted sericulturist Morikuni Uegaki (1753–1808) was even translated into French in 1848 when the country was not opened to the West yet). Instances included thermal management of silkworm development and crossbreeding of various productive strains; both of these scientific technologies were not well distributed yet in Western countries of those days. These technologies developed during the premodern

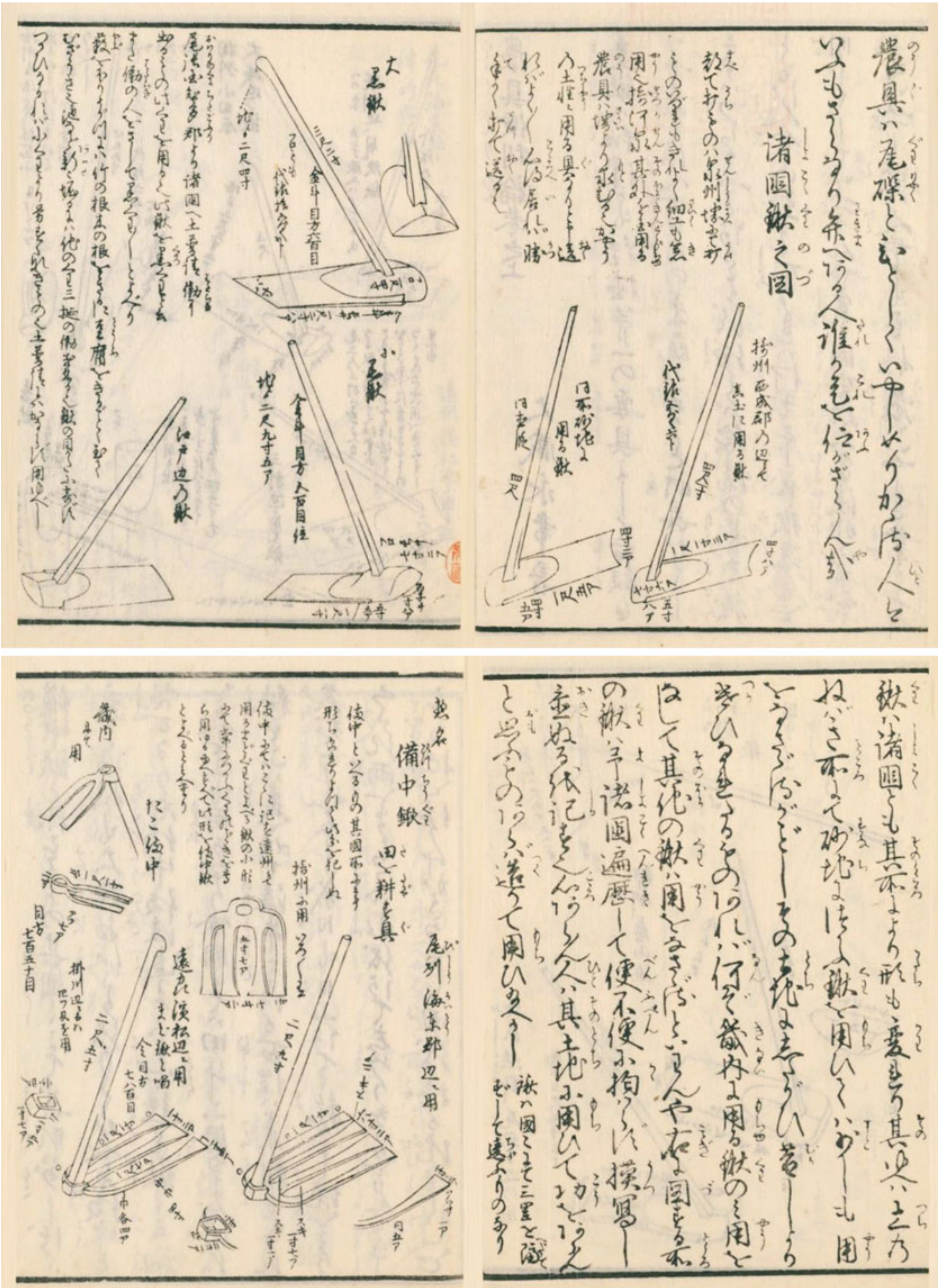


Agriculture in Japan, Fig. 3 A rice cultivation calendar in *Edo* Period, starting with the field preparation in spring and ending with the harvest processing in autumn (cited from the website of National Diet Library, Tokyo). The illustration was shown at the introduction of Miyazaki's famous book – Nōgyo Zensho. Farmers had to work very hard for the care of growth and maturation of paddy rice plants from early spring to the middle of autumn without any vacant days. (**a**) Preparing rice seedlings and paddy fields. (**b**) Carrying seedlings for transplant. (**c**) Transplanting seedlings. (**d**) Taking care of growing rice plants. (**e**) Harvesting rice. (**f**) Processing harvested rice

age later contributed to the further development of sericulture and silk-spinning industries in following Meiji Period.

Modernization in Japanese Agriculture After the Meiji Restoration

In the second half of the nineteenth century, Japan decided to open itself to international relations after a 200-year-long Sakoku. The Tokugawa regime lost its ability to govern effectively, and the feudal system finally came to an end in 1868. The new government under the restored emperor declared the beginning of the Meiji Period (1868–1912) and began to modernize Japan along contemporary Western lines. As Japan had almost no particular source of revenue except for agriculture at that time and since 80 % of the population belonged to the agrarian class, the collection of land taxes was of great concern to the new government. Introducing Western



Agriculture in Japan, Fig. 4 Various kind of hoes illustrated in *Nōgu Benri Ron* (An Investigation on Usefulness of Various Agricultural Tools) written by Nagatsune Ōkura late in the *Edo* Period (cited from the website of National Diet Library, Tokyo). He made a detailed investigation on the variation of different kind of hoes that were agricultural technology (*Taisei nōgaku*) was therefore an urgent project for the government, which wanted to increase the wealth and military strength of the country in order to catch up with European powers and the United States in a short amount of time.

However, the modernization of Japanese agriculture at the outset was not as successful as it was with industrialization, because the earliest foreign experts invited into the country simply tried to bring their own style of agriculture without any modification and did not consider the different state of affairs that existed between Japan and their homelands. However, a few European scientists used a different approach to developing Japanese agriculture by evaluating traditional technology and knowledge. For instance, Max Fesca from Germany made a huge scientific effort at analyzing traditional Japanese techniques of cultivation, applying Western technology to suit the needs of Japanese agriculture, and developing new technology for practical cultivation. *Rōnō* (rōnō refers to farmers with outstanding farming knowledge), who had fully mastered the knowledge and skills of traditional agriculture that had already been systematized in the Edo Period, also played an important role in the modernization of traditional agricultural technology and its extension throughout the country in the late nineteenth century.

In the early twentieth century, Japan had nearly completed establishing a public system of education and scientific research based on Western models with a modernized governing system. As centralized power became stronger through and after the First World War, various research results achieved at institutes and universities contributed to the remarkable increase in agricultural production from 1920 to 1940. Large-scale land innovation and wide distribution of chemical fertilizers also accelerated the progress. Studies on the genome of wheat strains by Hitoshi Kihara, the autumn deterioration of paddy soils by Matsusaburō Shioiri, and the selection of the famous Nōrin No. 10 wheat variety (Nōrin is the abbreviation for the Ministry of Agriculture and Forestry) were all world-renown accomplishments prior to the Second World War.

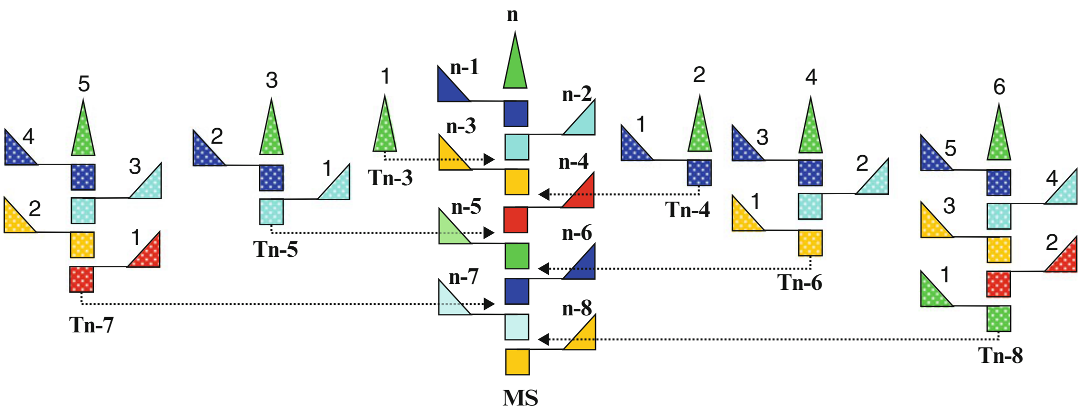
Through repeated crossing with various native cultivars from Mexico, for instance, the Nōrin No. 10 later obtained high-yielding dwarf cultivars, which increased wheat production in developing countries dramatically through the "Green Revolution." Also pursued was the concept of "synchronism in tillering and tiller development in rice, wheat, and barley crops" established by Tsukuda Katayama, which led to precise technology for monitoring the growth and improving the yield of rice and other grain crops (Fig. 5). In Western countries, phyllochron (leaf appearance interval) studies were initiated in the last 40 years to take precise control of the growth of improved wheat and other crops. In fact, Katayama and his students completed the principle of phyllochronic development of grain crops more than 60 years ago, although the original studies, written mostly in Japanese, were hardly read by Western researchers.

The scientific achievements made before the Second World War principally contributed to higher productivity (approaching to the level of 4,000 kg per hectare in case of rice); however, the farming system still remained unchanged in a traditional, labor-intensive state for individual farmers and villages.

Transfiguration of Traditional Agriculture After the Second World War

Invasive Imperial Warfare against the Allied Powers throughout the 1930s to 1945 came to an end with the unconditional surrender of the Japanese Empire. This defeat gave the Japanese people an opportunity to replace an autocratic system with a representative democracy akin to

Agriculture in Japan, Fig. 4 (continued) carefully modified for various cultivating purposes in various districts. *Top*: a comparison of different forms of *hiraguwa* (plowing hoes). *Bottom*: a comparison of the size and form of each part of *bitchuguwa* (cultivation hoes)



Agriculture in Japan, Fig. 5 **A schematic illustration of Katayama's Concept on tillering regularity in rice, wheat and barley plants— the synchronism in tillering and tiller development**. Mother shoot (MS), which forms her leaves in constant interval in any order, generally bears her daughter tillers regularly in parallel with successive leaf formation of MS, so that the new tiller appearance at the age of 'n'th leaf emergence of MS usually becomes apparent at the leaf axil of n-3 and the new-born tiller develops further with homologous leaf formation, resulting in successive increase in leaf number in lower daughter tillers. Thus the grain crop plant is an integrated unit of synchronously appeared tillers in various orders and synchronously developed leaves on synchronized tillers while showing different appearance. In the figure, ( ) indicates the top elongating leaf on any time. ( ) in various color denotes the expanded mature leaf attached to any node ( ) of MS or daughter tillers. Arrow is the position of the leaf axil with which successive daughter tiller is subtended. Daughter tillers are numbered acropetally with the codes as . . .Tn-5, Tn-4, and Tn-3, being subtended by . . .'n-5'th, 'n-4'th, and 'n-3'th leaves of MS, respectively. Number noted by each leaf of daughter tiller indicates the leaf position as counted from the initial foliage leaf of each tiller. Leaves with the same color denote the synchronous emergence (and analogy in size) on different tillers. The Katayama's Concept shown above had been very useful tool for developing the intensive technology in rice plant cultivation in Japan during the Postwar period

those in Western Europe and the United States. A thorough land reform was undertaken under the strict regulation of occupying powers, mainly the United States. The abolition of parasitic landlordism (*jinushisei*, the system which became dominant very quickly after the Meiji Restoration) and the creation of independent farmers, mainly from the ranks of previous tenant farmers, were achieved in a short time. The newly created independent farmers struggled to improve their yields of rice, even though their small, scattered landholdings put them at a severe disadvantage.

In the early postwar period, the most prominent popularization occurring in farmlands was the almost Japanese original machine called *kōunki* (cultivator) which reduced the amount of hard work required from farmers and stimulated agricultural growth in the first decade after the war (Fig. 6).

Remarkable progress was also made in the technical development of farming materials such as pesticides, insecticides, herbicides, and plastic films used for soil mulching and simplified greenhouses, all useful for small-scale, intensive agriculture. Advances in efficient fertilization, such as topdressing of nitrogen at the ear-formation stage of rice proposed by Shingo Mitsui, led to stable, high rice yields as well. When the farmers achieved an abundant harvest of 12 million tons of rice grain in 1955, the government declared that the country was in "no postwar situation any longer!"

Japan experienced rapid economic growth from 1955 to 1973, when an international oil crisis interrupted its progress. The Basic Agricultural Law (Nōgyō Kihonhō) was enacted in 1961, when a massive outflow of labor from the countryside had become apparent, in order to make farmers economically self-reliant with incomes about the same as those for urban laborers. The law concentrated on improving the productivity and efficiency of labor in agriculture through

Agriculture in Japan, Fig. 6 Kōunki, innovative cultivators that were intensively refined during the early postwar period in order to improve labor efficiency in small-sized fields that were usually covered with heavy wet soils. The improved machines achieved the easier and quicker farming practices in labor-intensive agriculture, relieving farmers who had previously been forced to work (A scene showing students from Hokkaidō University, 1976. Photo taken by Michiaki Ito, Niigata University. Used with his kind permission)

Agriculture in Japan, Fig. 7 Improved rice transplanter in action in paddy rice fields of a part-time farmer that owns 3 or 4 ha of land. Those part-time farmers normally complete routine tasks in 3 or 4 days during holidays in early May (Photo taken by Mutsuyasu Ito)

mechanization; the government did in fact succeed in improving agricultural labor productivity. Thus, rapid economic growth after the Second World War improved the standard of living for farmers – much more quickly than had been the case in Europe – and they have been relieved of a lot of heavy labor by such machines as four-wheeled tractors, rice transplanters, and rice harvesters (Figs. 7 and 8, both being Japanese originals) as well as various unique farming tools useful for Japanese intensive agriculture. However, the changes also created a serious inconsistency for the existence of traditional agriculture, which had been progressively systematized during the hundreds of years of farmers struggle. The double-cropping system with rice

Agriculture in Japan, Fig. 8 A rice combine harvester in action to harvest the yield of well-ripened rice crop, being easily operated by an aged farmer. Rice harvesting, which was once one of the most labor-intensive farming activities, is now usually completed by low number of workers – around one person/hectare/day or less (Photo taken by Mutsuyasu Ito)

and winter crops, almost a Japanese original technology, is indeed disappearing now.

The population of farmers, in consequence, decreased dramatically to about 3.3 % (in 2014, they are mostly above 60 years old) of the Japanese total work force in the past half century, and most of them are now living as part-time farmers dependent to a large extent on other industries. In the meantime, Japan has been simply exhorting the agricultural sector to be efficient economically; hence its output of such crops as wheat, barley, soybeans, and buckwheat gets beaten in international competition. Rice cultivation now narrowly survives harvesting ca. 8 million tons every year but is preferentially dependent on being located in optimal environments as well as the official policy of protection. The current, apparently irreversible trend foreshadows the increasing abandonment of agricultural land usage, further alienation of seminatural environments, and the inevitable decline of Japan's original agricultural practices and traditions which had been developed over almost two millennia.

References

Evans, L. T. (1975). Crops and world food supply: Crop evolution and the origins of physiology. In L. T. Evans (Ed.), *Crop physiology*. Cambridge: Cambridge University Press.

Fesca, M. (1880). *Nihon Chisan Ron (Contributions to the knowledge of Japanese agriculture: Translation of German original 'Beitrage zur Kentniss der Japanischen Landwirtschaft')*. Tōkyō: Nōmushō Chishitsu Chōsasho.

Furushima, T. (1947). *Nihon Nōgyōgijutsushi (History of agricultural technology in Japan)*. Tōkyō: Jichōsha.

Habu, J. (2004). *Ancient Jomon of Japan*. Cambride: Cambridge University Press.

Hanihara, K. (1991). Dual structure model for population history of the Japanese. *Japan Review, 2*, 1–33.

Katayama, T. (1951). *Ine Mugi no Bunketsu Kenkyū (Research on the tillering habits of rice plant, wheat and barley)*. Tōkyō: Yōkendō.

Kitō, H. (2000). *Jinkō kara Yomu Nihon no Rekishi (History of Japan as discussed with its demographic features)*. Tōkyō: Kōdansha.

Matsuo, T. (1955). *Rice culture in Japan*. Tōkyō: Yōkendō.

Mitsui, S. (1954). *Inorganic nutrition, fertilization and soil amelioration for lowland rice*. Tōkyō: Yōkendō.

Miyazaki, Yasusada. (1697). *Nōgyō Zensho (Complete writings on agriculture)*.

Ōkura, Nagatsune. (1822). *Nōgu Benri Ron (An investigation on usefulness of various agricultural tools)*.

Ōkura, Nagatsune. (1826). *Jokō Roku (A note on insect control)*.

Ōkura, Nagatsune. (1859). *Kōeki Kokusan Kō (Thoughts on the benefit of domestic production)*.

Sato, Y. (1992). *Ine no Kita Michi (The trace of rice arrival)*. Tōkyō: Shōkabō.

Smith, T. C. (1959). *The agrarian origins of modern Japan*. Stanford, CA: Stanford University Press.

Uegaki, Morikuni. (1803). *Yōsan Hiroku (A memoir on sericulture)*.

Xú, Guāngqǐ. (1639). *Nóngzhèng Quánshū (Complete book on the administration of farming)*.

Agriculture in South and Central America

Karl H. Schwerin

Conquest of South and Central America by the Spanish and Portuguese in the sixteenth century was rapidly followed by the introduction of Old World crops. These included both those familiar to European farmers, such as wheat, barley, oats, and many temperate vegetables and fruits catering to European food tastes, as well as tropical crops from Africa and Asia, such as bananas and plantains, sugar cane, and rice. At the same time many American crops were carried to the Old World – the most important being maize, potatoes, manioc, beans, and squash.

From the time of conquest to the present, agriculture in this region has been dichotomized between small-scale subsistence farming and large-scale monocrop operations producing for profit. Their development is summarized here.

Some native agricultural methods continued, such as ► swidden agriculture in temperate and tropical forested regions, field cultivation with the foot plow in the Andes, and intensive *chinampa* agriculture in central Mexico. Other techniques such as terracing declined, or as with raised fields, disappeared altogether. The small farmers incorporated some European crops as staples – wheat in Mexico (principally among mestizo farmers), barley in the Andes, onions, cabbage or collards almost everywhere. Bananas and plantains spread rapidly throughout the tropics. Agricultural technology continued much as before contact, perhaps because it was appropriate to traditional agriculture which, though small-scale, was highly productive.

Although early colonial institutions such as the *encomienda*, *corregimiento*, and *repartimiento* were designed to exploit native labor and mineral resources, they also produced surplus foodstuffs to support the European population, mining, and colonial administration. As native populations declined, large land holdings were granted to

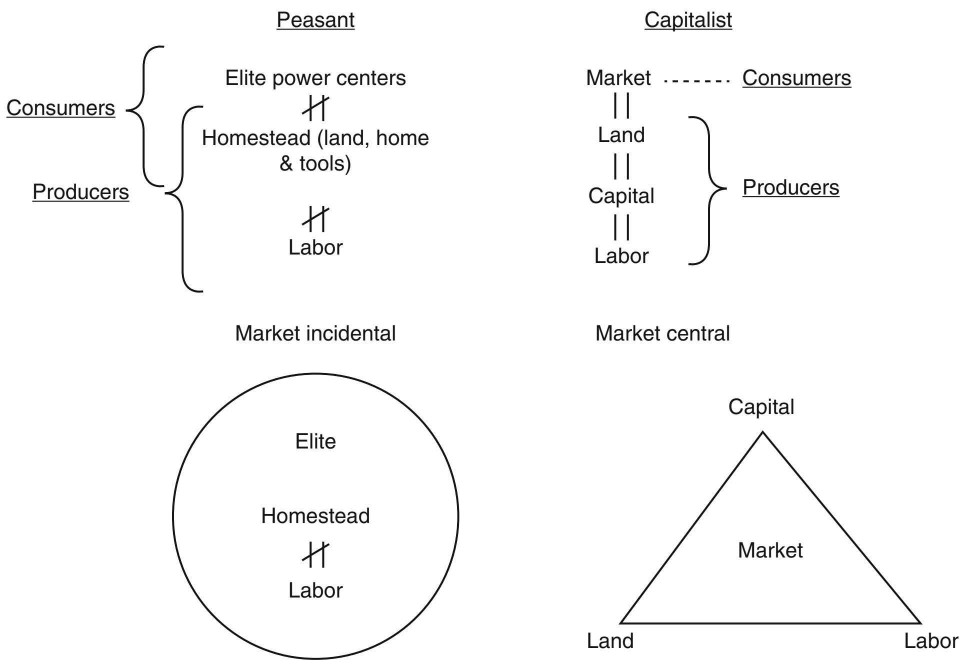
Agriculture in South and Central America, Fig. 1 Cachama. Bananas and manioc in a morichal field, Cachama, Venezuela. Drained field in a moriche swamp, Karinya Indians. 1962 (Photo by Karl H. Schwerin)

Spanish and Portuguese immigrants. Some were cultivated dilatorily, but others were transformed into plantation enterprises producing sugar, tobacco, cacao, indigo, or cochineal (a red dye obtained from the crushed dried bodies of female cochineal insects, used to color food and drinks and to dye fabrics) (also cattle, sheep, and horses) which soon supported a lucrative trade with the home country. Most plantations were dependent on slave labor. Sugar, consumed raw or distilled into *aguardiente* or rum, became the principal economic enterprise in Brazil and the Caribbean, and was particularly dependent on slave labor.

By the eighteenth century mining became concentrated in a few rich areas. Agriculture acquired more importance in the colonial economy. Land grants were increasingly cultivated to supply colonial needs for food grains and raw materials such as cotton. The *hacienda* became

Agriculture in South and Central America, Fig. 2 Mamo. Bananas, sugar cane, manioc in a morichal field, Yavito, Rio Yabo. Typical drained field in Yavito, in a moriche swamp. Karinya Indians. February 1962 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 3 Mamo. Fruit trees in patio 1967, Mamo, Venezuela. House garden. Karinya Indians. July 1967 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 4 The peasant economy versus the capitalist economy

Agriculture in South and Central America, Fig. 5 Maize field. Mexico, Tenancingo, Tlaxcala, Mexico. Typical peasant maize field. June 1957 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 6 Mamo. Maize field. Maize field and shelters of Francisco Vasquez, Isla La Isabel, Venezuela. Karinya Indians. February 1962 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 7 Forest and maize fields, Michoacan, Mexico. August 1962 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 8 Mamo, maize field on Isla La Isabel, Venezuela. Karinya Indians. February 1962 (Photo by Karl H. Schwerin)

the vehicle for accomplishing this production. Labor was secured through mechanisms such as debt peonage and was administered in such a way that it was almost impossible for the individual laborer to break free.

After independence early in the nineteenth century, slavery was gradually abolished throughout the Americas. The hacienda, however, continued as a major system of ensuring agricultural labor. It only began to disappear with the Mexican Revolution of 1910. Though much less important today, it continues to operate in some Andean countries and in parts of Brazil.

The nineteenth century was marked by widespread expansion of agricultural capitalism in the form of plantation systems producing a wide variety of crops for industrial and consumer markets in Europe and North America. These included *henequen* (fiber obtained from the leaves of the henequen agave plant, used in making rope, twine, and coarse fabric) from the Yucatan, bananas in Central America, and sugar in the Caribbean and Brazil. Coffee, one of the most profitable crops, was widely introduced, from Mexico to Brazil. In Mexico and parts of Central America, small farmers produced it; in Costa Rica and Colombia medium sized farmers were the rule; elsewhere large coffee *fincas* predominated. Particularly in the latter case, land was intensively exploited, without efforts at conservation or improvement, leading to rapid deterioration in soil quality and declining production. Where land was abundant, the response was to clear virgin land and plant new coffee groves. Uruguay and Argentina became major world producers of wheat, owing to the rich Pampean soil. In both Brazil and the pampas, immigrant labor was employed to clear the land, in exchange for temporary usufruct of part of the cleared area. Evicted after a time in favor of the landowner, some immigrants acquired their own (usually smaller) farms, but most withdrew to the cities, leaving only the larger *fincas* and *estancias* as significant agricultural producers.

Agriculture in South and Central America, Fig. 9 Tenancingo. Harvesting beans. Tenancingo, Tlaxcala, Mexico. Don Eleuterio Guzman pulling up bean plants in a maize field. July 1957 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 10 Tenancingo. Don Eleuterio Guzman harvesting beans in a maize field. Tenancingo, Tlaxcala, Mexico. July 1957 (Photo by Karl H. Schwerin)

Several different systems of agricultural exploitation can be identified in this region today. Yet agriculture has declined in importance in national economies throughout the century, dropping precipitously since 1980. Only in Central America, Mexico and Brazil is 15–30 % of the work force still farming, in most countries only 10 % is still employed in agriculture, which represents less than 10 % of the GDP for the region.

The persistent dichotomy between large, extensively cultivated holdings (*latifundio*) and small, intensively cultivated properties (*minifundios*) survives today. Though these are sometimes geographically separated, they frequently occur interspersed with each other interacting as a symbiotic whole. This dichotomy is also at the root of many economic and social problems. Although precise data on distribution of agricultural landholdings have not been reported since the 1970s, the extreme bimodal distribution has probably not changed significantly. In El Salvador, Guatemala, and Peru more than 90 % of agricultural landholdings were under 10 ha, yet represented only about 30 % of the area. In contrast, 26 % of the area in Guatemala and 61 % of the area in Peru were larger than 1,000 ha, yet represented less than 0.5 % of the holdings.

Some small-scale specialized farming techniques survive in scattered locales, such as localized irrigation systems, *chinampas* in the Valley of Mexico, drained fields among the Karinya in

Agriculture in South and Central America, Fig. 11 Mamo. Threshing beans. Ramón Antonio Vásquez threshing out beans by beating them with a pole. Isla La Isabel, Venezuela. Karinya Indians. March 1962 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 12 Manioc field, Kuri, Rio Platano, Honduras. Miskito Indians. January 1981 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 13 Cachama. Teresa Tamanaico pulling, up (harvesting) manioc tubers. Cachama, Venezuela. Karinya Indians. July 1962 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 14 Cachama. Teresa Tamanaico stripping manioc tubers from uprooted plants. Cachama, Venezuela. Karinya Indians. July 1962 (Photo by Karl H. Schwerin)

eastern Venezuela (Figs. 1 and 2), or terraces and lazy beds in Mesoamerica and the Andes. Traditional methods of agriculture generally promote ecological stability both because environmental disturbance is minimal and because the agroecosystem is stable. Unfortunately, development, modernization, and institutional pressures from the larger society often lead to abandonment of these techniques, in spite of their suitability to local conditions and often exceptional productivity. Thus most irrigation has been modernized and commercialized and relies on pumping, reservoirs, and lined canals. Yet there are efforts in some places to reintroduce ancient agricultural techniques, like ridged fields in the Titicaca Basin, which have proven superior to current practices. Many traditional practices should be preserved in order to exploit their productive advantages, utilize marginal microenvironments, maintain crop diversity, and minimize production risks.

► Swidden agriculture or shifting cultivation is still widely used in forested regions. It may support as many as 50 million people. It is relatively productive and successfully integrated into the ecological regime of the tropical forest, yet requires less labor than many other methods. It is a technology that does not require capital investment or

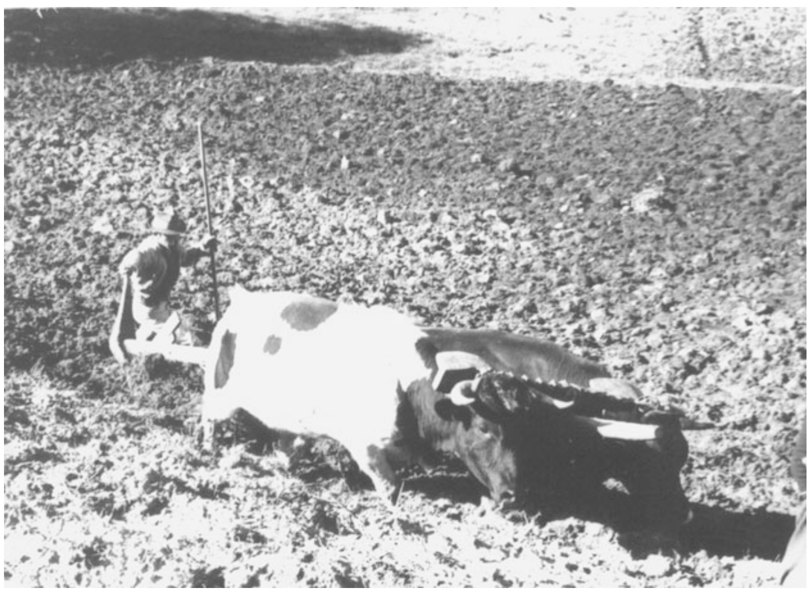
Agriculture in South and Central America, Fig. 15 Cachama. Teresa, Luis and Delia Tamanaico, loading manioc tubers into a basket to be carried home, for processing. Cachama, Venezuela. Karinya Indians. July 1962 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 16 Tenancingo. *Maguey* (*Agave* sp.) Tenancingo, Tlaxcala, Mexico. Nearly mature maguey plants planted along edge of field. July 1957 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 17 Tenancingo. Collecting *agua miel*. Tenancingo, Tlaxcala, Mexico. Mature maguey plant (Agave sp.) with heart carved out to create a cavity for collecting the sap or agua miel-subsequently fermented to produce pulque. July 1957 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 18 San Pedro. Hacienda peons. Hacienda San Pedro, Cañar, Ecuador. 1970 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 19 San Pedro. Team of oxen. Hacienda San Pedro, Cañar, Ecuador, José Narvaez loading plow on yoke to carry to field. 1970 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 20 San Pedro. Plowing field with oxen 1. Hacienda San Pedro, Cañar, Ecuador, 1970 (Photo by Karl H. Schwerin)

energy subsidies. When associated with sparse populations its environmental impact is minimal, perhaps even beneficial by stimulating renewed forest growth. When intensified to the point that the forest can no longer replace itself, swidden may produce widespread environmental degradation. Rapid population growth throughout Latin America has spurred migration in search of farmland in lowland tropical forests from the Peten and the Caribbean coast to the Amazon basin. Resulting widespread deforestation has had serious ecological repercussions.

Agriculture in South and Central America, Fig. 21 San Pedro. Plowing field with oxen 2. Hacienda San Pedro, Cañar, Ecuador, 1970 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 22 Wheat harvest 1. Hacienda El Colegio, Cañar, Ecuador. Mayordomo Augusto Urgiles oversees the cutting of wheat. October 1969 (Photo by Karl H. Schwerin)

One agriculture technique, the house garden, is nearly ubiquitous among small farmers, even in towns and cities. Their species diversity is high, providing supplementary food, condiments, herbs, medicinal remedies, fuel, fertilizer, and ornamental plants (Fig. 3).

Peasant farmers conduct most small-scale agriculture. A true peasant owns or controls his land, runs his own operation and makes his own decisions independently. The primary production objective is for subsistence and survival. Peasants do not think in capitalist terms, but instead are oriented around the homestead (land, home, tools), which cannot be converted or exchanged for other means of production (see Fig. 4). Because cash is limited, the peasant cannot afford

Agriculture in South and Central America, Fig. 23 Wheat harvest 2. Hacienda El Colegio, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 24 Wheat harvest 3. Hacienda El Colegio, Cañar, Ecuador, October 1969 (Photo by Karl H. Schwerin)

to take risks; he often resists trying new crops and techniques; technology remains traditional (paleotechnic).

The strength of peasant farming is its heterogeneity and diversity. Planting a variety of crops, in several locales, under varying conditions, minimizes risk. The most important crops are starchy staples – grains or root crops – and legumes; perhaps supplemented by a high value cash crop – tomatoes, coffee, or narcotics (Figs. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17).

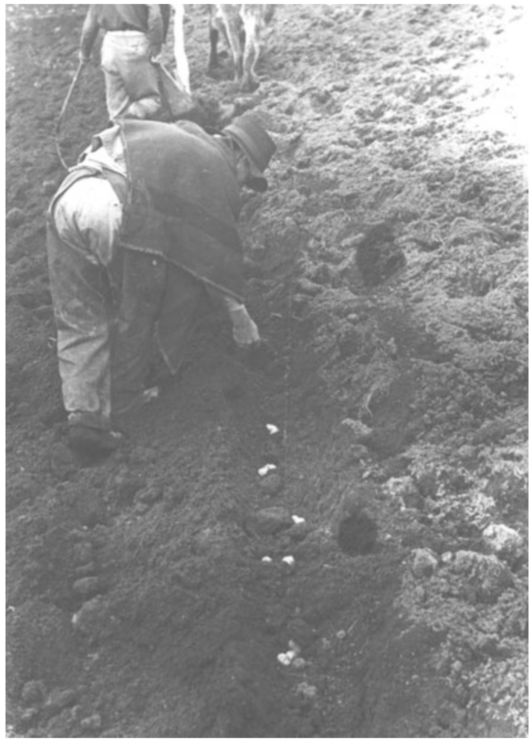
Large holdings can be roughly divided into haciendas, estancias, plantations, and agroindustrial enterprises. Hacienda organization represents a unique adaptation to abundant land and scarce capital. Labor to work the estate is attracted by offering small subsistence plots to

Agriculture in South and Central America, Fig. 25 San Pedro. Threshing barley with horses. Hacienda San Pedro, Cañar, Ecuador. Joaquin Fajardo, Cayetano Tenesaca, Corazon Murudumbay and Juan Jose Tacuri threshing barley September 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 26 Planting potatoes. Hacienda El Colegio, Cañar, Ecuador. September 1969 (Photo by Karl H. Schwerin)

A

Agriculture in South and Central America, Fig. 27 San Pedro. José Narvaez planting *ocas*. Hacienda San Pedro, Cañar. Ecuador. September 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 28 San Pedro. José Narvaez planting *ocas*. Hacienda San Pedro, Cañar, Ecuador. September 1969 (Photo by Karl H. Schwerin)

local smallholders or landless laborers (most commonly known as *peons*). Traditionally little or no wages exchanged hands; today real wages may actually be paid, although they are often seriously in arrears because capital remains scarce. For the same reason haciendas try to be self-sufficient in terms of basic needs. They also tend to be inefficient, relying on antiquated technology and cultivating only a small area of the best land, leaving the rest uncultivated or in the hands of the workers. Yet their production of staple cereals and tubers, or milk, meat, and wool may contribute significantly to national economies. Hacienda property may be viewed more as a basis for prestige or a hedge against inflation than as an income producer. For this reason, as well as scarce capital, haciendas also tend to resist innovation. Most surviving haciendas are found in highland areas of the Andes and Mesoamerica, though they have also been the object of land reform from Mexico to Bolivia, Peru and Ecuador (Figs. 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29).

Estancias are large holdings devoted to livestock production found mostly in the Southern Cone and northern Mexico, although in recent years cattle production has expanded rapidly in the Amazon lowlands and Central America to feed the North American demand for hamburger and processed meats.

The modern plantation contrasts with the traditional hacienda in that it is fully and efficiently

Agriculture in South and Central America, Fig. 29 Peons harvesting *mellocos* (*Ullucus tuberosus*). Hacienda El Colegio, Cañar, Ecuador. September 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 30 The hacienda and the plantation

CHARACTERISTICS OF THE PLANTATION

Distinguishing Characteristics of the Plantation

1. Sharp separation of classes
2. Capitalistic enterprise
3. Monocrop specialization
4. Continuous commercial production

(2–4) } Hacienda lacks these, tends toward self-sufficiency

plantation - A capitalistic type of agricultural organization in which a considerable number of laborers are employed under unified direction and control in the production of a staple crop for sale to an external market. (Sidney Mintz)

Contrasts Between the Hacienda and the Plantation

Hacienda	Plantation
abundant land	pervasive control of the land
scarce capital	abundant capital
pervasive control of labor	scarce labor, often mobile
tries to avoid wages	relatively high wages
ownership by family or traditional institution (church, government)	ownership by company or corporation
personalistic & paternalistic	universalistic & impersonal
economically inefficient	economically efficient
paleotechnic	neotechnic, often highly mechanized
produces for domestic market	produces for external market
participates in regional and national power structure	participates in international power structure

Agriculture in South and Central America, Fig. 31 Field of pyrethrum (*Chrysanthemum* spp.). Highland Ecuador. June 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 32 San Pedro. Laborers from Chimborazo Province hoeing pyrethrum 1. Hacienda/Plantation San Pedro, Cañar, Ecuador February 1970 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 33 San Pedro. Laborers from Chimborazo Province hoeing pyrethrum 2. Manuela Transito Balente and Transito Illapa Hacienda/Plantation San Pedro, Cañar, Ecuador February 1970 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 34 San Pedro. Floreras (peon women) picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 35 San Pedro. Olga Jachero picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Fig. 36 San Pedro. Olga Jachero picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)

operated with large amounts of capital (see Fig. 30). The plantation generally concentrates on monocrop specialization with the aim of continuous commercial production, usually for export. Although their proportion of total agricultural production has been declining, plantation crops such as sugar, coffee, bananas, pineapples, oil palm, cotton, tobacco, maize, and wheat continue to be the major source of foreign exchange for several countries (Figs. 31, 32, 33, 34, 35, 36, 37, and 38).

Large farms in central Chile, Northern Mexico, and Central America have also adopted this mode, producing fruits and vegetables for the winter market in North America. Production and marketing of feed products (maize, sorghum and millets, soybeans) and oilseeds (safflower, soybeans, cottonseed) have become important in Brazil, Argentina, Colombia, Guatemala, El Salvador, and Mexico. Commercial farming is almost always profitable, but profits increase exponentially with the size of the operation. They generally practise monocropping with chemical additives such as fertilizers and pesticides. Since larger commercial farmers participate in the international economy, they can survive bad years by falling back on economic institutions (loans, savings, insurance) to carry them through.

The North American Free Trade Agreement (NAFTA) has had serious repercussions in Mexico. Imports of agricultural products produced cheaply by large US and Canadian agribusinesses has undercut the production of small and medium

Agriculture in South and Central America, Fig. 37 San Pedro. Lucrecia Alvaros picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)

sized farmers in Mexico, forcing many to abandon the land, often moving to the cities in search of alternative employment.

Social consequences of these developments are that the peasantry is losing control over its productive processes and is being transformed into a rural proletarian underclass that is being exploited as the primary labor force. These factors have deeply transformed production relations within the agricultural sector, resulting in the modern agroindustrial complex. As a result of increasing commercialization of agriculture, the production of cash crops for export and industrial use has expanded at the expense of the production of basic food crops, leading to significant imports in many countries of basic foodstuffs (Tables 1 and 2).

Efforts at agricultural modernization vacillate between large, capital intensive projects and smaller "appropriate" technology, designed especially for small farmers. However, the bias is toward large-scale projects that are highly visible and politically profitable, but which are often viable only for the short term. In any case they are rarely beneficial to the small farmer.

Agriculture in South and Central America, Fig. 38 San Pedro. Peon women picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador. August 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Table 1 Most important crops for domestic consumption in Latin America

Maize	59,817
Manioc	29,633
Rice	23,217
Wheat	22,452
Potatoes	16,997
Dry beans	5,117
Sweet potato	1,796
Barley	1,646

From *Statistical Abstract of Latin America*. v. 38, 2002. Data for 1999 (in thousand metric tons)

Agriculture in South and Central America, Table 2 Export and industrial crops for Latin America showing principal exporting countries, 1999

	In thousand metric tons	Export value (millions of US dollars)
Cotton (Brazil, Argentina, Paraguay)	1,164	261
Sugar cane	539,308	4,457
Coffee	3,693	7,912
Bananas	22,279,000	2,816
Maize (Argentina, Paraguay)	13,183	832
Soybeans (Argentina, Brazil, Paraguay)	5,141	2,481
Wheat (Argentina)	14,500	999

From *Statistical Abstract of Latin America*. v. 38, 2002 and *International Trade Statistics Yearbook*, 2001

See Also

- ▶ Food Technology in Latin America
- ▶ Potato: Origins and Conservation of Potato Genetic Diversity
- ▶ Swidden

References

Barkin, D., Batt, R. L., & DeWalt, B. R. (1990). *Food crops vs. feed crops: Global substitution of grains in production*. Boulder, CO: Lynne Riener Publishers.

Cardoso, E., & Helwege, A. (1992). *Latin America's economy: Diversity, trends and conflicts*. Cambridge, MA: MIT Press.

Crespi, M. K. (1968). *The patrons and peons of pesillo. A traditional hacienda system*. Ph.D. Dissertation, University of Illinois.

Denevan, W. M. (1980). Latin America. In G. A. Klee (Ed.), *World systems of traditional resource management* (pp. 217–244). New York: Halsted Press.

González, A. (1985). Latin America: Recent trends in population. Agriculture and food supply. *Canadian Journal of Latin American and Caribbean Studies, 10*(20), 3–13.

Lambert, J. (1967). The Latifundio. In J. Lambert (Ed.), *Latin America. Social structures and political institutions* (pp. 59–105). Berkeley, CA: University of California Press.

Llambi, L., & Cousins, A. L. (1989). Petty-capitalist production in agriculture. *Latin American Perspectives, 16*(3), 86–120.

McDonald, J. H. (1997). Privatizing the private family farmer: NAFTA and the transformation of the Mexican dairy sector. *Human Organization, 56*(3), 321–332.

Mintz, S. W. The plantation as a socio-cultural type. In V. Rubin (Ed.), *Plantation systems of the new world*. Washington, DC: Pan American Union. 42–53.

Rubin, V., Steward, J., et al. (1959). *Plantation systems of the new world*. Washington, DC: Pan American Union.

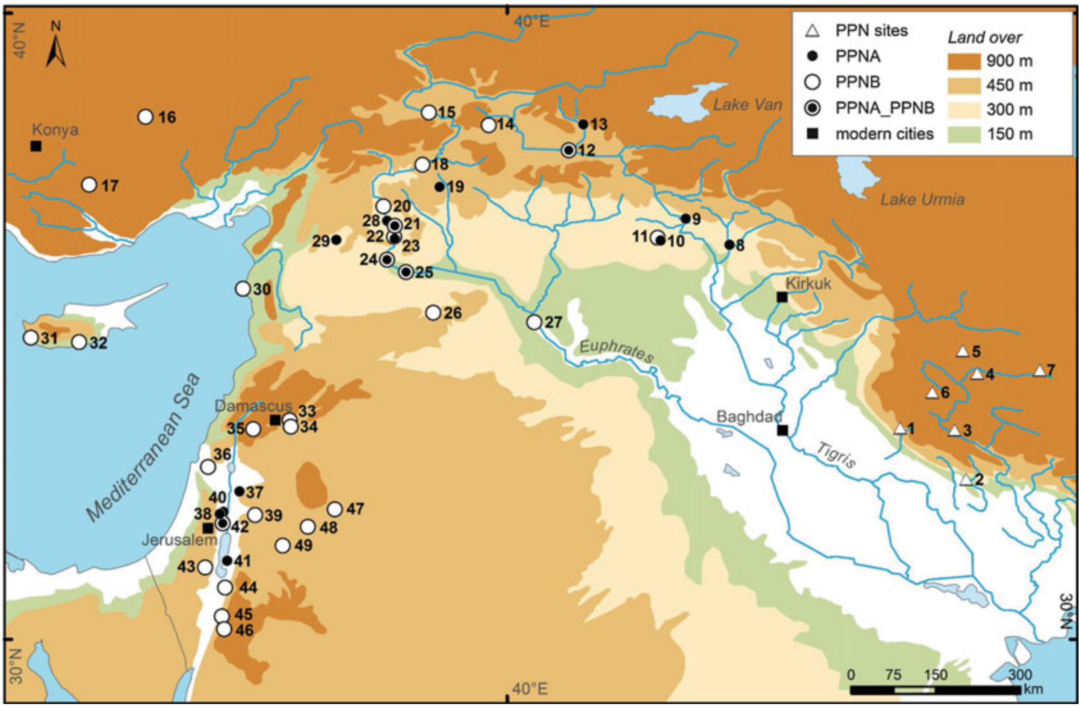
Teubal, M. (1987). Internationalization of capital and agroindustrial complexes: Their impact on Latin American agriculture. *Latin American Perspectives, 14*(3), 316–364.

Wolf, E. (1966). *Peasants*. Englewood Cliffs, NJ: Prentice-Hall.

Agriculture in the Ancient Near East

Simone Riehl
Institute for Archaeological Sciences, University of Tübingen, Tübingen, Deutschland, Germany

Agriculture in the ancient Near East is a topic mainly studied by archaeologists and philologists who contribute to our knowledge with the earliest archaeological evidence of cultivation as well as with complex descriptions of field management through the study of cuneiform texts. Extensive contributions also derive from biological and environmental sciences studying the genetics and origins of our modern crops and the ancient environmental conditions of agricultural development by investigating archaeobotanical, zooarchaeological, and



Agriculture in the Ancient Near East, Fig. 1 Location of the earliest archaeological sites with cultivated and/or domesticated species in the Fertile Crescent: (*1*) Chogha Golan, (*2*) Ali Kosh, (*3*) Chia Sabz, (*4*) Ganj Dareh Tepe, (*5*) Sheikh-e Abad, (*6*) Jani, (*7*) Tepe Abdul Hosein, (*8*) M'lefaat, (*9*) Nemrik, (*10*) Qermez Dere, (*11*) Magzalia, (*12*) Körtik Tepe, (*13*) Hallan Cemi, (*14*) Cayonu, (*15*) Cafer Hoyuk, (*16*) Asikli Hoyuk, (*17*) Can Hasan III, (*18*) Nevali Cori, (*19*) Göbekli Tepe, (*20*) Akarcay Tepe, (*21*) Djade, (*22*) Halula, (*23*) Jerf al Ahmar, (*24*) Mureybet, (*25*) Abu Hureyra, (*26*) El Kowm I and II, (*27*) Bouqras, (*28*) Abr, (*29*) Qaramel, (*30*) Tell Ras Shamra, (*31*) Kissonerga, (*32*) Parekklisha-Shillourokambos, (*33*) Tell Ghoraifé, (*34*) Tell Aswad, (*35*) Tell Ramad, (*36*) Yiftah'el, (*37*) Iraq ed Dubb, (*38*) Gilgal, (*39*) 'Ain Ghazal, (*40*) Netiv Hagdud, (*41*) Dhra, (*42*) Jericho, (*43*) Nahal Hemar, (*44*) Wadi Fidan, (*45*) Beidha, (*46*) Basta, (*47*) Dhuweila, (*48*) Azraq 31, (*49*) Wadi Jilat 7; PPNA: Pre-Pottery Neolithic A (9800–8700 BC), PPNB: Pre-Pottery Neolithic B (8600–7000 BC), PPN is applied to Iranian sites, because PPNA and PPNB have additional cultural connotations that do only apply to sites in the western and northern part of the FC

geoarchaeological remains from archaeological sites in this large geographic area.

This article sets a geographic focus on the Fertile Crescent, an area of relatively high precipitation that stretches from the Levant in the west to the Turkish-Syrian border in the north and Iraq and Iran down to the Persian Gulf in the southeast. The Fertile Crescent is the area where agriculture is known to have evolved and developed into an economy that supported the emergence of ancient civilizations (Fig. 1). The close relationship between cultural and agricultural development defines the structure of this entry with tripartite division into (1) emerging agriculture in Neolithic populations; (2) the establishment of agricultural production, expansion of human populations, and genesis of first cities; and (3) complex agricultural systems in city-states and oriental empires until roughly 300 BC.

Emerging Agriculture

Considered as the basis for the development of early civilizations, agricultural beginnings reach back more than 12,000 years. Archaeological and archaeobotanical research in the Fertile Crescent during the last decades decisively determined our current knowledge on the earliest findings of systematically gathered wild progenitor species of modern crops in the late Upper Paleolithic period (ca. 21000 BC), on the cultivation of wild cereals, and on the appearance of first domesticated species in the Aceramic Neolithic (syn. Pre-Pottery Neolithic) period.

The first domesticated species in the Fertile Crescent are einkorn (*Triticum monococcum* ssp. *monococcum*), emmer (*Triticum turgidum* ssp. *dicoccum*), barley (*Hordeum vulgare*), lentil (*Lens culinaris*), garden pea (*Pisum sativum*), chickpea (*Cicer arietinum*), bitter vetch (*Vicia ervilia*), and linseed (*Linum usitatissimum*) (Fig. 2). Singular finds of broad bean (*Vicia faba*) and grass pea (*Lathyrus sativus*) have also been discovered in the Aceramic Neolithic, but become frequent only from the late Neolithic onwards. Possibly also rye belongs to the early domesticated species, as recorded at Abu Hureyra and a number of other sites (Hillman, Hedges, Moore, Colledge, & Pettitt, 2001). It disappears from the Fertile Crescent during the early Holocene and has its comeback only in the Central European Iron Age. Remains of free-threshing wheat (*Triticum aestivum/durum*) also occur very early, but become abundant not before the Early Bronze Age. Horticulture starts much later than the cultivation of cereals, pulses, and linseed – in the Chalcolithic period at earliest.

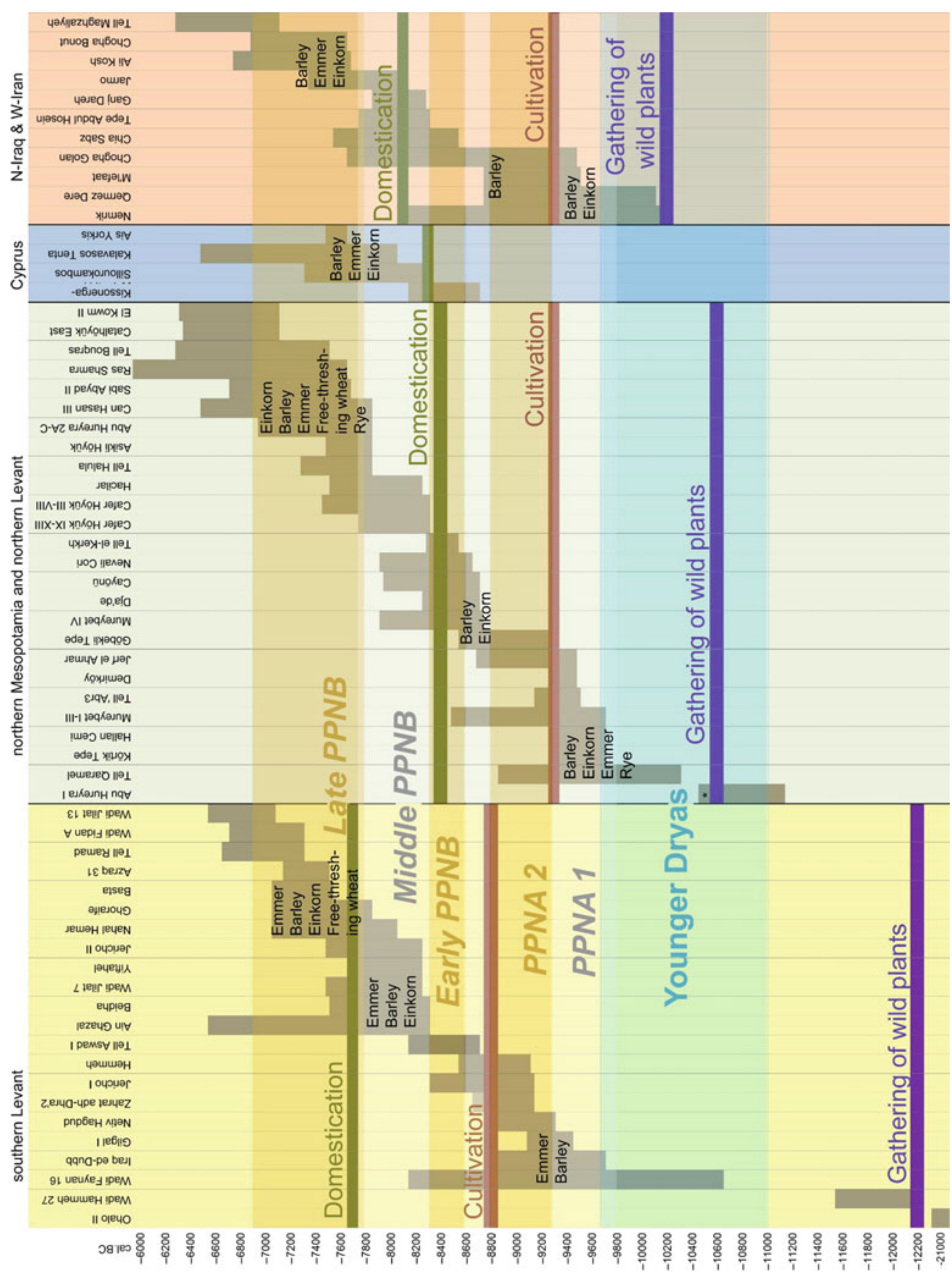
While the use of plants in subsistence has already been demonstrated for Paleolithic sites, the so far oldest evidence for systematic large-scale gathering of wild cereals dates to 21000 BC and derives from late Upper Paleolithic Ohalo II in Israel. The cultivation of wild cereals started between 9500 and 9000 BC in the Aceramic Neolithic (syn. Pre-Pottery Neolithic) period at a small number of sites (e.g., Jerf el Ahmar, Syria, or Chogha Golan, Iran).

Populations of Aceramic Neolithic sites with evidence of pre-domestication of wild cereals continued hunting wild sheep and goat, while for some of the sites, the beginning management of these animals is suggested (Zeder & Hesse, 2006). Early settlements of cultivators are often accompanied by storage structures, ground stone tools such as grinding stones and mortars, and, as concerns possible, harvesting tools, sometimes yield blades with sickle gloss (Riehl, Zeidi, & Conard, 2013; Fig. 3). During these periods changes in the settlement structures were also observed and related with population growth and social change, including monolithic communal architecture.

Until recently important questions on the emergence of agriculture were addressing the timing and the localization of early domesticated species. There is meanwhile agreement that domesticated species occurred in a number of archaeological sites throughout the Fertile Crescent (multiple origins model; Fuller, Willcox, & Allaby, 2011) more or less simultaneously from the PPNB onwards and started to dominate plant assemblages from the mid-PPNB (Pre-Pottery Neolithic B; 8300–7500 BC) onwards (Nesbitt, 2002; Fig. 2).

Domesticated species evolved through the management of their wild progenitors; thus the identification of cultivation of the wild progenitor species (syn. pre-domestication cultivation) is essential for our understanding of how hunter-gatherers evolved into farmers. Pre-domestication cultivation began more or less simultaneously, but the crop species cultivated varied in the different areas (Willcox, 2013). Archaeobotanical data suggests that the transition from pre-domestication cultivation starting around 9500 BC to the first occurrence of domesticated phenotypes took several hundreds of years; thus archaeobotanical and archaeological research questions on the emergence of agriculture now address the reasons for the slow development of agriculture, while some genetic studies on modern cereal crops still favor models of a rapid transition to agriculture.

The role of climate has been frequently discussed as one potential main release factor for the emergence of agriculture. While earlier studies were attributing more relevance to the cooler climatic conditions of the Younger Dryas, suggesting a decrease of resources to have pushed hunter-gatherers into agriculture, recent research acknowledges regional variation of climatic effects due to the very diverse geomorphological layout and rather focuses on the warmer and moister conditions during the early



Agriculture in the Ancient Near East, Fig. 2 Timeline of levels of plant management throughout the Epipaleolithic and Aceramic Neolithic periods in the different regions of the Fertile Crescent

Agriculture in the Ancient Near East, Fig. 3 Archaeological tools with potential agricultural use from the Aceramic Neolithic site of Chogha Golan (Iran); from *left* to *right*: mortar, pestle, blades

Holocene to have provided an ideal environment for larger-scale cereal cultivation. Also the end of the early Neolithic (PPNB cultures) has been related to climate fluctuations – the 8200 BP event, respectively (Bar-Yosef, 2009).

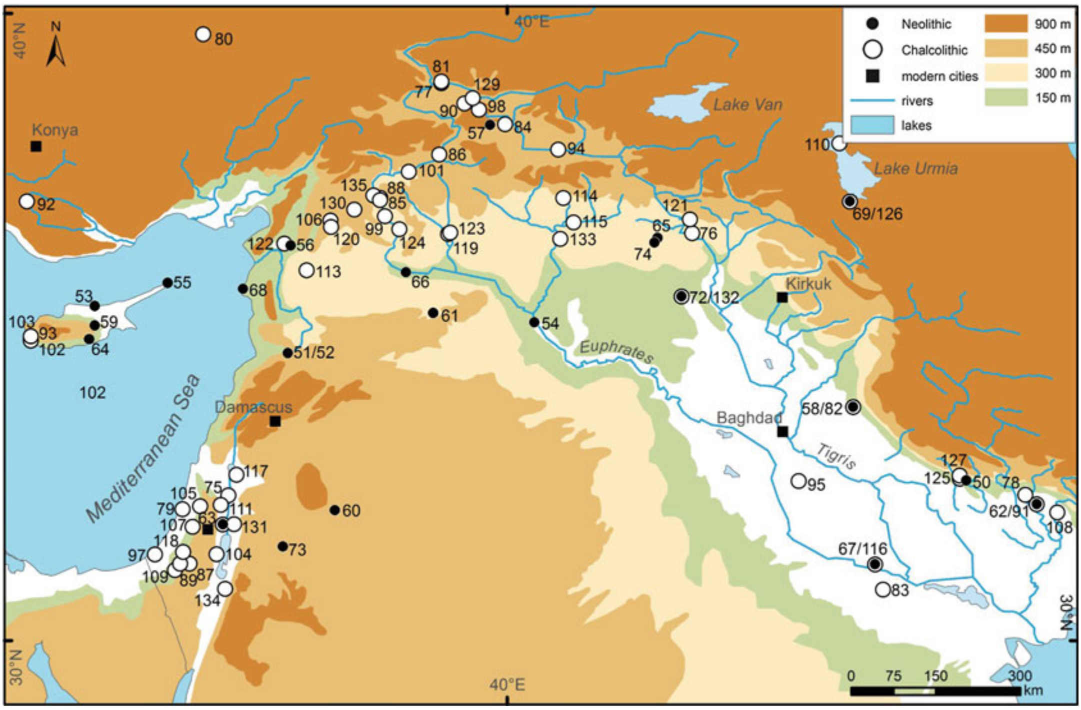
Most of the local evidence for climate effects on subsistence development is however currently too coarsely resolved to allow general conclusions on the relationship between climate fluctuations and the emergence of agriculture. Future research will have to focus on local paleoclimate archives in the direct vicinity of archaeological sites to address questions of interactions between people and climate.

Established Agricultural Societies

While the emergence of agriculture fascinated many researchers, much less is known on agriculture in settlements of the Pottery Neolithic (syn. late Neolithic: 6800–5300/5200 BC), while there is more information again on Chalcolithic (5200–4000 BC) agriculture (Fig. 4).

For the late Neolithic a variety of cultures overlapping in space and time has been defined, such as the Hassuna (c. 6500–6000 BC), Samarra (c. 6000–5500 BC), or Halaf cultures (c. 6000–5400 BC), with settlements of very diverse size, duration, and layout. Although some settlements were very large and of long-term occupation (e.g., Tell Sabi Abyad or Tell Halula), small, temporary sites were much more frequent, suggesting that the population had a high degree of mobility (Akkermans & Schwartz, 2003).

As concerns agriculture, this period may be seen as a consolidation period when domesticated species had completely replaced their wild progenitors; cultivation on extended territories and intensive storage along with an increase in pastoralism took place, which allowed population growth (cf. Neolithic demographic transition). Agriculture was cereal based with mainly barley and emmer wheat. Free-threshing wheat is also present in larger numbers in some Syrian settlements, while einkorn is better represented towards the coast in Palestine, Cyprus, and Turkey. All other early Neolithic crop species continued to be cultivated. Despite a focus on crop species, wild plants still seem to play a major role in the human diet, and similarly hunting contributed largely to subsistence. Although ancient people were always using a wide array of plant food, the cultivation of vegetables is extremely difficult to prove, because in contrast to seeds and fruit stones, their soft tissues preserve rarely in the archaeological context and they are extremely difficult to identify. Therefore knowledge on vegetable cultivation mainly derives from the textual evidence of the Early Bronze Age onwards



Agriculture in the Ancient Near East, Fig. 4 Archaeological sites of the late Neolithic (Pottery Neolithic) and Chalcolithic periods with archaeobotanical information: (*50*) Ali Kosh, (*51*) Arjoune, (*52*) Arjoune, (*53*) Ayios Epiktitos Vrysi, (*54*) Bouqras, (*55*) Cape Andreas Kastros, (*56*) Catal Hoyuk, (*57*) Cayonu, (*58*) Choga Mami, (*59*) Dhali Agridhi, (*60*) Dhuweila, (*61*) El Kowm I, (*62*) Jaffarabad, (*63*) Jericho, (*64*) Khirokitia, (*65*) Magzalia, (*66*) Tell Abu Hureyra, (*67*) Tell el'Oueili, (*68*) Tell Ras Shamra, (*69*) Tepe Hasanlu, (*70*) Tepe Musiyan, (*71*) Tepe Yahya, (*72*) Umm Dabaghiyah, (*73*) Wadi Jilat 7, (*74*) Yarim Tepe I, (*75*) Abu Hamid, (*76*) Arpachiyah, (*77*) Aswan region, (*78*) Bendebal, (*79*) Bnei Beraq, (*80*) Çadir Höyük, (*81*) Cayboyu (Aswan), (*82*) Choga Mami, (*83*) Eridu, (*84*) Girikihaciyan, (*85*) Hacinebi Tepe, (*86*) Hassek Höyük, (*87*) Hirbet el-Msas (Tel Masos), (*88*) Horum Hüyük, (*89*) Horvat Beter, (*90*) Ikiztepe, (*91*) Jaffarabad, (*92*) Jawa, (*93*) Jericho, (*94*) Kenan Tepe, (*95*) Kish, (*96*) Kissonerga, (*97*) Kissufim Road, (*98*) Korucutepe, (*99*) Kosak Shamali, (*100*) Kumtepe, (*101*) Kurban Höyük, (*102*) Lemba-Lakkous, (*103*) Mylouthkia, (*104*) Nahal Mishmar, (*105*) Nahal Qanah Cave, (*106*) Oylum Höyük, (*107*) Sataf, (*108*) Sharafabad, (*109*) Shiqmim, (*110*) Tappeh Gijlar, (*111*) Tel Saf, (*112*) Tell Abu Matar, (*113*) Tell Afis, (*114*) Tell Aqab, (*115*) Tell Brak, (*116*) Tell el'Oueili, (*117*) Tell Esh-Shuna, (*118*) Tell Halif, (*119*) Tell Hammam et-Turkman, (*120*) Tell Ilbol, (*121*) Tell Karrana, (*122*) Tell Kurdu, (*123*) Tell Sabi Abyad, (*124*) Tell Shiukh Fawqani, (*125*) Tepe Farukhabad, (*126*) Tepe Hasanlu, (*127*) Tepe Sabz, (*128*) Tepe Yahya, (*129*) Tepecik, (*130*) Tilbeshar, (*131*) Tuleilat Ghassul, (*132*) Umm Dabaghiyah, (*133*) Umm Qseir, (*134*) Wadi Fidan, (*135*) Yarim Höyük

(Waetzoldt, 1987). The occasional presence of storage of wild plant seeds in Neolithic sites (Fairbairn, Martinoli, Butler, & Hillman, 2007) suggests a broad-spectrum economy rather than specialized agricultural production. On the other hand, irrigation techniques as evident for the central Mesopotamian Samarra culture (e.g., Choga Mami; Helbaek, 1972) imply collective aims to increase crop yields in these societies which consequently led to a higher degree of specialization. In a highly variable landscape like the Fertile Crescent as a whole, with regionally strong susceptibility to drought, people were settling in regions where freshwater was easily available, even in the regions of higher precipitation such as northern Syria during the Neolithic Halaf period, where most of the sites were located close to flowing water.

The Chalcolithic period is associated with a range of changes in the organization of subsistence and lifestyle. The southern Iraqi site of Tell al-Ubaid (6500–3800 BC) is name giving for the cultural traditions of the Chalcolithic. The Ubaid culture expanded into northern Mesopotamia roughly 1,000 years later and is considered as the starting point towards urbanization and the basis for the later Sumerian civilizations in the south. Small cities and religious centers developed in this area (e.g., Eridu), and together with a precursor of the later emerging writing system, the beginnings of controlling trade were set (Nissen, 1999).

Farmers of the southern Mesopotamian Ubaid culture were applying irrigation techniques on the alluvial soils of the Euphrates resulting in high yields which supported rapid population growth. The presence of early irrigation has been recognized also in the geoarchaeological record, i.e., directly in the forms of canals and indirectly by the location of archaeological sites in regions of low mean annual precipitation (Wilkinson, 2003).

The Chalcolithic period is also closely related to the beginnings of horticulture. As it requires the technological knowledge of vegetative propagation, it is generally considered to have developed after grain agriculture had been fully established. In contrast to cereal agriculture, there is also a higher necessity of a year-round sedentary lifestyle to protect the plants from pests and browsing damage which should have resulted in a generally lower mobility at least for parts of the population.

In the archaeobotanical record, the morphological differentiation between wild and domesticated fruit stones is generally problematic which explains the difficulty to determine the precise beginnings of fruit domestication. Also the extent of fruit cultivation is impossible to assess without textual sources which are available only from the Early Bronze Age onwards.

While single olive stones occur at least since the Aceramic Neolithic or even earlier (e.g., at Epipaleolithic Ohalo II/Israel), they become more frequent in the Chalcolithic period. The natural distribution of wild olive (*Olea europaea* ssp. *oleaster*) follows the Mediterranean coast, limited in distribution into the inland regions of the Fertile Crescent through summer drought. This explains the presence of olive mostly in the western part of the Fertile Crescent during the Chalcolithic period. Olive finds from further inland Early Bronze Age sites are discussed for their origin, as irrigation practice may well have allowed olive cultivation outside its natural distribution area, while trade of economic products already played a certain role and may have equally contributed to the extended area of findings. A comparatively moister climate during the early to mid-Holocene may have also played a role in ancient crop plant distribution differing from modern patterns (Riehl, Pustovoytov, Weippert, Klett, & Hole, 2014).

In contrast to olive the natural distribution of wild grape (*Vitis vinifera* ssp. *sylvestris*) extends further inland along the lower foothills of the Taurus Mountains between southern Turkey and northern Syria. Its archaeological finds therefore extend further into these inland regions during the Chalcolithic period. Although earliest finds of grape date back to the Neolithic period, its domestication in the Fertile Crescent has long been considered to have happened during the Early Bronze Age. However, recent findings, such as the Chalcolithic winery of Areni in Armenia (4000 BC), suggest possibilities of earlier or simultaneous cultivation outside the Fertile Crescent (Barnard, Dooley, Areshian, Gasparyan, & Faull, 2011).

As with the two previous fruit crops, fig (*Ficus carica*) has been found in early prehistoric sites, but its domestication probably occurred during the Chalcolithic period, although there are claims for domestication at Aceramic Neolithic Gilgal I/Israel (Kislev, Hartmann, & Bar-Yosef, 2006). Seeds of wild fig are indiscernible from domesticated seeds and a final proof of very early domestication is therefore pending. Its relatively large size and high content in carbohydrates may explain its attractiveness for gathering humans.

Date (*Phoenix dactylifera*) is mainly found in archaeological sites located within the natural distribution area of the tree which is south of 32°N latitude. Beside of some very early finds, date stones appear domesticated around 4000 BC in southern Mesopotamia at the site of Eridu and a number of other Chalcolithic sites in Iraq, Iran, and Jordan. It becomes a very important economic plant in later history, i.e., during the Early Bronze Age when oasis agriculture developed (Tengberg, 2012). Rosaceae fruits (apple, pear, plum, cherry) need grafting/vegetative propagation and are intensively cultivated not before classical antiquity (Greek and Roman times).

The end of the Chalcolithic has been related with diverse catastrophic events, including invasions and climate change, i.e., the 5200 BP event (Bar-Matthews & Ayalon, 2011). Such an event, as recorded for the western part of the Fertile Crescent, may have resulted in increased interannual variation in precipitation and extended droughts that would have affected yields. Although the $\delta^{13}C$ record in Chalcolithic barley grains reflects increased drought for Tell esh-Shuna in Jordan and Tell Shioukh Faouqani in northern Mesopotamia, the effects in other regions of the Fertile Crescent of such climate fluctuations may have been very diverse (Riehl, Pustovoytov, Weippert, Klett & Hole, 2014).

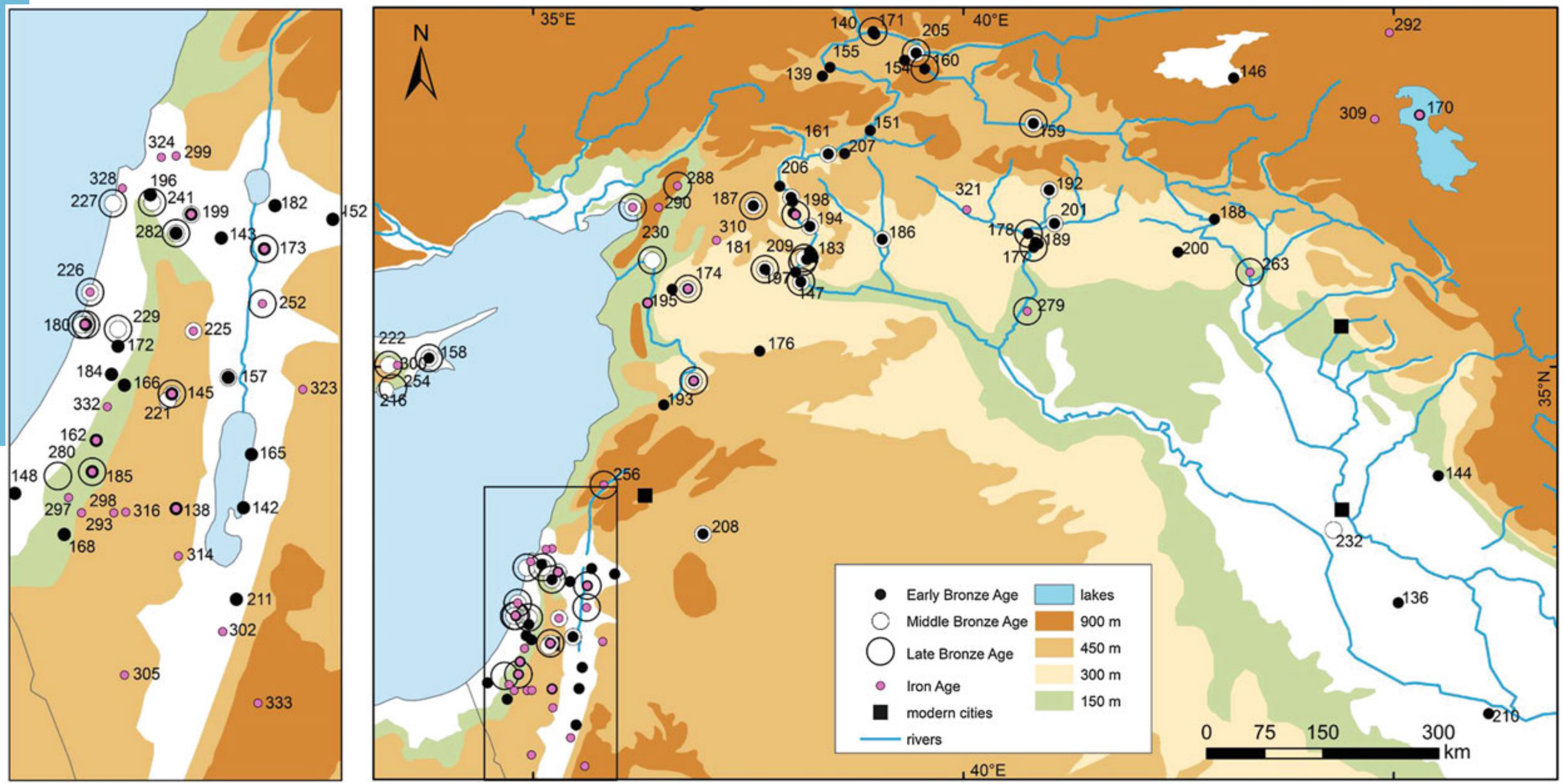
Complex Agricultural Systems

The city-states and empires of the Bronze and Iron Ages and their sociopolitical layout under numerous different kings cannot be discussed here in detail (for more information, see Akkermans & Schwartz, 2003; Van De Mieroop, 2003; Nissen, 1999; and other textbooks). There is a massive amount of data on agricultural techniques in southern Mesopotamia from cuneiform texts (various volumes of the *Bulletin on Sumerian Agriculture*), while information on agricultural production in other regions of the Fertile Crescent also derives from archaeological and archaeobotanical studies (Fig. 5).

The Uruk period (4300–3100 BC), the transition from the late Chalcolithic Ubaid into the Early Bronze Age period, combines all attributes of increasingly complex societies, such as population growth and progressive social stratification, including side effects of competition for resources and the need for institutionalized organs coordinating the more and more complex processes within the society. The development of writing in form of pictograms supported the increasing complexity of administration.

These developments were part of the urbanization process which was naturally bound to increasing agricultural yields which were particularly profitable in regions with developed irrigation systems (Postgate, 1992). Geoarchaeology considerably contributes to our knowledge of how these systems functioned and could be maintained in the face of changing environments and increasing food demands from rising populations. Five stages in the development of Mesopotamian irrigation systems can be discerned from their initial development in prehistoric times to their demise starting in later Islamic times (Wilkinson, 2003, chap. 5).

With the beginning of the Early Bronze Age, cities of various ranks evolved also in upper Mesopotamia and Syria, although the type of city-states, based on agricultural surplus, only becomes evident from 2600 BC onwards. The processes that started in the Chalcolithic period continued in the following Early Bronze Age Jemdet Nasr (3100–1900 BC) and Early Dynastic (2900–2334 BC) periods when the plow was developed and agricultural surplus was used for importing other goods into the south, such as construction wood and mineral resources through long-distance trade. Trade of agricultural products such as olive oil and grape wine is well documented in cuneiform sources from the Early Bronze Age (e.g., Ebla/Tell Mardikh 2400 BC) onwards as well as in later archaeological finds, such as the Late Bronze Age shipwreck of Uluburun (Haldane, 1993). While single oil presses are known from the Mediterranean region during the Chalcolithic, they only become more frequent during the Early Bronze Age. Agricultural surplus production was regionally intensified by focusing on few crop species with reliable yields, such as barley which was a main crop in many northern Mesopotamian cities (e.g., Emar; Riehl, Pustovoytov, Dornauer, & Sallaberger, 2012). The broad spectrum of crops observed since the Neolithic was however still cultivated, but barley became the most abundant cereal crop during the Early Bronze Age. Free-threshing wheat was cultivated particularly in inland



Agriculture in the Ancient Near East, Fig. 5 Archaeological sites of the Bronze Age periods and the Iron Age with archaeobotanical information (locations with multiple numbers are multi-period sites; only the first number appears in the map): (*136*) Abu Salabikh, (*137/212/289*) 'Afula, (*138/291*) Arad, (*139*) Arslantepe, (*140/141/249*) Aswan region, (*142*) Bab'edh Dhra, (*143*) Beth Shean, (*144*) Choga Mami, (*145/213/251/295*) City of David, (*146*) Dilkaya Höyük, (*147/214/253*) Emar, (*148*) En Besor, (*149*) Gre Virike, (*150*) Hajji Ibrahim, (*151*) Hassek Höyük, (*152*) Hirbet ez-Zeraqon, (*153*) Horum Hüyük, (*154*) Ikiztepe, (*155*) Imamoglu, (*156*) Jawa, (*157/215*) Jericho, (*158/217/255*) Kalopsidha, (*159/218/257*) Kenan Tepe, (*160/259*) Korucutepe, (*161/220*) Kurban Höyük, (*162/304*) Lachish, (*163/261*) Malyan, (*164/223*) Mezraa Hoyük, (*165*) Numeira, (*166*) Sataf, (*167*) Shahr-i Sokhta, (*168*) Shiqmim, (*169*) Sotira Kaminoudhia, (*170/315*) Tappeh Gijlar, (*171*) Taskun Mevkii (Aswan), (*172*) Tel Dalit, (*173/267/318*) Tell Abu al-Kharaz, (*174/228/268/319*) Tell Afis, (*175*) Tell al-Raqa'i, (*176*) Tell al-Rawda, (*177*) Tell Atij, (*178/271*) Tell Bderi, (*179/231*) Tell Brak, (*180/233/272/320*) Tell el Ifshar, (*181*) Tell el'Abd, (*182*) Tell Esh-Shuna, (*183*) Tell es-Sweyhat, (*184*) Tell Gezer, (*185/275/322*) Tell Halif, (*186/236*) Tell Hammam et-Turkman, (*187*) Tell Jerablus Tahtani, (*188*) Tell Karrana, (*189*) Tell Kerma, (*190*) Tell Matsuma, (*191/237/277/325*) Tell Mishrifeh, (*192/238*) Tell Mozan, (*193*) Tell Nebi Mend (Kadesh), (*194/239*) Tell Qara

A

settlements, while emmer wheat was represented with higher proportions in the coastal regions. Particularly for the sites in the north (e.g., Urkesh/Tell Mozan), knowledge on ancient agriculture is well founded on bioarchaeological results (Doll, 2010; Riehl, 2010b). While in the drier south irrigation was necessary to receive sufficient yields to support large populations, farming was mostly rain-fed in the north, although the water of the rivers Khabur and Euphrates could have been used occasionally for irrigation of specific crops, as is evident for later periods at the upper Euphrates (Riehl 2010a).

While potential weed species are already identified in Aceramic Neolithic sites, and in these contexts interpreted to indicate early cultivation of wild progenitor species of modern crops, they are much more numerous from the Bronze Age onwards and have been used by archaeobotanists to investigate local crop husbandry practices at some archaeological sites (van Zeist, 1993).

Textual evidence suggests that the central organization of the northern Mesopotamian city-state included the majority of the inhabitants and that agriculture was organized as collective labor (Sallaberger & Ur, 2004), which would correspond to organizational forms in southern Mesopotamia, although irrigation was not a significant part of labor organization in the north. Redistribution of the communally harvested crops according to status seems to have been the rule. For southern cities very detailed information on the organization of crop and animal husbandry, including administrative management, is available from textual records (e.g., Hruska, 1990; Powell, 1984). As taxation could have been a problematic burden particularly in years with crop failures, the economic relations to the north and other regions for subsidizing were a significant political aspect. Increasing population pressure particularly in the south is considered to have provoked competition for resources between different city-states during the Early Dynastic period which was accompanied by developing dynasties and war.

Shortly before the end of the Early Bronze Age, the Akkadian Empire (2334–2193 BC) becomes dominant in the whole region of southern and northern Mesopotamia and beyond. In the south the third dynasty of Ur came into power in the twenty-first century BC for a short time. Involved into diverse warfare, accompanied by famine, it came to an end around 2004 BC. The collapse of the Akkadian Empire at the end of the Early Bronze Age has frequently been related with the Holocene climatic fluctuation of 4200 BP (Staubwasser & Weiss, 2006). It corroborates the geoarchaeological record in the region, indicating a distinct change in the regime of water streams from relatively stable, moderately strong water flows to increasingly rare, erratic, and stronger flows, which suggests increasing aridity (Riehl et al., 2012). As large-scale environmental change is generally related to bottlenecks in agricultural production and accompanied by migration (e.g., the nomadic Amorites), upheaval, raids (e.g., invasions of the Gutians), and war may have contributed to the collapse of the empire, similarly as with Ur III. In fact, archaeobotanical

Agriculture in the Ancient Near East, Fig. 5 (continued) Quzaq, (*195/326*) Tell Qarqur, (*196*) Tell Qashish, (*197*) Tell Selenkahiye, (*198/281/330*) Tell Shiukh Fawqani, (*199/240/282*) Tell Taannach, (*200*) Tell Taya, (*201*) Tell Zagan, (*202/242/284*) Tepe Farukhabad, (*203/243*) Tepe Hissar, (*205/244/285*) Tepecik, (*206/245/286*) Tilbeshar, (*207*) Titris Höyük, (*208/246*) Umbashi, (*209/247/287*) Umm el-Marra, (*210*) Ur, (*211*) Wadi Fidan, (*216*) Kalavasos village, (*219/258/303*) Kinet Höyük, (*221*) Manahat, (*222/262*) Marki-Alonia, (*224/264/308*) Pirak, (*225/311*) Shiloh, (*226/265/317*) Tel Michal, (*227/266*) Tel Nami, (*229/269*) Tell Aphek, (*230/270*) Tell Atchana, (*232*) Tell ed-Der, (*234/273*) Tell Gerisa, (*235/274*) Tell Hadidi, (*241/283*) Tell Yoqneam, (*243*) Tepe Hissar, (*248*) Apliki, (*250*) Ayios Dhimitrios, (*252/296*) Deir'Alla, (*254*) Hala Sultan Tekke, (*256/301*) Kamid el-Loz, (*260*) Kusakli, (*263/306*) Nimrud, (*276*) Tell Hwes, (*278*) Tell Munbāqa, (*279/329*) Tell Schech Hamad, (*280*) Tell Sera, (*288/334*) Zincirli, (*290*) 'Ain Dara, (*292*) Bastam, (*293*) Beer-Sheba, (*294*) Çadir Höyük, (*297*) En Rahel, (*298*) Hirbet el-Msas (Tel Masos), (*299*) Horbat Rosh Zayit, (*300*) Idalion, (*302*) Khirbet en-Nahas, (*305*) Moa, (*307*) Nush-i Jan, (*309*) Qal'eh Ismail Aqa, (*310*) Rifa'at, (*312*) Susa, Ville Royale, (*313*) Tahirbaj Tepe, (*314*) Tamara, (*316*) Tel 'Ira, (*321*) Tell Halaf, (*323*) Tell Hesban, (*324*) Tell Keisan, (*327*) Tell Qasile, (*328*) Tell Qiri, (*332*) Tzafit, (*333*) Udhruh barley from this region shows increased drought stress in the second half of the Early Bronze Age (Riehl, Pustovoytov, Weippert, Klett & Hole, 2014). Extended drought may have also strongly affected agricultural production further south by decreasing yields and increasing soil salinity which has been already discussed in earlier works on southern Mesopotamian agriculture (Jacobsen & Adams, 1958).

During the Middle Bronze Age (c. 2000–1500 BC), the major empires of Babylonia (c. 1894–539 BC), a foundation of the nomadic Amorite dynasties, located in southern Mesopotamia, the Old Assyrian Empire (c. 2000–1400 BC) in the area of the upper Tigris river in northern Mesopotamia, and the Hittites (2000–1200 BC) were controlling the Near East, probably with a certain continuity of economic interests that already existed during the Early Bronze Age.

The political history of the Middle Bronze Age empires is well documented in ancient texts, and there is equally comprehensive information on agricultural organization in the middle Euphrates region (Lafont, 2000) and crop products in the Hittite area of influence in central Anatolia (Hoffner, 1974).

While the middle and lower Euphrates regions are bare of any archaeobotanical studies, some few results from Hittite settlements in Anatolia indicate a broad-spectrum plant production with additional crop species, such as einkorn (*Triticum monococcum*), spelt (*Triticum spelta*), or millet (*Setaria italica*), that are not cultivated farther south. This supports the importance of cereals in the Hittite economy as suggested by the cuneiform evidence, indicating a high diversity of names describing different types of bread. Lentil is the generally preferred pulse crop, as archaeobotanical studies mostly in northern Mesopotamia and the Levant suggest, although its cultivation slightly decreases during the Middle Bronze Age. The reduction of some of the pulse crops with higher water requirements corroborates a general trend in the Middle Bronze Age which has been interpreted as a shift in agricultural production towards more drought-resistant species as a consequence of increasing aridity with the end of the Early Bronze Age (Riehl, 2009). In most of the Syrian archaeological sites, barley is the main crop. At the middle Euphrates city of Mari, the lack of man power for cultivating the fields was a problem leading to local underproduction which forced the palace to acquire barley on the market (Lafont, 2000).

For Babylonia, there is no indication of economic decline in the first three centuries of the second millennium, although in the north political conflict and continuous change of political regimes and economic structures seems to have been the rule during the Middle Bronze Age.

The Late Bronze Age saw a number of different competing kingdoms and powers, expanding and retreating in the different geographic areas of the Fertile Crescent (for details on the political and cultural history, see Nissen, 1999) which probably had its effects on agricultural economy.

An influential Hurrian state in northern Mesopotamia at the transition from the Middle to the Late Bronze Age was Mitanni (1500–1300 BC). The end of the Middle Bronze Age is marked by the attack of the Hittites on Yamkhad, a northwestern Mesopotamian kingdom with its center at modern day Aleppo.

Material culture and the continuation of important empires such as the Hurrians and Hittites suggest an even transition to the Late Bronze Age (Akkermans & Schwartz, 2003). Some Hurrian settlements already existed during the Early Bronze Age (e.g., Urkesh/Tell Mozan). Egypt was also strongly represented, particularly in the area of modern Syria. Overseas trade played an increasing role and was a sign of, and a means for, the international character of a large number of territorial states, shaping agricultural production for specific needs, such as olive oil and wine.

Although with the transition from the Middle to the Late Bronze Age, many powerful cities disappeared, and discontinuation of administrative and scribal practices decreased, in terms of cultivated crop species, there is no particular difference visible between Middle and Late Bronze Age agriculture, despite a possible intensification of olive cultivation through extending the production area into the northern Levant and the upper Euphrates region (Riehl et al., 2012).

The end of the Bronze Age has often been explained as a consequence of the putative invasion of the Sea Peoples. Aside from political conflicts, economic decline has been proposed as a reason for the collapse of the Late Bronze Age civilizations as well as a climatic impact (Bond event no. 2).

The global cooling event between 1200 and 700 BC (Bond et al., 2001) corresponds well with the stable oxygen isotope data from Lake Van (Litt et al., 2009) and thus might have had an impact on Near Eastern agriculture. A climatic reasoning has also been discussed in the literature before, as the "1200 BC hypothesis" of increased aridity (Neumann & Parpola, 1987), supported by archaeoclimatological models (Bryson, Lamb, & Donley, 1974). Similarly Rohling, Hayes, Mayewski, and Kucera (2009) have suggested that the cooling period at the end of the Late Bronze Age adversely affected the agricultural quality in the northern and northeastern regions of the Aegean, thus triggering end-of-Bronze Age migrations.

Most likely complex interactions between political and ecological factors were responsible for these massive supraregional changes. Complete restructuring of the society must have taken place due to large-scale nomadization, migration, internal population movements, and technological and trade network changes. How these changes influenced agricultural organization is still unclear, but there is also some evidence for the maintenance and restoration of the lower Khabur and middle Euphrates canals by local rulers (Fales, 2008).

With the beginning of the first millennium BC, the political situation in the Near East had become more stable, and a new network of states arose, which becomes tangible in the ninth century BC by written records again. Iron Age Syria has been characterized as a region of numerous small states, which was absorbed into the provincial systems of vast multiregional empires (Akkermans & Schwartz, 2003). The generally broadening network of commercial connections doubtlessly had an influence on agricultural production.

Agricultural organization during the Neo-Assyrian Empire (934–609 BC), which embraced practically the whole Near East, was the planned distribution of rural labor forces, the installation of large-scale irrigation systems, and a centralized program of rural land settlement policy (Bagg, 2000). Agricultural surplus was also possible due to a dense rural population.

New crops appear in the archaeobotanical assemblages, such as cotton (*Gossypium* sp.), pomegranate (*Punica granatum*), and cucumber (*Cucumis sativus*), most of them requiring irrigation in areas of irregular and low rainfall. This corroborates the importance of irrigation as is evident from the texts. Changes in persisting crop species are particularly visible in free-threshing wheat and grape ubiquities, which occur generally more often in the archaeobotanical record of the Iron Age (Riehl, 2009) and which are confirmed by the textual evidence of numerous vineyards in northern Mesopotamia. The larger body of textual evidence from the first millennium also reveals more linen textiles than in the second millennium. Flax for linen production requires additional irrigation. Still, the textual evidence is almost exclusively for the import of linen as tribute from Syria to the Neo-Assyrian Empire. Only later during the Neo-Babylonian period (626–539 BC) do we find evidence for more frequent linen cultivation. Olive is not frequently mentioned in ancient texts, but the import of olive oil from the west is attested, corresponding with the archaeobotanical record. A local increase in the water supply is also visible in the Iron Age $\delta^{13}C$ values (Riehl, Pustovoytov, Weippert, Klett & Hole, 2014).

Perspectives

Although substantial contributions are available from ancient philology, archaeology, and the natural sciences on different aspects of ancient Near Eastern agriculture, no systematic overview has been published yet, which is partly due to the diversity of the sources and the methodological problems of interpreting these sources within a wider framework.

The rich textual record of cuneiform tablets, which has been estimated to number more than

500,000 texts, covers a broad range of information related to agriculture that has not yet been systematically analyzed. Archaeobotanical databases (e.g., www.ademnes.de) comprise millions of seed records from Near Eastern sites. Local geoarchaeological studies, including geographic information system (GIS)-based analysis of satellite imagery and modeling, have been published and helped with the identification of settlement and land use patterns as aspects of early economic systems in some few regions of the Near East. Additional independent methods, such as stable carbon isotope analysis, which has been used for investigating water stress on crop plants during their grain-filling period, can help verify these results. Syntheses of these different data sources, after careful analysis of the methodological problems, will provide more comprehensive results on ancient agriculture in the near future, which may be also of some relevance to issues of conservation of genetic resources in the Near East.

References

Akkermans, P. M. M. G., & Schwartz, G. M. (2003). *The archaeology of Syria. From complex hunter-gatherers to early urban societies (ca. 16000–300 BC)*. Cambridge: Cambridge University Press.

Bagg, A. (2000). *Assyrische Wasserbauten. Landwirtschaftliche Wasserbauten im Kernland Assyriens zwischen der 2.Hälfte des 2. und der 1. Hälfte des 1. Jahrtausends v.Chr* (24th ed.). Mainz: Philipp von Zabern.

Bar-Matthews, M., & Ayalon, A. (2011). Mid-Holocene climate variations revealed by high-resolution speleothem records from Soreq Cave, Israel and their correlation with cultural changes. *The Holocene, 21*(1), 163–171. doi:10.1016/j.jaridenv.2011.11.022/10.1177/0959683610384165.

Barnard, H., Dooley, A. N., Areshian, G., Gasparyan, B., & Faull, K. F. (2011). Chemical evidence for wine production around 4000 BCE in the Late Chalcolithic Near Eastern highlands. *Journal of Archaeological Science, 38*(5), 977–984. doi:10.1016/j.jas.2010.11.012.

Bar-Yosef, O. (2009). Social changes triggered by the Younger Dryas and the early Holocene climatic fluctuations in the Near East. In C. T. Fisher, J. B. Hill, & G. M. Feinman (Eds.), *The archaeology of environmental change: Socionatural legacies of degradation and resilience* (pp. 192–208). Tucson: The University of Arizona Press.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M. N., Showers, W., et al. (2001). Persistent solar influence on North Atlantic climate during the Holocene. *Science, 294*, 2130–2136.

Bryson, R., Lamb, H., & Donley, D. (1974). Drought and the decline of Mycenae. *Antiquity, 48*, 46–50.

Doll, M. (2010). Meat, traction, wool: Urban livestock in Tell Mozan. In K. Deckers, M. Doll, P. Pfälzner, & S. Riehl (Eds.), *Ausgrabungen 1998–2001 in der Zentralen Oberstadt von Tall Mozan/Urkeš: The development of the environment, subsistence and settlement of the city of Urkeš and its region* (3rd ed., pp. 191–358).

Fairbairn, A., Martinoli, D., Butler, A., & Hillman, G. (2007). Wild plant seed storage at Neolithic Çatalhöyük East, Turkey. *Vegetation History and Archaeobotany, 16*(6), 467–479. doi:10.1016/j.jaridenv.2011.11.022/10.1007/s00334-006-0069-3.

Fales, M. (2008). Canals in the Neo-Assyrian rural landscape: A view from the Habur and Middle Euphrates. In H. Kühne (Ed.), *Umwelt und Subsistenz der assyrischen Stadt Dur-Katlimmu am Unteren Habur* (Berichte der Ausgrabung Tall Šēḫ Ḥamad / Dūr-Katlimmu, Vol. 8, pp. 181–186). Harrassowitz Publishing House, Wiesbaden.

Fuller, D., Willcox, G., & Allaby, R. G. (2011). Cultivation and domestication had multiple origins: Arguments against the core area hypothesis for the origins of agriculture in the Near East. *World Archaeology, 43*(4), 628–652.

Haldane, C. (1993). Direct evidence for organic cargoes in the Late Bronze Age. *Word Archaeology, 24*(3), 348–360.

Helbaek, H. (1972). Samarran irrigation agriculture at Choga Mami in Iraq. *Iraq, 34*, 35–48.

Hillman, G. C., Hedges, R. E. M., Moore, A., Colledge, S., & Pettitt, P. (2001). New evidence of Lateglacial cereal cultivation at Abu Hureyra on the Euphrates. *The Holocene, 11*(4), 383–393.

Hoffner, H. A. (1974). *Alimenta hethaerorum: Food production in Hittite Asia Minor* (Vol. 55). New Haven, CT: American Oriental Society.

Hruska, B. (1990). Das landwirtschaftliche Jahr im alten Sumer: Versuch einer zeitlichen Rekonstruktion. *Bulletin on Sumerian Agriculture, 5*, 105–114.

Jacobsen, T., & Adams, R. M. (1958). Salt and silt in ancient Mesopotamian agriculture. *Science, 128*(3334), 1251–1258.

Kislev, M. E., Hartmann, A., & Bar-Yosef, O. (2006). Early domesticated fig in the Jordan Valley. *Science, 312*, 1372–1374.

Lafont, B. (2000). Irrigation agriculture in Mari. In R. M. Jas (Ed.), *Rainfall and agriculture in Northern Mesopotamia* (Vol. LXXXVIII, pp. 129–146). Leiden: Nederlands Instituut voor het Nabije Oosten.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., et al. (2009). 'PALEOVAN', International Continental Scientific Drilling Program (ICDP): Site survey results and perspectives. *Quaternary*

Science Reviews, 28, 1555–1567. doi:10.1016/j.jaridenv.2011.11.022/10.1016/j.quascirev.2009.03.002.
Nesbitt, M. (2002). When and where did domesticated cereals first occur in southwest Asia? In R. T. J. Cappers & S. Bottema (Eds.), *The dawn of farming in the Near East* (pp. 113–132). Berlin: Ex oriente.
Neumann, J., & Parpola, S. (1987). Climatic change and the 11th-10th century eclipse of Assyria and Babylonia. *Journal of Near Eastern Studies, 6*, 161–162.
Nissen, H. J. (1999). *Geschichte Alt-Vorderasiens*. München: Oldenbourg Wissenschaftsverlag.
Postgate, J. N. (1992). *Early Mesopotamia: Society and economy at the dawn of history*. London/New York: Routledge.
Powell, M. A. (1984). Sumerian cereal crops. *Bulletin on Sumerian Agriculture, 1*, 48–72.
Riehl, S. (2009). Archaeobotanical evidence for the interrelationship of agricultural decision-making and climate change in the ancient Near East. *Quaternary International, 197*, 93–114.
Riehl, S. (2010a). Maintenance of agricultural stability in a changing environment – the archaeobotanical evidence at Emar. In U. Finkbeiner, & F. Sakal (Eds.), *Emar after the closure of the Tabqa dam. The Syrian-German excavations 1996–2002* (Late Roman and Medieval cemeteries and environmental studies, Vol. 1, pp. 177–224). Brepols, Turnhout.
Riehl, S. (2010b). Plant production in a changing environment – The archaeobotanical remains from Tell Mozan. In K. Deckers, M. Doll, P. Pfälzner, & S. Riehl (Eds.), *Ausgrabungen 1998–2001 in der Zentralen Oberstadt von Tall Mozan/Urkeš: The development of the environment, subsistence and settlement of the city of Urkeš and its region* (Vol. SUN, Serie A, Vol. 3, pp. 13–158). Harrassowitz Publishing House, Wiesbaden.
Riehl, S., Pustovoytov, K., Dornauer, A., & Sallaberger, W. (2012). Mid-late Holocene agricultural system transformations in the northern Fertile Crescent: A review of the archaeobotanical, geoarchaeological, and philological evidence. In L. Giosan, D. Fuller, K. Nicoll, R. K. Flad, & P. Clift (Eds.), *Climates, landscapes, and civilizations* (Vol. 198, pp. 115–136). Washington, DC: American Geophysical Union monograph series.
Riehl, S., Zeidi, M., & Conard, N. J. (2013). Emergence of agriculture in the foothills of the Zagros Mountains of Iran. *Science, 341*(6141), 65–67. doi:10.1016/j.jaridenv.2011.11.022g/10.1126/science.1236743.
Riehl, S., Pustovoytov, K.E., Weippert, H., Klett, S., & Hole, F. (2014). Drought stress variability in ancient Near Eastern agricultural systems evidenced by δ13C in barley grain. *Proceedings of the National Academy of Sciences* 111, 12348–12353.
Rohling, E. J., Hayes, A., Mayewski, P. A., & Kucera, M. (2009). Holocene climate variability in the eastern Mediterranean, and the end of the Bronze Age. In C. Bachhuber & G. Roberts (Eds.), *Forces of transformation: The end of the Bronze Age in the Mediterranean*. Oxford, UK: Oxbow.
Sallaberger, W., & Ur, J. (2004). Tell Beydar/Nabada in its regional setting. *Subartu, XII*, 51–71.
Staubwasser, M., & Weiss, H. (2006). Holocene climate and cultural evolution in late prehistoric-early historic West Asia. *Quaternary Research, 66*, 372–387.
Tengberg, M. (2012). Beginnings and early history of date palm garden cultivation in the Middle East. *Journal of Arid Environments, 86*, 139–147. doi:10.1016/j.jaridenv.2011.11.022.
Van De Mieroop, M. (2003). *A history of the ancient Near East ca. 3000–323 BC*. Oxford: Blackwell.
van Zeist, W. (1993). Archaeobotanical evidence of the Bronze Age field weed flora of northern Syria. In C. Dissertationes Botanicae. Brombacher, S. Jacomet, & J. N. Haas (Eds.), *Dissertationes Botanicae; The Zoller Festschrift: Contributions to the philosophy and history of the natural sciences, evolution and systematics, ecology and morphology, geobotany, pollen analysis, and archaeobotany* (pp. 499–511). Berlin, Germany: E. Schweizerbart'sche Verlagsbuchhandlung
Waetzoldt, H. (1987). Knoblauch und Zwiebeln nach den Texten des 3. Jahrtausends. *Bulletin on Sumerian Agriculture, 3*, 23–56.
Wilkinson, T. J. (2003). *Archaeological landscapes of the Near East*. Tucson: University of Arizona Press.
Willcox, G. (2013). The roots of cultivation in southwestern Asia. *Science, 341*(6141), 39–40. doi:10.1016/j.jaridenv.2011.11.022/10.1126/science.1240496.
Zeder, M., & Hesse, B. (2006). The initial domestication of goats (*Capra hircus*) in the Zagros Mountains 10,000 years ago. *Science, 287*, 2254–2257.

Agriculture in the Islamic World

Lucie Bolens

The success of classical Islamic agriculture is due to the adaptation of agrarian techniques to local needs, and this adaptation itself is due to a spectacular cultural union of scientific knowledge from the past and the present, from the Near East, the Maghreb and Andalusia. A culmination more subtle than a simple accumulation of techniques, it has been an enduring ecological success, proven by the course of human history.

In the definitions which open the *Kitāb al-filāḥah* (Book of Agriculture), this function is said to be blessed by God because it has as its end the production of the sustenance of life. Agriculture consists of restoring to the earth what has been furnished by harvesting from it, by fertilizing, watering and making efforts to avoid the problems caused by excessive heat. This restoration to the soil implies a knowledge of the whole – the soils, the plants, the most suitable tools. Balance (*mizān*) is the aim, or reciprocity between what is taken from the earth and what must be given back in order to make this vital alliance with Nature endure.

The complex union of facts with the general conjunction of the Mediterranean world between the eleventh and the fifteenth centuries means that a de-positioning of history is indispensable for understanding a crisis as well as a success. No progress is linear, and it is always useful to draw inspiration from the aleatory nature of history, in order that this discipline, fundamentally cultural, may also have a practical impact.

The successional right of the four Islamic judicial schools permits "holdings" according to a customary right which is similar to the right to private property of the Romans. Royal power encouraged territorial expansion among the princes of the blood and high officials of the state.

From a historical point of view, the important thing is the fact of reciprocal information throughout the *Dār al-Islām* (the Islamic world). There emerges the impression of a coherent school and a general movement – of people, goods and ideas – from the East to the Islamic West.

The ancient tradition, prolonged and recovered from the ancients (*al-Alwālī*), integrated the ideas of fourth century scholars like Aristotle, Dioscorides, Galen and Anatolius Democritus with those of the botanists of the ninth century and contemporary scholars of geoponics, the art and science of cultivating the earth. If the mysterious *Filāḥat al-Nabaṭiyyah* (Nabataean Agriculture, by Ibn Wahshiyyah, ca. 1,000) traces the origins of agriculture back to Adam, those who lived in the classical age were equally inspired by knowledge obtained from anonymous farmers who retained the memory of ancient ways. Tradition and scientific curiosity have not always been at odds with each other.

On a religious level, the earth and water, as in the Hebraic tradition, belong to no one person; they belong to God. Historical accounts of Islamic expansion distinguish between Arab lands and lands situated in the conquered countries. Under the early caliphs, Arab lands were surveyed and registered. A basic tax was established, 10 *dirhams* for a *jerib* of grapes, 8 *dirhams* for a *jerib* of palm trees, 6 on a *jerib* of sugar cane, 2 on barley. The *jerib*, a unit of measure, equaled 360 cubits, according to al-Mawardī. The lands of people who freely converted to Islam were subject to a deduction of a tenth, *dīme*, varying according to province and century from the eighth to the twentieth centuries. In Andalusia, the tax was one-fifth. After the Reconquista, the farmers there continued to be called *quinteros*.

Lands which were forcibly conquered were redistributed. Al-Wansharisī, a fifteenth century Maghreb legal expert, notes numerous examples for studying classical Islamic agriculture in Andalusia and the Maghreb.

Collective lands, *jema'a*, existed in certain parts of *Dār al-Islām*, used for the movement of flocks of large and small grazing stock. Cultivated land was also divided up legally and parceled out.

"Tributary" lands were conquered lands lying outside Arabia, beginning with Syria (Sham). They were considered lands not belonging to anyone, the property of the state or the caliph. By contrast, they were left to their former owners, according to a right of use. A land tax called *kharaj* was paid to the Treasury (*bayt al-māl*) and the amount of tax was set according to the quality of the soil. From the 700s, the principle was applied in the form of a supplemental tax to Jews, Christians and Sabeans, being the *Ahl al-kitāb* (People of the Book), or *dhimmis*.

Individual land holdings were called *iqtā;* they were lands grafted to a private individual according to clauses which were more or less restrictive depending on rents. All lands which the caliph gave to his subjects so that they might transform and cultivate them were so designated. *Waqf* lands were lands granted by private individuals to mosques, hospitals, schools and other charitable institutions. They are often translated as charitable properties. They were not subject to land speculation.

All these lands, except for the *waqf* properties, could be the object of commercial transaction – sale, rent, or purchase – which had nothing to do with feudal land statutes. In the twelfth century, the Sevillian Ibn Abdūn, in his *Treaty of ḥisbās*, encouraged personal appropriation of land as a means of stimulating economic growth.

The information which appears in the documentation needs examining. It is based on experimentation which resulted in the shattering of prior philosophical premises. Empiricism appeared to be the condition of renewing knowledge and techniques. Ibn al-ʿAwwām writes: "I affirm nothing which seems right to me without having proven it in numerous experiments". In agriculture, the results refer to the practical successes of sheaves of grain, fruits, or taxes.

The theory of climates, *al-iklim*, compares Andalusia with Iraq and makes pertinent constant reference to Nabatean agriculture.

"Indeed", writes Ibn al-ʿAwwām, "what suits our country is the result of what comes from the concordance of tradition with experimental results". The respect for ecological balance – *mizān* – between the soil, the microclimate, and various cultivated plants guarantees the success of the harvest. The "weather" governs the results, and the seasons are stated in the "Calendar of Seville" according to their names in Syrian, Persian, Hebrew and in indigenous romance languages. More subtle than a syncretism, it was a question of a whole society.

Islamic agriculture had, at first, been Arab agriculture, since Islam first appeared in the Arabian peninsula, among the Bedouins and camel drivers. Around the big cities, agriculture was the agriculture of the oasis, a natural miracle brought about by the presence of water in a desert of sand and stones. The history of agriculture in Islamic countries, established over a long duration as Fernand Braudel has described, is made up of a fundamental unity. The first great geo-climatic regions were sub-arid dominants around the Mediterranean basin. The Ummayyad empire, then the Abbasid empire, finally integrated the sub-tropical regions with temperate ones. However, the essential originality of Islamic agriculture is still linked to the Mediterranean regions and to the fluvial valleys. The first Islamic empires and the caliphate of Andalusia owed their agriculture to the great rivers carrying water and fertilizing silt (alluvium); the Tigris, Euphrates, Nile, Guadalquivir and the Guadiana all gave both soil and waterless, sun baked lands.

Between the seventh and the thirteenth centuries, the displacement of peoples and technical skills gave rise to a migration of cultivated plants, from the East towards the West, from subtropical zones towards the Mediterranean basin, from the monsoon regions to semi-arid lands; from China towards Persia, passing through India; and from Afghanistan towards the Fertile Crescent and the Maghreb, creating in its passing the gardens of Sicily and of Andalusia. Just as the ancient Romans constructed aqueducts and waterworks to provide food on a scale for the cities and municipalities which were their centres of power, so the Islamic empire, founded on caravan cities, also wove a net across the countryside of hydraulic equipment for agricultural adaptation, for example *acequias* [an earthern channel that conveys water], *qanats* [a water management system] and *norias* [a stone grinding wheel]. In spite of the progressive climatic diversification which occurred as the area ruled by Islamic law increased, from the Sudan to the Caspian seaports, from the Straits of Gibraltar to the boundaries of the Ottoman Empire and to India, the determining character of their agricultural system remained the adaptation of irrigation to local and regional needs and the spread of plant species away from their original ecosystems.

The spread of agricultural land and the intensification of irrigation in sub-Iberian regions which tended to be hot and very humid sub-arid areas were spectacular. Legal aspects of land holding were closer to those of Rome and Byzantium than the medieval West. Individual property ownership was actively encouraged.

Technological and cultural methodologies were informed by the need for renovation while remaining empirical. Among the agrarian jobs, that of the autumn harvest is characteristic in that the human job prevails over the financial investment. The swing plough was preferred over the heavy Brabout plough of the French colonist; not exposing the deep beds of cultivated land to erosion and intense heat was the golden rule of ecology in Andalusia. In the golden Andalusian age, this protection of the Mediterranean soils was subject to laws of a scrupulously careful ecology. The *mishā*, a heavy, hand-held spade was the tool for restoring the soil. The object of such agriculture was closing the soil, not opening it.

Among agricultural systems, the biennial rotation of crops is essential for maintaining fallow fields. Biennially or by a more complex number of years, but always by an even number, the rotation of crops shows a deep understanding of the plant world. The refertilization of soil, the base of all agriculture, comes about through the joint knowledge of plants and soils, the mastery of botanical and edaphic science. In Andalusia, well before the era of the English physiocrats of the 1800s, this agriculture revolution was closely based on high level of knowledge of the life sciences and on a love of nature which was the common gift of both the Islamic and the Hebraic tradition.

Certain plants modified dietary habits, for example sorghum, a common basis of diet in Asia and Africa; rice in flooded areas; sugar cane which is used for preserving and for therapeutics; the eggplant transported by the Jews in the second diaspora; citrus fruits from China; durum wheat from Africa, a nutritional mainstay in the form of bulgur and couscous; watermelons; and banana trees, acclimated in Egypt before arriving in the Maghreb and Andalusia.

The cultivation of other plants influenced styles and types of clothing throughout the Islamic regions. There was cotton, introduced to Andalusia after the arrival of the Kurd Ziriyab in the 900s, dye plants which brought a passion for Persian and Indian colours to the puritanical Berbers, and perfume which supplied the base of a whole range of products, such as lotions, salves, and soaps, and which was manufactured from the almost limitless supplies of fragrant flowers from Turkey and Morocco.

With a deep love of nature and a relaxed way of life, classical Islamic society achieved ecological balance, a successful average economy of operation, based not on theory but on the acquired knowledge of many civilized traditions, a society which wanted to live without the spectre of famine and hunger.

Colonialism seriously upset the traditional agricultural balance in order to increase profitability for the colonizers. This has been widely written about and is proven today by global economic realities. In the 1900s, colonial settlers and city authorities (wrongly) interpreted the indigenous practice of transhumance (moving flocks of animals from one area to another) as non-ownership of land. This distortion of a multisecular custom of complement between plant and animal husbandry (for example, in the Maghreb) caused grave damage to the native economy. Colonial agriculture thus found pseudo-legal advantages in a vast redistribution of land, which brought great economic benefit to the colonial settlers who had come out from the cities and towns.

We are witness today to the slow recovery of agrarian balance in former colonies like Algeria.

See Also

▶ Irrigation in the Islamic World
▶ *Qanat*
▶ Technology in the Islamic World

References

al-Hassan, A. Y., & Hill, D. R. (1986). *Islamic technology*. Paris: UNESCO.
Bolens, L. (1978). La révolution agriciole andalouse du XIè siècle. *Studia Islamica, 47*, 121–141.
Bolens, L. (1981). *Agronomes andalous du Moyen Age*. Genève, Switzerland: Droz.
Carabaza Bravo, J. M. (2002). La Filaha yunaniyya et les traités agricoles arabo-andalous [La Filaha yunaniyya and the Arabo-andalusian Treatises on Agriculture]. *Arabic Sciences and Philosophy, 12*, 155–178.
Fahd, T. (1965). Filāḥa. In *Encyclopedia of Islam* (pp. 920–32). Leiden, Netherlands: Brill.

Fahd, T. L'Histoire de l'agriculture en Irak: al-Filāḥa an-Nabatiyya. *Handbuch der Orientalistik* 6 (1952–1959): 276–377.
Glick, T. F. (1979). *Islamic and Christian Spain in the early Islamic world*. Princeton, NJ: Princeton University Press.
Watson, A. (1983). *Agricultural innovation in the early Islamic world*. Cambridge, UK: Cambridge University Press.

Agriculture in the Pacific

William C. Clarke

The environments where traditional agriculture was practiced in the Pacific Islands ranged from frost-prone but gardened mountain slopes at 8,500 ft (2,600 m) in Papua New Guinea to tiny atoll islets lying scarcely above the reach of the waves in the always warm equatorial ocean. Heavy downpours almost everyday keep some places in the Pacific Islands permanently humid; short wet seasons followed by long dry spells characterize the rainfall in other places. Still others with almost no rainfall are true deserts. Some single islands contain this whole range – the big island of Hawaii, with its high, massive volcanoes and its sharply contrasting windward and leeward coasts, is a notable example of such climatic variety. A comparable dissimilarity exists in Pacific Island soils, with some young volcanic soils being highly fertile, whereas on atoll islets the only natural soil material may be rough coral rubble, which is alkaline, has a very low water-holding capacity, contains little organic matter, and is unable to supply plants adequately with many of the nutrients required for vigorous growth.

Traditional Pacific Island agriculturalists met this wide range of often challenging conditions with an even wider range of agronomic techniques and crops, which enabled food production on all but the most barren islets or at the highest elevations of the larger volcanic and continental islands. This universe of agroecosystems included elaborate terracing and irrigation to grow the water-loving taro, massive drainage works to grow less water-tolerant crops such as sweet potatoes, mulching and composting to enrich the soil and to slow water loss, planting crops in built-up mounds of soil to encourage cold-air drainage and so lessen frost damage, planting in excavated pits to reach the water table on dry atoll islets, and (in systems of shifting cultivation) the use of forest or woodland fallow – planted in some places, spontaneously natural in others – to restore fertility to soils after they had been gardened.

The Origin and Evolution of Pacific Island Agriculture

When, from the sixteenth century onwards, European explorers began to encounter the sophisticated Pacific Island agriculture then practiced, it was not surprising that some of them believed they had sailed to a Garden of Eden, where breadfruit trees and coconut palms provided food without work, and where only a little labor was needed to make irrigated terraces of taro bear heavy harvests of starch-rich corms or tilled beds of sweet potatoes produce many baskets full of nutritious tubers. Initially, Europeans saw this productive agriculture as though it were some sort of a divine gift given to the Pacific Islanders, who had been favored with gardens and orchards that yielded unchangingly through time and that remained continuously in harmony with local environments. It is now clear on the basis of the extensive research into Pacific prehistory carried out only over the past few decades that such a view is far from accurate.

Pacific Island agriculture has never been static. It has been evolving constantly from its beginnings, as migration led people to new environments where there were previously unknown wild plant species, as the agriculture itself changed the environment, as the need for food expanded with growing island populations, as new crop plants were introduced, or as the agriculturalists experimented and introduced productive innovations. The Pacific Island agriculture first seen by Europeans was only an instant snapshot of a long and very dynamic history.

Twenty-five years ago it would have been asserted confidently by many scholars that Pacific Island agriculture had originated in southeast Asia and that Pacific Island cultivated plants had been domesticated in that same hearth. All that the ancestors of Pacific Islanders had done was to carry the Asian techniques and crops with them as they dispersed to the farther oceanic islands. It was recognized that the sweet potato and a few other less important crops did not fit this scenario, having been shown to have originated in the American tropics. However, the presence of these exceptions was explained away by various, often fanciful, theories of migration or simply as the result of introductions by Portuguese or Spanish voyagers during the fifteenth and sixteenth centuries – though recent archeological research in the Cook Islands (central eastern Polynesia) shows the sweet potato to have been present there by about AD 1000.

We know now that although some plants of Southeast Asian origin and domestication were transferred without significant change far into the Pacific (some species of yam, for instance), there is also evidence in support of early indigenous domestication and development of agriculture in the Pacific, specifically in western Melanesia (Solomon Islands and the island of New Guinea). The length of occupation there (at least 40,000 years in New Guinea) is more than sufficient for the experimentation necessary for independent domestication. And chromosomal and paleobotanical studies now indicate that plants that may have been domesticated in this region include sago, one type of *Colocasia* taro, one kind of banana, sugar cane, *Canarium* (a nut-bearing tree), *Saccharum edule* (a relative of sugar cane with an edible inflorescence), *kava* (the ritual and social drink still important in many parts of the Pacific Islands), and a variety of other plants, including several fruit trees. This attention to trees and the creation of orchards is a characteristic of food production all across the Pacific and was probably carried by itinerant colonist-cultivators from its place of origin in western Melanesia to Polynesia and Micronesia.

Further, especially strong evidence for the early development of agriculture to the east of southeast Asia comes from an archeological study in the Papua New Guinean highlands at a place called Kuk. A great deal has been written about Kuk, and the evidence has been interpreted in various and changing ways, but there is general agreement that Kuk demonstrates a long history of agricultural development, beginning about 9,000 years ago and involving, among much else, an ever-growing complexity of drainage works and water control in a large swamp, changes over time in cropping combinations from mixed gardens to taro monoculture to sweet potato dominance, responses to deforestation and land degradation brought about by shifting cultivation on the surrounding slopes, and the development of planted or encouraged tree fallows. Kuk, as well as evidence from prehistory elsewhere in the Pacific, shows that a dynamic agronomic and botanical science has long existed in the Pacific, in terms both of basic understanding and applied techniques. The origins of agriculture in the Pacific can now be said to have a time depth comparable to that of better known sites in southwestern Asia and tropical America.

No less mistaken than the view that traditional agriculture has been static in the Pacific Islands is the view that it has always been in harmony with its environment. Rather, as in the history of any dynamic agriculture, there have been episodes of deforestation, serious soil erosion, land degradation, and crop failure. Pacific Islanders did what all peoples, especially pioneers, do: in their efforts to make a living, they actively manipulated, modified, and, at times, degraded the ecosystems in which they lived, producing environmental changes that in turn required ecological adaptations and social adjustments. Considering the whole landscape, the most widespread of the human-induced changes in the prehistoric Pacific has been deforestation, with the cleared forests replaced by grasslands that required cultivation techniques different from those associated with forest-fallowed gardens. In many places, fire-maintained fern grass savannas underlain by infertile, eroded, or truncated soils came into existence or were extended by agricultural activities. This distinctive plant – soil complex is known as *toafa* in several Polynesian islands and as *talasiga* in Fiji. These dramatic landscape changes resulting from pioneering clearance for agriculture did not, however, bring unmitigated environmental degradation. Rather, in many places, they resulted in what has been termed "landscape enhancement," whereby the eroded soil transported down the slopes filled in the lower valleys and created swampy zones that were ideal sites for what came to be sustained yield, intensive cultivation of wetland taro. Other responses included the development of dryland cultivation techniques to cope with the changed agricultural environment, irrigated terracing, and an elaborated use of trees.

Traditional Agriculture in the Pacific Islands

The wide range of agricultural systems and techniques devised by Pacific peoples over millennia can be considered as ways of solving the agronomic problems presented by the great variety of island environments. For instance, in forested areas of low population density, soil fertility was maintained by simple no-tillage shifting cultivation wherein natural forest fallow rehabilitated the soil after gardening. Where forest was diminished, leguminous or other nitrogen-fixing trees (such as *Casuarina* spp.) were encouraged or planted. In grasslands a variety of mulching and composting techniques were developed. On atolls where soil was poor or absent and rainfall often low, Islanders created an ingeniously productive and sustainable agricultural environment for the giant swamp taro (*Cyrtosperma chamissonis*) by excavating a pit to reach the water table ("the freshwater lens") below the coral rubble and building up fertile soil in the pit by composting leaves of breadfruit and several other wild or semidomesticated trees as well as seaweed, pumice, and other materials.

The management of wet and dry conditions by irrigation and drainage was widespread and ranged from very simple ponds and small ditches to elaborate, kilometer-long, stone-lined channels and extensive hillside terracing. Irrigation and drainage were not necessarily spatially exclusive in that the ditches that drained water away from sweet potato beds were used to provide a moist growing site for taro and other water-loving crops. Water control may also have been used to control insect pests. As population densities increased or as political control expanded enabling greater labor mobilization, some systems of wet cultivation of taro in Polynesia became very intensive, productive of yields as high as from 30 to 60 metric tons per hectare.

The agricultural tool kit of the traditional Pacific was simple, mostly derived from unprocessed natural materials: wood, plant fiber, stone, shell, and bone. Wooden spades were elaborated in places where tillage and swamp cultivation was common. Wooden hoes were made here and there but were rare. The paramount agricultural tool was the digging stick. Used for loosening soil, digging roots and corms, making holes for planting and house posts, or as poles for carrying burdens, digging sticks ranged in size from heavy, 2-m, two-man tools used cooperatively to turn grassland or swampland sod to the light sticks used by girls to open shallow holes in soft forest soil. They remain widely in use today, and modern technology has yet to find a better tool for planting taro.

Before being replaced by steel tools, stone adzes and axes were effective in opening vast areas of forest and were far more sophisticated than they might seem at first glance. For instance, the cutting edges of stone axes might be facetted and asymmetrical to make resharpening more effective and to prevent the blade sticking in the tree during felling. Wooden spades and the way they were handled had similarly subtle attributes.

Organization of agricultural labor varied across the Pacific, with, for example, men doing the clearing but women most of the gardening in Melanesia, whereas in Tonga and Samoa in Polynesia men carried out all the agricultural tasks. Traditional Pacific livestock comprised the pig and chicken. Pigs were of great importance ritually and socially in many places and were a way to "bank" the food produced in tuberous starchy vegetables, which did not store well. During the periods when pigs were being accumulated for ceremonial feasts, considerable land and agricultural labor would be devoted to producing their food.

Like all traditional agriculturalists, Pacific Islanders possessed an enormous store of knowledge about both the domesticated and the wild plants and animals in their environment. This indigenous knowledge was organized by means of complex folk taxonomies that provided a framework for pleasurable intellectual activity as well as serving practical purposes. Similarly, aesthetics was a part of Pacific Island science of agriculture and land use management. Pacific people in traditional landscapes enjoyed the arrangement of productive diversity all around. Medicine here, perfume there, fiber in the hibiscus stem, fruit, timber, edible leaves, and so forth. There is a strong aesthetic pleasure in these observations of utilitarian diversity. As Malinowski (1935) wrote about the Trobriand gardens he made famous in Papua New Guinea:

> The gardens are, in a way, a work of art. Exactly as a native will take an artist's delight in constructing a canoe or a house, perfect in shape, decoration and finish, and the whole community will glory in such an achievement, exactly thus will he go about the laying out and developing of his garden. He and his kinsmen and his fellow-villagers as well, will be proud of his labours... During all the successive stages of the work, visits are exchanged and mutual admiration and appreciation of the aesthetic qualities of the gardens are a constant feature of village life.

In the Pacific, as elsewhere, the complexity of traditional agriculture has undergone a simplification in modern times. Polycultural gardens of subsistence crops have been replaced by monocultural stands of commercial crops such as coconuts, ginger, coffee, and citrus. Intensive systems of irrigated taro or dryland yam cultivation have fallen out of use, often replaced by the less demanding cassava (manioc). On the other hand, with the current interest in locally based sustainable development, there is a growing concern to revive some of the indigenous traditional systems that served Pacific Islanders well in their past.

See Also

▶ Agroforestry in the Pacific Islands

References

Barrau, J. (1958). *Subsistence agriculture in Melanesia* (Bernice P. Bishop Museum bulletin, Vol. 219). Honolulu, HI: Bernice P. Bishop Museum.

Barrau, J. (1961). *Subsistence agriculture in Polynesia and Micronesia* (Bernice P. Bishop Museum bulletin, Vol. 223). Honolulu, HI: Bernice P. Bishop Museum.

Bellwood, P. (1978). *Man's conquest of the Pacific: The prehistory of Southeast Asia and Oceania*. Auckland, New Zealand: Collins.

Kirch, P. V. (1985). *Feathered Gods and fishhooks: An introduction to Hawaiian archaeology and prehistory*. Honolulu, HI: University of Hawaii Press.

Kirch, P. V. (1991). Polynesian agricultural systems. In P. A. Cox & S. A. Banack (Eds.), *Islands, plants, and Polynesians: An introduction to Polynesian ethnobotany* (pp. 113–133). Portland, OR: Dioscorides Press.

Klee, G. A. (1980). Oceania. In G. A. Klee (Ed.), *World systems of traditional resource management* (pp. 245–281). London: Edward Arnold.

Malinowski, B. (1935). *Coral gardens and their magic* (2 vols.). London: George Allen and Unwin.

Myllyntaus, T., Hares, M., & Kunnas, J. (2002). Sustainability in danger? Slash-and-burn cultivation in nineteenth-century Finland and twentieth-century Southeast Asia. *Environmental History, 7*, 267–302.

Oliver, D. (1989). *Oceania: The native cultures of Australia and the Pacific Islands* (2 vols.). Honolulu: University of Hawaii Press.

Yen, D. E. (1991). Polynesian cultigens and cultivars: The question of origin. In P. A. Cox & S. A. Banack (Eds.), *Islands, plants, and Polynesians: An introduction to Polynesian ethnobotany* (pp. 67–95). Portland, OR: Dioscorides Press.

Yen, D. E., & Mummery, J. M. J. (Eds.). (1990). *Pacific production systems: Approaches to economic prehistory*. Canberra, Australia: Department of Prehistory, Research School of Pacific Studies, The Australian National University.

Agriculture of the Ancient Maya

Timothy Paul Beach
Washington, DC, USA

The Maya are a diverse group of Native Americans, who speak 31 languages within the

Mayan Language Family. They live in Southern Mesoamerica, in Mexico from Chiapas through Yucatan and south through Guatemala in the Peten lowlands and mountainous highlands and into Belize, Honduras, and El Salvador. Settlements started as early as 2,000 BCE along the mangrove coastal margins of the Pacific, but most settlements started after about 1200 BCE, with identifiable ceramics, and lasted through the Pre-Classic 1200 BCE to BCE 250 and the Classic Period from (BCE 250) to (BCE 850). Declines or transitions punctuated their history at the end of the Pre-Classic, perhaps in the Middle Classic, (BCE 500), the sharp decline often called the Maya "Collapse" in ninth century (BCE), and the population collapse due to the diffusion of European diseases and conquests starting in the sixteenth century. All but the last of these major transitions are regional, and the most famous is the Terminal Classic Collapse of the ninth century (BCE), which occurred in the central lowlands of Guatemala's Peten state and adjacent Belize, Honduras, and Mexico's Chiapas and southern Yucatan. Much of the writing about the Maya, including about its agriculture and environment, focuses on this Terminal Collapse and the Late Classic period (BCE 550–850) that preceded it though more and more publications are dealing with both the pre and post classic periods. The terminal classic in the central Lowlands represents an end to this intensive urban and agricultural civilization's great achievements in building, writing, art, astronomy, and agriculture, and the relatively quick return of tropical forests that enveloped the temples and terraces that had functioned for centuries.

The Maya World has two main geographic divisions: volcanic highlands and limestone lowlands. The highlands center on a series of north-south running and variably active volcanoes along the Pacific Coast side, which abut a complicated series of metamorphic and sedimentary rocks to their east. The Maya farmed these slopes and river valleys from Chiapas, Mexico into Guatemala, Honduras, and El Salvador. These uplands generally have deep and fertile soils, though rainshadow driven dryness, steep slopes, some poor soils, and seismic volcanic events have limited subsistence in different places at different times. The lowlands mainly refer to the limestone Yucatan platform ranging from Mexico, through Guatemala, to Honduras. Within this division are the karst plains of the northern Yucatan with no rivers but sinkholes, the faulted, karstic central and southern Yucatan, the more complicated geology to the south (including the granitic Maya Mountains); and the surrounding coastal zones with rivers and more coastal resources.

Climate also varies significantly across this region, from the semi-arid northwest Yucatan with about 500 mm of annual rainfall to the high elevations of the Maya Mountains that receive almost ten times more rainfall. Generally, the lowlands receive about 1,000–2,000 mm of rainfall and most of the region does have a distinct dry season from December to May that must be figured into every agricultural practice and adaptation in the region. These general regions all provide different potential resources and limitations for agriculture. One limitation for the whole region was recurring drought that corresponds to cultural declines especially with the Terminal Classic Collapse (Hodell, Brenner, & Curtis, 2000).

Research into Maya agriculture is long and rich. The start of agriculture in the Maya World comes from the earliest evidence of maize in the floodplains of coastal Veracruz by about 7,000 BP and evidence from starch grains for root crops in nearby Panama comes about the same time (Piperno, Ranere, Holst, & Hansell, 2000). This beginning of Mesoamerica's great triumvirate of staple crops – maize, bean, and squash – comes with the spread of extensive ► swidden or *milpa* farming and perhaps floodplain farming. This shows up in the Maya Heartland of Guatemala's Peten and nearby Belize from about 5,000 to 4,000 BP as increased charcoal and pollen from the weeds that usually accompany agriculture. Pollen from maize and manioc actually show up before 5,000 BP in Belize (Jones, 1994; Pohl, Pope, Jones, Jacob, Piperno et al., 1996).

In the early twentieth century, scholars viewed swidden agriculture as the means for how the ancient Maya fed themselves because many had observed *milpa* farming across the region and studies showed that it provided a level of subsistence needed for the dispersed populations of a tropical forest civilization. In the 1960s, though, many scholars came to see the *milpa* as insufficient to feed the growing estimates of ancient Maya populations. Many regional surveys started showing more and more large-scale Maya sites that must have had high populations, and studies for decades had reported evidence for intensive forms of agriculture, including extensive, well-made terraces.

The agricultural staples of the Maya worlds were of course maize, beans, and squash, though there were a host of other possible and known crops like cassava, sunflower, amaranth, and many other fruits and vegetables, whether cultivated or collected. There were also sources of meat from turkeys, ducks, doves, deer, fish, and other animals, though what role they played in Maya agriculture and what proportion of Maya diets they made up is still not well known. Cacao was certainly an important commodity grown in different environments over much of the Maya Lowlands. Since we know from documents and archaeological evidence that the Maya and other Mesoamerican peoples highly prized cacao, scholars have tried to identify cacao in many possible ways: by noting the requirements of the crop, using ethnohistorical information, and looking for pollen and other fossil evidence. Tobacco, cotton, palms, and many others were nonsubsistence crops. This cornucopia of known foods has also fueled discussion of other possible staples to feed large populations and solve the riddle of Maya subsistence (Dahlin et al., 2006). Scholars have found evidence for use of many other crops like agave and many arboreal ones like ramon or breadnut (Gomez-Pompa, Salvador Flores, & Aliphat Fernandez, 1990).

Forms of Agriculture

We should note that we still know little about the agriculture of the ancient Maya, but many traditional and novel techniques are turning up more evidence with each field season (Beach, Luzzadder-Beach, & Dunning, 2006b). Traditional research tools are still the backbone of research and include regional survey, sampling, mapping, and archaeological excavation. Adding to these methods have been an array of steadily improving geophysical, chemical, and biological methods. Each of these methods are whole subjects in themselves but we should not divorce a discussion of the methods from the findings, because techniques change and may make findings obsolete. For example, remote-sensing technologies have added to our breadth of knowledge, but some radar images have produced false-positive identifications for vast wetland agriculture in areas that are not even wetlands.

We can divide ancient Maya Lowlands agriculture into upland and lowland forms and outfield and infield forms. Upland agriculture occurred on well-drained and seasonally drained soils and lowland farms had to contend with seasonally or perennially high water tables. Outfields simply refer to fields at some distance from Maya sites and infields were agricultural areas within or adjacent to sites and thus more likely the focus of intensification techniques.

One type of infield in Maya societies is kitchen gardens or solares, which is still a common feature of traditional and indigenous communities. These, like similar farming systems around the world, are intensive, high input, close-to-home adaptations for growing crops. Kitchen gardens often use polycultural methods that grow as much on small areas as possible by arranging crops at different levels or canopies. Ethnohistorical studies have found that polycultural gardens produce about 11 % of domestic caloric intake and few bulk staples, focusing more on dietary supplements, medicinals, ornamentals, and ritual objects. Archaeological evidence such as the size of walled areas around mounds may however, suggests greater pre-Hispanic contributions from kitchen gardens at certain periods (Beach et al., 2006b).

In uplands, milpa, or slash and burn farming, is the mainstay of nonintensive agriculture. A milpa is small farm that *milperos* slash and burn usually toward the end of dry season (from December to May). *Milperos* slash the tropical forest vegetation today with metal machetes (or more mechanized implements) but had to use stone tools in antiquity. They would slash vegetation, including girdling trees to make the vegetation dry enough to burn, and thus produce enough wood ash to enrich and prepare the seed bed for planting. They would usually plant multiple crops (e.g., corn, beans, squash, and chilies) in each milpa and indeed prepare more than one milpa every year to insure against the vicissitudes of climate (e.g., drought and hurricanes) and pests in these seasonally dry tropics. Each milpa might remain productive for 2 or 3 years and then weed competition and nutrient depletion would drive farmers along to new areas to slash and burn. Farmers might return to the old milpas after fallows of 10 or more years and restart the process. Although this is extensive agriculture, farmers might intensify this by shortening the fallow time, but this requires more labor for weeding and fertilizing (Beach et al., 2006b).

Upland agriculture occurred along slopes of varying degrees and, for any semblance of long-term sustainability, required conservation techniques to limit soil erosion in the Maya Lowlands, where the limestone soils were already thin, and in the Highlands, where slopes are much steeper and longer. We have substantial evidence that soil erosion, in lake sedimentation and buried depression soils, started early, by about 3,000 BP, in the Maya Lowlands. Rates of erosion only rise when major drivers of erosion occur and the main evidence for such drivers is the coincidence of weed and crop pollen, charcoal, and mineral sediments. These link deforestation and Maya farming together with increased runoff, caused by some combination of decreased transpiration and infiltration into soils. The increased erosion may have also coincided with another erosion driver, namely moving deforestation onto steeper slopes, where gravity can act to accelerate overland flow and all major types of water erosion. Modern evidence in this region shows that erosion rates are very high after deforestation and soils erode to bedrock surprisingly fast. Some scholars have even linked soil erosion with the Terminal Maya Collapse (Beach, Dunning, Luzzadder-Beach, Lohse, & Cook, 2006a).

Ancient Maya farmers, like early farmers everywhere, had to adjust their early pioneering experience. They had several options that all required more labor inputs: conservation techniques on slopes or management of flat or depression environments. The least laborious options would have been to farm flat areas, but there were too few flat areas that were not seasonally waterlogged around the settlement-carpeted limestone, karstic ridges of much of the central Maya Lowlands.

Upland Agriculture and Terrace Systems

In many places around the Maya Lowlands are large tracts of terraced lands. Indeed, travelers have mentioned terraces since at least the early twentieth century, and they have since identified many types of terraces that take advantage of specific slope situations. Terrace systems are intensive forms of agriculture that attempt to engineer slopes to make them sustainable. Indigenous terrace systems, starting more than 5,000 years ago, are nearly a universal human adaptation to farming on steep slopes, with several ancient terrace systems such as those in the Philippines, recognized as UNESCO World Heritage Sites. The factors that make steep slopes unsustainable are thin soils that cannot store enough water or nutrients and extremes of water: either too much destructive overland flow or too little to support crop needs during the dry season. Thus for terracing to be worth the heavy labor efforts, farmers must build up soils, minimize the impacts of overland flow, and maximize soil moisture for the growing season. Terrace systems also must return nutrients harvested in crops to maintain crop yields over time. Studies have thus attempted to find evidence for soil depletion coinciding with the Terminal Classic Collapse as well as find evidence for terrace soil maintenance from night soil, composted waste, and wetland organic matter (Turner, 1974; Beach, Luzzadder-Beach, Dunning, Hageman, & Lohse, 2002).

Terraces must function to slow the destructive force of overland flow, divert water away or to soils, help drain excess water, and dam up soils and potential fertility. There are surprisingly common terrace remnants left in the Peten after more than a thousand years and most tend to be engineered from limestone boulder dams, though some are earthen and some might have been vegetative hedges as well, which have left no obvious traces. The terrace dams were either single rows of large boulders or double rows of boulders with gravel, cobble, and ceramic fills. They often had gravel bases and cobble buttresses and some still testify to pre-Maya times with soils buried below the terrace dams and below soil sequences that filled in behind the dams unintentionally or by active human manipulation. Terraces occur in many slope positions: contoured around slopes, across channels, as boxes with little slope, around crests, and prominently at the base of slopes. Some landscapes have all types; others only have one. Since each has a different slope position, each creates a different microenvironment with different soil moisture conditions and aspects or orientations to the sun. In most cases a large part of the terrace system has eroded away, and, thus, our real evidence for an agricultural landscape integrated with diversion cannels is often only theoretical.

All of the terrace types are common, though box terraces are much smaller and more easily expunged by tree roots and slope wash. Some scholars have linked these systems with intensive nursery crops that could be replanted at some point in their lifecycle. Footslope terraces show up in many places because they are usually constructed of larger boulders that persist through time. These may have functioned to build up some areas above water tables in large, low elevation seasonal wetlands. Hence, we think the base of slopes that often ring depressions was an important focus of agriculture, where soil depth, fertility, and moisture could have been managed to lengthen the growing season. Likewise, upland sinkholes, called *aguadas* or *rejolladas*, could also have been a focus for agriculture because soil depths, fertility, and moisture could have been managed to lengthen growing seasons.

Some evidence exists for early terrace adoption, perhaps by 2600 BP, though most evidence of terracing coincides with the other large-scale building of the Late Classic period. Many sites in the Maya world, such as Caracol, La Milpa, the Rio Bec, Xunantunich, and the Petexbatun, had widespread terracing by the Late Classic period, though other notable sites like Copan and the Central Peten lakes region provide only meager evidence (Beach et al., 2002, 2006a, 2006b; Beach & Dunning, 1995).

Another form of upland soil management is field ridging, which looks like plowed furrows but required significantly more labor in Maya societies where beasts of burden were not available. Field ridging has been reported in many parts of Mesoamerica, but the most significant are the preserved fossil ridges in the ash covered, Maya Pompeii site of Ceren, El Salvador, which blankets a Classic Maya village from ca. BCE 650. The low ridges formed the seedbeds, and maximum air and water drainage could occur in the furrows. At Ceren, only one of eight excavated fields was in fallow, probably indicating much more intensive farming on these fertile, volcanic soils than could be possible in lowlands milpas that required years of fallow or heavy fertilizing and weeding (Beach et al., 2006a, 2006b).

Lowland Intensive Agriculture

Lowland agriculture takes advantage of low sites where erosion is not significant, but water management is necessary to provide enough water in dry sites and enough root aeration in wet sites. These areas do not suffer from much erosion but all agricultural lands must still be fertilized for intensive long-term cropping.

One particular Maya region provides an interesting case study: the northwest Yucatan site of Chunchucmil. Here the soils are thin or nonexistent and the rainfall is spotty and low; yet this Maya site had many thousands of inhabitants around BCE 400–600, where today a few hundreds have trouble growing enough food. Milpa farming today produces only a small fraction of food requirements, but somehow high populations occupied this region ca. 1,500 years ago. Thus, either they imported food based on some other trade commodity or they used some extremely intensive systems. One line of evidence lies in the numerous polygonal wall systems around habitation mounds and surrounding empty lands. The walls only tell us that groups were trying keep predators or people out, and scholars are looking for every line of evidence about manufacturing and markets that might have functioned to provide trade goods for food from elsewhere. But these may also have been intensive kitchen gardens with traditional or special crops that were heavily fertilized with all possible wastes the site and organic matter from nearby wetlands. Modern farmers do enhance their solares this way, and we can balance subsistence for large ancient populations by maximizing infield, arboriculture, and surrounding outfield production (Dahlin et al., 2006).

Another type of agriculture that occupies the middle ground between uplands and lowlands is *bajo* or karst-depression agriculture (Beach et al., 2002; Dunning et al., 2002). This ranges from cropping that occupies the backslopes of small sinkholes of a hectare or less called *aguadas* or *rejolladas* to cropping into and around large seasonal sinks called *bajos* that are sometimes many square kilometers. Pollen of maize, cassava, and other crops in bajo sediments shows evidence of nearby agriculture, and excavation of surrounding terrace berms may show soil and water management in these "ecotonal" zones, i.e., regions that straddle two ecosystems.

Agriculture in these bajos was similar to agriculture in seasonally flooding valleys. In these environments, farmers had to manage water extremes, flooding in the wet season and insufficient soil moisture in the dry season. One globally widespread adaptation to such environments is a risky but productive technique called flood recessional agriculture. Farmers using this technique plant into the wet soils of receding floods to take advantage of plenty of soil moisture that might get a crop through the dry season. As does all farming to varying degrees, this plays the probabilities of potential drought and enough seed-corn to persist through recurrent floods. Farmers could also more actively manage soil moisture by ditching, draining, and damming.

Another option for intensive farming was manipulating perennial wetlands (Duzzader-Beach & Beach, 2006). All over the Maya Lowlands perennial wetlands bear witness to a wide diversity of rectilinear features that look like cobwebs or other polygonal patterns from the air. Early on scholars suggested that these may be relicts of ancient Maya intensive wetland cultivation because the patterns look similar to the historical Mexica wetland plots or *chinampas* around the Basin of Mexico, which, like the terraces of the Aztec Realm, were highly productive systems. These *chinampas* are still very much working plots in Xochimilco on the outskirts of Mexico City, though today they are more for flowers and tourists than subsistence.

Farming wetland fields requires using plants that can grow in saturated soils or manipulating the soils and water table. Indeed, one explanation for the polygonal field patterns is that they are simply ditches to drain the fields and lower the water table below the root zone of typical crops. Thus such drained fields could function as long as there was a lower part of the landscape where water could be drained. A more elaborate model is a raised field, in which the ditches are built and the excavated soils and organic matter are used to build up and fertilize the soil plots. In both models, canals can be occasionally cleaned out and used to renew fields. In the Aztec fields, alder and willow trees were planted around the field edges to protect the sides from slumping and erosion (Armillas, 1971). An even more elaborate model envisions a complex of farming and aquaculture akin to the productive but laborious Chinese rice paddy, aquaculture systems.

There are also more natural explanations for the polygonal wetland patterns. These range from human ditching in response to sea level rise and ground water rise to differential expansion patterns caused by a landscape building up from gypsum precipitating from saturated ground and surface waters. The first explanation sees wetland ditching as a Pre-Classic agricultural adaptation to wetland formation, though in the broader region other research teams saw the same patterns as evidence of Late Classic intensive cultivation with copious evidence for maize. The differential heave explanation does not discount the possibility of human modification of polygonal field patterns but argues for a landscape co-evolving from human and natural factors.

Another hypothetical use of wetlands for agriculture comes from the rock alignments of northeastern Yucatan. Perhaps these rock-aligned wetlands were used to raise algae or periphyton, which are cyanobacteria communities that have fertilizer and pesticide characteristics. Or, perhaps these were dryland plots created before sea level rise made these wetlands. In either case, Maya scholars have attempted to use every line of evidence and push the limits of science to come up with explanations for Maya subsistence. Sometimes they have pushed too far and too fast, but it was usually tin the spirit of seeking out explanations for the profound and vexing riddles of the past.

Debates about all forms of ancient agriculture underscore the difficulty of understanding ancient subsistence. We only have the lines of evidence and no historical accounts. Thus, we have vast terrace systems, walled fields, ridged fields, and numerous wetland polygons that coincide with millions of house mounds and massive buildings from especially the Late Classic. We have evidence of buried soils, elevated chemicals, fossil seeds, pollen, and other proxies of the past.

Since there are many types of intensive and extensive agriculture from around the Maya realm, many Maya scholars think the ancient Maya used heterogeneous types of farming, adapted for the different landscapes, soils, and climates of the region. Many Maya sites are on ecotones, such as at bajo edges and ridges that lie between two and more environments. Around the sites, evidence for many agricultural adaptations often occur. This makes us guess that, where possible, ancient Maya farmers tried to do with intensive systems what contemporary, traditional Maya farmers do in milpas: minimize risk by taking advantage of a diversity of sites. What is different about ancient Maya farming, however, are the many kinds of intensive agricultural systems with their extremely high labor demands.

See Also

▶ Ceramics: Maya Pottery
▶ Swidden

References

Armillas, P. (1971). Gardens on swamps. *Science, 174*, 653–661.

Beach, T., & Dunning, N. P. (1995). Ancient Maya terracing and modern conservation in the Petén rain forest of Guatemala. *Journal of Soil and Water Conservation, 50*, 138–145.

Beach, T., Luzzadder-Beach, S., Dunning, N., Hageman, J., & Lohse, J. (2002). Upland agriculture in the Maya lowlands: Ancient conservation in Northwestern Belize. *The Geographical Review, 92*(3), 372–397.

Beach, T., Dunning, N., Luzzadder-Beach, S., Lohse, J., & Cook, D. (2006a). Ancient Maya impacts on soils and soil erosion. *Catena, 66*(2), 166–178.

Beach, T., Luzzadder-Beach, S., & Dunning, N. (2006b). A soils history of Mesoamerica and the Caribbean Island. In J. R. McNeill & V. Winiwarter (Eds.), *Soils and societies: Perspectives from environmental history* (pp. 51–90). Isle of Harris, UK: The White Horse Press.

Dahlin, B. H., Beach, T., Luzzadder-Beach, S., Hixson, D., Hutson, S., Magnoni, A., et al. (2005). Reconstructing agricultural self-sufficiency at Chunchucmil, Yucatan, Mexico. *Ancient Mesoamerica, 16*, 229–247.

Dunning, N., Luzzadder-Beach, S., Beach, T., Jones, J. G., Scarborough, V., & Culbert, T. (2002). Arising from the Bajos: The evolution of a neotropical landscape and the rise of Maya civilization. *Annals of the Association of American Geographers, 92*(2), 267–283.

Gomez-Pompa, A., Salvador Flores, J., & Aliphat Fernandez, M. (1990). The sacred cacao groves of the Maya. *Latin American Antiquity, 1*, 247–257.

Hodell, D., Brenner, M., & Curtis, J. (2000). Climate change in the North American tropics and subtropics since the last ice age: Implications for environment and culture. In D. Lentz (Ed.), *Imperfect balance: Landscape transformations in the Precolumbian Americas* (pp. 13–38). New York: Columbia University Press.

Jones, J. G. (1994). Pollen evidence for early settlement and agriculture in Northern Belize. *Palynology, 18*, 205–211.

Luzzadder-Beach, S., & Beach, T. (2006). Wetlands as the intersection of soils, water, and indigenous human society: In the Americas. In J. R. McNeill & V. Winiwarter (Eds.), *Soils and societies: Perspectives from environmental history* (pp. 91–117). Isle of Harris, UK: White Horse Press.

Piperno, D. R., Ranere, A. J., Holst, I., & Hansell, P. (2000). Starch grains reveal early root crop horticulture in the Panamanian tropical forest. *Nature, 407*, 894–897.

Pohl, M. D., Pope, K. O., Jones, J. G., Jacob, J. S., Piperno, D. R., deFrance, S. D., et al. (1996). Early agriculture in the Maya lowlands. *Latin American Antiquity, 74*(4), 355–372.

Turner, B. L., II. (1974). Prehistoric intensive agriculture in the Mayan lowlands. *Science, 185*(4146), 118–124.

Agriculture: Ancient Methods

Alexia Smith

Today very few communities subsist upon hunting and gathering, with the majority of the world's population living a sedentary life dependant upon agriculture. The shift from gathering wild plants and hunting wild animals to dependence upon crop production and animal herding took place independently in different parts of the world at different times. The earliest development of agriculture is widely thought to have occurred around 12,000 years ago in the Fertile Crescent of Southwest Asia. The Fertile Crescent forms an arc leading up the Levant from the Negev Desert of Israel to southeastern Turkey, turns east along the Taurus-Zagros mountain chain, and then south between the Tigris and Euphrates rivers down to the Persian Gulf. Independent development of agriculture occurred later in South and North China, Central America, South Central Andes, the Eastern United States, sub-Saharan Africa, and perhaps Papua New Guinea.

Food Production Terminology

The ways in which societies throughout the world have organized food production varies greatly through time, and the terminology used to discuss early agriculture underscores the diversity of methods that can be used to produce or acquire food. In its widest sense, agriculture refers to the cultivation of crops and the rearing of animals. Animal husbandry refers to general animal rearing, whereas pastoralism describes a socioeconomic specialization in production where animal rearing forms the primary economic endeavor of a community. The methods of production can vary widely, including nomadic pastoralism, which involves permanent migration and seasonal transhumance – where animals are moved periodically from a home base to pasture land. The term cultivation describes the preparation of land and tending of crops, which can include large- or small-scale crop production and slash-and-burn agriculture. Horticulture relates specifically to the production of fruits, vegetables, and flowers, and in preindustrialized societies was usually garden-based. Domestication is more difficult to define and there is no universally agreed upon definition. In general, however, domestication refers to the selection of desirable traits in plants and animals that leads to the genetic modification of a species, and reduces its ability to reproduce without intervention by people. Desirable traits may include reduced aggression in animals, allowing them to be controlled more easily, or ease of harvest and greater yields in plants. It is possible, therefore, to cultivate wild plants with domestication occurring only when selection processes affect natural reproduction mechanisms.

Evidence for Ancient Agriculture

Throughout the world, writing or notation systems developed well after the beginnings of agriculture, so there are no texts documenting the transition and our knowledge is based entirely on archaeological observations of plant and animal remains, changes in settlement size and patterns, storage facilities, and tools. Zooarchaeology examines ancient interaction with animals. The species, age, and sex of animal bones retrieved from archaeological sediments can be determined by reference to modern comparative skeletal material, and this information can be used to examine herding and hunting strategies. Paleoethnobotany or archaeobotany examines plant use in the past. Plant remains are preserved on archaeological sites predominantly through charring, an accidental process that renders them inert to bacterial or fungal decay; less frequently plant remains become preserved through waterlogging, desiccation, freezing, proximity to toxic metals, or indirectly by leaving an impression in ceramic vessels. Excellent preservation conditions are provided under waterlogged and desiccated conditions, although such finds are in the minority and are generally restricted to lakes and coastal margins or deserts. Charred remains are retrieved using flotation, whereby an archaeological sediment sample is placed in a large container of water and, following gentle agitation, the plant remains float to the surface where they can be collected. The remains are identified based on morphological similarity to modern reference material, and knowledge of crop and weed assemblages can be used to investigate a number of topics including crop domestication and methods of crop production, harvesting, and processing. Until recently, most paleoethnobotanical research had focused upon identifying cereal, legume, fruit, and weed seeds in the archaeological record but now, following pioneering work by Hather, increasing emphasis is being placed upon identifying tubers and investigating the role that vegetables played in the ancient diet. Such research is in its infancy, however, so the importance of horticulture in antiquity is likely underestimated.

Theories Explaining the Origins of Agriculture

A number of theories have been proposed to explain the origins of agriculture. Since farming was developed independently in different locations, the motives likely vary reflecting local social, cultural, environmental, and climatic factors. In Southwest Asia, the change occurred during a period of climatic amelioration after the Younger Dyras, a cold period marking the end of the Pleistocene and the beginning of the Holocene. Building upon work by Raphael Pumpelly, V. Gordon Childe argued in the 1930s that climatic deterioration forced people to concentrate within small oases and that these new conditions would have stimulated cultivation. His “Oasis” or “Propinquity” theory is not supported by paleoclimatic data, does not adequately explain the changes, and furthermore is viewed as too environmentally deterministic. To its credit, however, the theory stimulated much research on the origins of agriculture. In the 1960s and 1970s, Binford, Cohen, and Hassan put a number of related “Push” models forward. They argued that population growth or climatic change disrupted the food balance and provided the necessary incentive to begin cultivating crops. These models have also been criticized for being oversimplistic and monocausal as well as deterministic. Flannery expanded upon Binford’s ideas and proposed a “Broad Spectrum Revolution”. Citing data from Southwest Asia and Mesoamerica, Flannery argues that prior to the dependence upon agriculture, people greatly widened the range of plant and animals exploited, and developed new tool types, different methods of storage, and gained familiarity with other food resources. These changes created the necessary preadaptations for cultivation, which he argued most likely occurred in marginal areas on the fringe of production, where wild resources were less abundant. The Broad Spectrum model is largely supported by both plant and animal data from Southwest Asia. Recent research at Ohalo II, a waterlogged site off the coast of the Sea of Galilee where preservation conditions are excellent, has underscored the importance of wild cereal collection by preagricultural groups approximately 23,000 years ago, well before the beginning of farming. Lastly, following critiques of the use of external factors and system analogies to explain change in the past, a number of social or “Pull” theories have been sought to explain the origins of agriculture. Bender and Hayden argue that domestication took place in resource-rich areas and that the ready availability of large amounts of specialty food may have led to social changes within preagricultural societies, placing greater emphasis on competitive feasting. This, in turn, would have elevated the demand for resources, acting as a precursor for cultivation and later animal herding.

The Rise and Development of Agriculture in Southwest Asia

The first domesticated crops in Southwest Asia include cereals (emmer wheat, *Triticum dicoccum* Schübl.; einkorn wheat, *T. monococcum* L.; and two-row hulled barley, Hordeum *vulgare* subsp. *distichum* (L.) Thell.), leguminous crops (lentil, *Lens culinaris* Medik.; pea, *Pisum sativum* L.; chickpea, Cicer arietinum L.; bitter vetch, Vicia ervilia (L.) Willd.), and flax (*Linum usitatissimum* L.), which together form the "founder crops" of Neolithic agriculture. Early farmers selected cereals with plumper, larger grains and ears that did not shatter easily, leading to greater yields and enhanced efficiency of harvesting. Transitional forms of domesticated plants and animals and their wild predecessors can be difficult to identify from the archaeological remains, but the available evidence suggests that the process took place quickly over several centuries.

Animal domesticates include sheep (*Ovis aries*), goat (*Capra hircus*), pig (*Sus scrofa*), and cattle (*Bos taurus*), each of which were ecologically and behaviorally suited to domestication due to their general diets, ability to breed in close conditions, social nature, and dominance hierarchy. Due to the selection of more docile animals, domesticated fauna tend to be smaller than their wild predecessors. The domestication of each species took place in different locations throughout Southwest Asia after communities had become sedentary and begun cultivating crops. Later a wide range of specialized pastoral practices was developed.

The adoption of agriculture in Southwest Asia was termed the "Agricultural Revolution" or the "Neolithic Revolution" by V. Gordon Childe, and it was truly revolutionary since it marked a drastic shift in the way people obtained food, placing greater emphasis on using land for production. It also involved the need to maintain and protect seed stores for the following year as well as ensure that animals were kept alive and well until they were deemed fit for slaughter. Intensive cultivation is associated with increased sedentism, which provides different opportunities for building social relationships and spacing births. Furthermore, with the accumulation of surplus crops, differential wealth could be accumulated, enabling parts of the population to be freed from farm labor. This in turn allowed for the development of institutionalized craft specialization and, some time later, the rise of urbanized state-level societies with social hierarchies, bureaucratic and administrative systems, long distance trade, monumental and public architecture, and some form of writing or record keeping.

The Construction of Cities and the Secondary Products Revolution

The first urban centers arose in Mesopotamia, the land between the Tigris and the Euphrates in modern-day Iraq around 5,500 years ago. Shortly later, urban centers developed in Egypt. Both developed along river courses and the use of irrigation to enhance crop yields is thought to have been instrumental in the rise of these city-states. Ancient irrigation canals dating between ca. 5,500 and 5,000 years ago have been located in Mesopotamia. The construction of earthen structures to control the natural flooding of the Nile banks in Egypt likely played a similar role. Concomitant with the development of cities in Mesopotamia and Egypt, an agro-economic shift took place in between these regions in the Levant, perhaps stimulated by enhanced trade with adjacent regions. The Mediterranean economy, including cultivation of cereals and legumes, viticulture and olive production, and herding of sheep and goats, together with use of animal drawn ploughs became widely established for the first time. Sherratt refers to these changes in agricultural production as the "Secondary Products Revolution," which placed greater emphasis on the use of animals for traction and for secondary products such as milk, blood, wool, and dung. Most early ploughs would have been constructed from wood, but because of their perishable nature, they do not readily preserve intact in the archaeological record. The earliest depictions of a plough, which likely postdate its invention, come from cylinder seals from Mesopotamia, dating to approximately 4,300 years ago, and terracotta figurines of yoke-bearing oxen from the Greek site of Tsoungiza dating to the Early Bronze Age. The ard, which scratches the surface of the land was developed first, with mould-board ploughs that turn soil and create furrows being developed much later. Prior to the invention of the plough, fields would have been prepared by hand, so the shift allowed larger tracts of land to be cultivated. This effect was intensified during the Iron Age, beginning around 3,200 years ago, with the manufacture of iron agricultural tools, rather than flint and bone sickles or wooden ards.

The exploitation of animals for milk and wool in Southwest Asia is reflected in animal bones that document the preferential culling of young males and the tending of a larger number of female animals to an older age. In order to release milk freely to people, lactating animals need to be separated from their young and become accustomed to being milked by hand, so initial attempts at milking were likely a perilous endeavor.

Zeder and McCorriston argue that the raising of sheep for wool fiber greatly modified the agroeconomics of Southwest Asia, and led to a reduced reliance upon flax fibers; the local importance of wool as a commodity in northern Syria allowed urban centers that controlled its production to prosper. Concomitant with the rise of urban societies, the need for a recording system developed in order to log economic transactions. The invention of writing provides an additional window into agricultural production in antiquity. Clay tablets from Uruk in modern-day Iraq, dating to ca. 4,400 years ago, provide the earliest evidence of writing in the world with initial documents being used to list commodities. An extensive archive of cuneiform tablets was found at the site of Ebla in Syria, approximately 60 km south of Aleppo. These texts, dating to between 4,400 and 4,350 years ago, represent the earliest written reference to olive and grape production, although archaeological evidence of the plant remains predates the texts by almost a millennium. Since textual accounts and archaeological data provide different insights into past societies, this example demonstrates how the two records can be used to complement one another. Other cuneiform texts include the "Farmer's Instructions" from Mesopotamia dating to ca. 3,800–3,600 years ago. Civil has interpreted the text to be a Sumerian agricultural manual which outlines instructions from an old man to his son on how to prepare a field for irrigation; how and when to harrow, plough, sow seeds, inspect, harvest, thresh, and winnow the crop; maintain tools; as well as describing a desirable work ethic. It is likely that the text was used to teach scribes how to write Sumerian, since the content of the text would have been familiar to many.

Early Agriculture Outside of Southwest Asia

Following the development of agriculture in Southwest Asia, farming began to be practiced in Turkey and then Greece, followed by the rest of Europe. Models of this spread are debated, with some arguing for movements of people and other arguing for a transfer of ideas and new technology. New evidence based on plant data suggests that a complex mix of both was involved. Based on radiocarbon-dated finds of plant remains, the spread took place at an estimated rate of 1 km/year, likely being adopted in fertile river valleys first.

Independent domestication of plants and animals took place in Southeast Asia approximately 8,000–7,500 years ago, with distinct modes of production evolving along the Yellow River in northern China and the Yangtze to the south. One of the most important domesticates from China is rice (*Oryza sativa* L.); rainfed lowland rice was grown initially, followed some time later by upland and deep-water rice. Due to the natural distribution of wild rice, which extends from India eastwards across China to the coast, the center of domestication was thought to lie in the southern part of China, but new finds of early domesticates in the Yangtze valley have expanded this range. Ongoing research and more extensive excavations are required until the debate regarding the location of rice domestication can be resolved fully. By approximately 7,000–5,000 years ago, rice production spanned large areas of Southeast Asia and India. Early tools found at the waterlogged site of Hemudu in China, dating to ca. 7,200 years ago, include two digging implements constructed from a water buffalo scapula (shoulder bone) attached to a wooden handle, but such finds are exceptional and as with other areas, the full range of early agricultural implements is unknown.

Further to the north, between the highlands and the plains along the Yellow River, rainfall tends to be lower and drought-tolerant species were chosen as the first domesticates. Here, broomcorn millet (*Panicum miliaceum* L.) and foxtail millet (*Setaria italica* [L.] Beauv) became important crops for Peligang communities just over 7,000 years ago. Dogs, pigs, chickens (*Gallus gallus domesticus* L.), and water buffalo (*Bubalus bubalis* L.) were the most important animal domesticates, although wild resources including various nuts, jujube dates (*Zizyphus jujuba* Mill.), and deer remained important components of the diet. It is likely that chickens were first domesticated just after 8,000 years ago in northern China.

Agriculture developed in the Americas later than in the Old World. In North America, early crops include goosefoot (*Chenopodium berlandieri* Moq.), sunflower (*Helianthus annus* L.), and marsh elder (*Iva annua* L.). Within Mesoamerica, most research has centered along the Oaxaca and Tehuacán valleys of Mexico; important domesticates include maize (*Zea mays* L.) derived from the annual grass teosinte, squash (*Cucurbita* spp.), beans (*Phaseolus vulgaris* L.), avocado (*Persea americana* Mill.), dog, turkey, and perhaps cottontail rabbit. Maize domestication is widely thought to have occurred around 7,000 years ago, but this date has recently been disputed; new radiocarbon dates of the oldest known domesticated corn cobs places them at approximately 4,600 years old. Cocoa (Theobroma cacao L.) also became an important domesticate in Mesoamerica. The Nuttall Codex, dating to AD 1051, depicts an early use ritual of cocoa. Further south in the Andes, llama (*Lama glama*), alpaca (*Lama pacos*), and guinea pigs (*Cavia porcellus*) were herded. Important crops include quinoa (*Chenopodium quinoa* Willd.), and tubers such as oca (*Oxalis tuberosa* Mol.), mashua (*Tropaeolum tuberosum* Ruíz & Pav.), ullucu (*Ullucus tuberosus* Caldas.), and potatoes (*Solanum tuberosum* L.). Drawings of agricultural scenes by conquistadores in the 1500s depict the use of foot ploughs and hand hoes in the Andes.

Within Africa, agriculture first arose in the Nile Valley of Egypt, following the introduction of sheep, goat, cattle, and cereals, around 6,500 years ago from areas to the north. Independent innovation and domestication of local, indigenous species occurred between 5,000 and 3,000 years ago in a band between the Sahara and the equator, at a time when rainfall was higher than today. Important domesticates include cattle, sorghum (*Sorghum bicolor* [L.] Moench.), pearl millet (*Pennisetum glaucum* [L.] R. Br.), and much later, dating to around AD 200, African rice (*Oryza glaberrima* Steud.). African rice is still grown in parts of West Africa, although Asian varieties originally domesticated in China predominate today.

Continental Transfer of Crops

Throughout the world, the form that early agriculture took reflects, for the most part, an adoption of locally available plants and animals, with cereals such as wheat, barley, millet, and rice predominating in the Old World, and potatoes, maize, and squash predominating in the New World. There are numerous examples of people adopting non-native species throughout history, however, which demonstrates the dynamic nature of agricultural production and underscores how food production forms an integral component of social histories. The potato, for example, a native of Chile and Peru, was first introduced into Northern America and Europe during the late

1500s, after which time it became an important crop. By the 1800s, it formed the dominant staple in Ireland and the spread of potato blight resulted in the great famine that began in 1845. Tomatoes (*Lycopersicon esculentum* Mill.) were also introduced to Europe from Tropical America by Spanish conquistadors and Atlantic slave traders in the mid-1500s. Tomatoes were initially treated with suspicion due to their perceived similarity to deadly nightshade which was associated with witchcraft; they later became viewed as aphrodisiacs, rendering them the common name, "love apples." The introduction of maize, beans, cassava, and potatoes into West Africa during the Atlantic slave trade of the 1500s is particularly noteworthy. McCann provides a history of the adoption of maize throughout Africa and today it has become an important staple at the expense of indigenous crop. In Zambia and Malawi, maize contributes more than 50 % of the calorific content of people's diet, greater than that in Mexico where the plant was originally domesticated, and this has resulted in a drastic narrowing of dietary breadth. Indeed, in all parts of the world, reliance upon agriculture has led to a more restricted diet than that consumed by hunting and gathering communities. Examination of paleopathology within early agricultural communities in both the Old and New worlds has shown that farming led to an initial decline in general health and nutrition.

Water Management

Through time, people have increasingly adapted their environment to grow the crops that they desire. Limits exist to the extent that the landscapes can be modified, and these limits have shifted through time as technology has evolved and as labor divisions and economic incentives have shifted. The choice of what and where to grow crops is not, therefore, always predicated upon environmental considerations, and social or economic factors can weigh more heavily. Nabatean farmers at Avdat in the Negev Desert of Israel, for example, situated their settlements at strategic locations along spice trade routes during the first century BC, and were able to grow crops in areas that received limited amounts of rainfall by using water harvesting techniques. Depending upon the timing and distribution of rainfall throughout the year, rainfed farming cannot generally be practiced in areas that receive less than 250 mm per annum. By clearing rocks from the hillsides and placing them in long lines running down slope, the thin soils were exposed to rainfall, encouraging them to slake and enhance runoff. Rainfall was then channeled down the slope into the valley bottom where walls constructed across the valley impeded the flow, minimized soil erosion, and enhanced infiltration of water into the soil allowing crops to grow successfully.

An equally ingenious method of water control was employed in South America where raised fields were used to grow potato. Raised fields have been found in dense concentrations in the Lake Titicaca area of Bolivia and Peru, and from above resemble a patchwork of fields. Raised fields were created by digging a network of ditches and placing the excess soil on top of the field to be cultivated. The fields provide optimal conditions for crop production in this area where weather conditions can be unpredictable; water can be maintained in the furrows between the fields and used for irrigation during dry spells, it can be drained away through the channels following heavy rainfall, and it also helps minimize diurnal temperature shifts, thereby reducing the risk of frost damage. There has been some interest in reintroducing this form of cultivation on a large scale today as part of the sustainable development movement, and while there are many benefits from an agronomic perspective, it is not clear how practical the construction and maintenance of raised fields would be from a social perspective because they require large investments of time. In the past they were likely constructed with corvée labor.

It is difficult to determine exactly when irrigation was first practiced because canals do not always preserve well and, additionally, preserved features can be difficult to date. Informal watering is likely as old as cultivation itself, particularly within food gardens close to the home, but more formal irrigation did not develop until much later. The earliest forms of irrigation would have employed water diversion structures such as deflection dams and gravity canals as seen in Mesopotamia; it was not until Roman times that engineering developed sufficiently to allow for water to be lifted from a river and distributed onto an adjacent field. Early examples of norias (water-powered wheels that scoop water), can be found in the more arid parts of the Roman empire including Syria, North Africa, and Spain. Horizontal wheels were also commonly used for irrigation during the Tang Dynasty (AD 618–907) in southern China, and may have been used as early as 200 BC. The Archimedean screw, invented by Archimedes during the third century BC, uses a helix placed at a 45-degree angle within a tube to raise water when rotated. Despite these developments, as well as the invention of drip and sprinkler irrigation much more recently, floodwater farming continues to be a highly effective method of irrigation where topographic conditions are suitable. It was heavily utilized by the Hohokam of the Sonoran Desert in south Central Arizona, between AD 200 and 1450 to support large communities in an area of low rainfall.

Terracing

Other modifications to the environment include terracing and the cultivation of hill slopes. Due to erosion, ancient terraces are not always preserved, although examples do exist. Terraces can also be difficult to date, but based on embedded pottery finds, terracing may have been practiced in Southwest Asia during the Early Bronze Age around 5,000 years ago, perhaps being prompted by a greater demand for olive and grape commodities such as oil and wine associated with the rise of urban life in Egypt and Mesopotamia. Extensive tracts of terraced hillsides are also evident in the Peruvian highlands where numerous varieties of potatoes were grown, as well as throughout Indonesia where sophisticated methods of terrace maintenance and water use were developed and integrated into the social and religious calendar.

Soil Fertility Management

Assessing early methods of soil fertility management is more difficult since they leave fewer traces in the archaeological record and are not always documented in textual accounts. The practice of fallowing, or leaving land uncultivated for a year or more, is believed to have been an important method and it forms an integral role in slash-and-burn agriculture (swidden) that has been documented in tropical counties in Asia and Africa. In more arid areas, where slash-and-burn is not a feasible method of production, the need to maintain soil fertility was likely recognized following the first cultivation of crops, but little is known about the methods, if any, that were used. In northeastern Syria, Wilkinson observed scatters of pottery sherds surrounding large sites dating to the Bronze Age, which he interprets as non-perishable remnants of night soil or urban waste used to fertilize the fields. Since leguminous crops such as lentil, pea, and bitter vetch that fix nitrogen in the soil were important crops during the Bronze Age, it is also likely that crop rotations may have been used to maintain soil fertility, but it is difficult to assess this with any degree of certainty from archaeological evidence. It seems probable, however, that some form of crop rotation in Southwest Asia was practiced much earlier than the formalized introduction of the Norfolk four-course rotation of wheat, barley, clover, and turnips that was adopted in Europe, predominantly England, during the late 1600s and early 1700s.

More Recent Developments

Within the past century, the large-scale introduction of mechanized farming has greatly increased the efficiency of preparing land and harvesting crops. Mechanization has not been adopted uniformly throughout the world, however, and in many developing countries, animal traction is still relied upon for field preparation. The Green Revolution of the 1960s also markedly changed production following the introduction of high-yield varieties of wheat and rice throughout numerous developing countries, notably in Asia. These varieties required a strictly defined regimen of fertilizer and pesticide application for optimal growth. While many farmers enhanced yields, many of the poorer farmers whom the improved grain was intended to help were not always able to afford the prescribed chemical fertilizers and pesticides and, as a consequence, yields sometimes fell below those obtained from local varieties. While farmers have long recognized the benefits of local varieties for subsistence agriculture, the lessons from the Green Revolution prompted numerous agricultural development agencies and agricultural research stations around the world to compile seed banks to store diverse crop varieties for future generations.

The most recent, and potentially revolutionary, change in agricultural technology concerns the development of genetically modified crops. From agriculture's earliest inception, selection of species with desirable traits has led to genetic change; this selection became formalized with intentional cross breeding. The creation of genetically modified crops differs from cross breeding in that DNA is physically spliced, potentially from one species to another. Genetic modification offers enormous potential to develop crops that are able to grow productively under adverse conditions, or which contain medicines or vaccinations that can be used in remote areas without refrigeration. Such crops have not been widely accepted, however, and studies examining potential environmental, economic, and social impacts continue. It is possible to produce seed stock that will yield sterile grain that cannot be used to replant the following season. While this development protects the economic investments of the producer, it has raised enormous concerns among subsistence farmer who would not be able to use harvested crops for reseeding. The debate is likely to continue for some time.

In the eighteenth century, Reverend Thomas Malthus expressed his views regarding the balance between population growth and food production, claiming that due to the inelasticity of food supply, once population levels increased beyond the "carrying capacity" of the land, the surplus population would be eliminated either by direct starvation, or by positive checks such as misery and vice or moral restraint. Boserup counter-argued that population pressure would stimulate the creation of new methods of production that would enhance yields. The historical developments of agriculture through the ages demonstrate periodic innovation which has allowed the carrying capacity to increase. The relationship between population and carrying capacity is enormously complex and while people have continually adapted agricultural technology in order to enhance yields, as Amartya Sen has argued, social factors play an equally important role in ensuring that people are fed.

See Also

▶ Animal Domestication
▶ Potato: Origins and Conservation of Potato Genetic Diversity
▶ Rainwater Harvesting
▶ Swidden

References

Ammerman, A. J., & Cavalli-Sforza, L. L. (1973). A population model for the diffusion of early farming in Europe. In C. Renfrew (Ed.), *The explanation of cultural change*. London: Duckworth.

Archi, A. (1990). Agricultural production in the Ebla region. *Annales archéologiques arabes syriennes, 40*, 50–55.

Bender, B. (1978). Hunter-gatherer to farmer: A social perspective. *World Archaeology, 10*, 204–222.

Binford, L. R. (1983). *In pursuit of the past: Decoding the archaeological record*. New York: Thames and Hudson.

Boserup, E. (1993). *The conditions of agricultural growth. The economics of agrarian change under population pressure*. London: Earthscan Publications. First published in 1965.

Civil, M. (1994). *The farmer's instructions. A Sumerian agricultural manual. Aula orientalis supplement 5*. Barcelona, Spain: Editorial AUSA.

Cohen, M. N. (1977). *The food crisis in prehistory. Overpopulation and the origins of agriculture*. New Haven, CT: Yale University Press.

Colledge, S. J. C., & Stennan, S. (2004). Archaeobotanical evidence for the spread of farming in the eastern Mediterranean. *Current Anthropology, 45*, S35–S58. Supplement.

Damania, A. B., et al. (Eds.). (1998). *The origins of agriculture and crop domestication*. Aleppo, Syria: ICARDA. The Harlan Symposium.

Evenari, M., Shanan, L., & Tadmor, N. (1982). *The Negev. The challenge of the desert*. Cambridge, MA: Harvard University Press.

Flannery, K. V. (1969). Origins and ecological effects of early domestication in Iran and the Near East. In P. J. Ucko & G. W. Dimbleby (Eds.), *The domestication and exploitation of plants and animals* (pp. 73–100). Chicago: Aldine.

Flannery, K. V. (1973). The origins of agriculture. *Annual Review of Anthropology, 2*, 271–310.

Gordon, C. V. (1934). *New light on the most ancient East. The oriental prelude to European prehistory*. New York: D. Appleton-Century.

Hassan, F. (1977). The dynamics of agricultural origins in Palestine: A theoretical model. In C. A. Reed (Ed.), *The origins of agriculture* (pp. 685–709). The Hague, Netherlands: Mouton.

Hather, J. G. (Ed.). (1994). *Tropical archaeobotany. Applications and new developments*. London: Routledge.

Hather, J. G. (2000). *Archaeological parenchyma*. London: Archetype Publications.

Hayden, B. (1992). Models of domestication. In A. B. Gebauer & T. D. Price (Eds.), *Transitions to agriculture in prehistory* (pp. 11–19). Madison, WI: Prehistory Press.

Hedrick, U. P. (Ed.). (1919). *Sturtevant's notes on edible plants* (Report of the New York agricultural experiment station for the year 1919, Vol. II). Albany, NY: J. B. Lyon Company.

Kislev, M. E., & Bar-Yosef, O. (1988). The legumes: The earliest domesticated plants in the Near East? *Current Anthropology, 29*(1), 175.

Long, A., et al. (1989). First direct ams dates on early maize from Tehuacán Mexico. *Radiocarbon, 31*(3), 1035–1040.

Malthus, T. (1970). *An essay on the principle of population*. London: Penguin. First published in 1798 ed.

McCann, J. (2001). Maize and grace: History, corn, and Africa's new landscapes, 1500–1999. *Comparative Studies in Society and History, 43*(2), 246–272.

McCorriston, J. (1997). The fiber revolution. Textile extensification, alienation, and social stratification in ancient Mesopotamia. *Current Anthropology, 38*, 517–549.

Pullen, D. J. (1992). Ox and plow in the early bronze age Aegean. *American Journal of Archaeology, 96*(1), 45–54.

Sen, A. (1999). *Development as freedom*. New York: Knopf.

Sherratt, A. (1981). Plough and pastoralism: Aspects of the secondary products revolution. In H. Ian, I. Glynn, & N. Hammond (Eds.), *Pattern in the past. Studies in honour of David Clarke* (pp. 261–305). Cambridge: Cambridge University Press.

Smith, B. D. (1998). *The emergence of agriculture*. New York: Scientific American Library.

Stager, L. E. (1985). The first fruits of civilization. In J. N. Tubb (Ed.), *Palestine in the bronze and iron ages: Papers in honor of Olga Tufnell* (pp. 172–188). London: Institute of Archaeology.

Stiner, M. C. (2001). Thirty years on the "broad spectrum revolution" and Paleolithic demography. *Proceedings of the National Academy of Sciences of the United States, 98*(13), 6993–6996.

Ucko, P. J., & Dimbleby, G. W. (Eds.). (1969). *The domestication and exploitation of plants and animals*. Chicago: Aldine.

Weiss, E., et al. (2004). The broad spectrum revisited: Evidence from plant remains. *Proceedings of the National Academy of Sciences of the United States, 101*(26), 9551–9555.

Wilkinson, T. J. (1982). The definition of ancient manured zones by means of extensive sherd-sampling techniques. *Journal of Field Archaeology, 9*, 323–333.

Zeder, M. A., & Cities, F. (1991). *Specialized animal economy in the ancient near east. Smithsonian series in anthropological inquiry*. Washington, DC: Smithsonian Institution Press.

Zohary, D., & Hopf, M. (2000). *Domestication of plants in the old world. The origin and spread of cultivated plants in West Asia, Europe and the Nile Valley*. Oxford, UK: Oxford University Press.

Agriculture: Origins of Agriculture in Brazil

Rafael Feltran-Barbieri
Faculty of Economics, Business and Accounting, Universidade de São Paulo, São Paulo, SP, Brazil
Accounting, Actuarial and Financial Research Institute Foundation – FIPECAFI – São Paulo, SP, Brazil

What caused people to cultivate the land? There are at least two main hypotheses, which try to produce an answer to what is regarded as one of the most fascinating issues in our cultural history. The first postulates climate restrictions, while the second defends the gradual shortage of extractive resources imposed by increasing demographic pressure. We ought not to discard either of them and even the combination of both, especially because agriculture emerged in diverse points and times, in a wide variety of environments. The oldest appeared in the "fertile crescent" of the Middle East 10,000 years before the present (BP) and in Mesoamerica 9,000 years BP.

However, whatever the motivations that led to systematic and lasting cultivation of the soils, the agricultural awakening did not emerge quickly. It would have taken thousands of years until we could understand plant reproduction, leading us to imitate the natural process in supervised planting beds.

The first vegetable gardens incidentally appeared by the spontaneous sprouting of wasted seeds during the handling and preparation of meals or from those that had been thrown as offerings over the mausoleums. However, when judged by the behavior of Brazilian Indians as witnesses of their ancestors, the formation of the first garden plots was deliberate.

It is explicit in açai palms (*Euterpe oleracea*) in the Amazon or jussara palm (*Euterpe edulis*) in the Atlantic rain forest where the coexistence of fruits, seeds, and seedlings in the most varied stages of development offers an example of ontogenetic succession. These scenarios did not go unnoticed by the locals that frequently visited such redoubts not only to collect victuals but also to surprise the hunted animals that were equally attracted by the abundance of food.

As many studies show, the handling of such resource islands through the cleaning and removal of undesired plants, and consequent intensification of edible species, and the seedling transplant for the formation of home orchards and even along tracks are customary practices in Brazil. This includes peoples that do not have other agricultural provisioning systems as some ethnicities of macro-Jê that honor their newborn children with a planting of seedlings, or seeds of fruit trees, mainly pequi (*Caryocar brasiliense*). For many peoples, perennial agriculture has been around for a long time. One of the oldest documents that systematized the agricultural practice of Brazilian natives, dated 1,583, says that the perennial peanut was the only common cultivar in the vast region of Mato Grosso. Even now, perennial agriculture continues to be important for many peoples, because for the Indians, their growing areas are not restricted to their surroundings but are also scattered throughout their territorial domains, as a stock provision.

In the literature, agriculture is customarily focused on a single cultivation of temporary plants, because then there is a homogeneous harvest in a short term. Without any doubt, this type was the most used among farmers around the world, having prospered especially in regions with great climatic seasonality. More than this, these crops need intensive care and surveillance, so a feed function becomes a founding element of sedentary societies with a complex work division.

But perennial agriculture also has its benefits, particularly for the Brazilian way of living. The outdated idea that the peoples of Brazil were nomads, compared with Mesoamerica, flourished because the tribes relocated according to the abundance of resources and soil fertility, keeping the link with the "old villages" with frequent visits to the old orchards. The relationship of plant production to labor unit is favorable to perennial cultures, and the lack of assistance renders the temporary ones impossible. Among the Kuikuro Indians, for example, the handling of orchards limited the people to sporadic cuts of lianas and the fertilization of trees by gathering dry leaves to the bottom part of the plant. Moreover, for peoples whose calendar is based on flowering and fruiting, the orchards in the new villages signaled what was happening inside the territory, optimizing the return to the old sites and even the harvesting of wild specimens.

However, if perennials represented agricultural dawning for many nations, the development and consolidation of agriculture was reached with the growing of some temporary cultivars. Among them are calabash, sweet potato, and cassava (*Manihot* ssp.). It is of this Euphorbiaceae family that flour and beiju are produced, the food basis of Brazilian ethnic groups. Also it is from that family that fermented drinks are extracted such as the jacuba and other products such as starch for ceramics and poisons for hunting and fishing. As part of a cultural heritage, because cassava is in many Indian myths, the preservation of typical varieties is so rooted in the identity of the tribes that anthropologists use the plant varieties to recognize various ethnic groups. Therefore, the peoples of the Amazon owe their agricultural origin to the cultural diffusion derived from the Andean Center, typified by the use of mandioca brava (angry cassava), a local variety of cassava. The nations of Central Brazil seem to have received this influence from coastal groups, with the main use of mandioca mansa (soft cassava), both initiated concurrently, about 3,000 years AP.

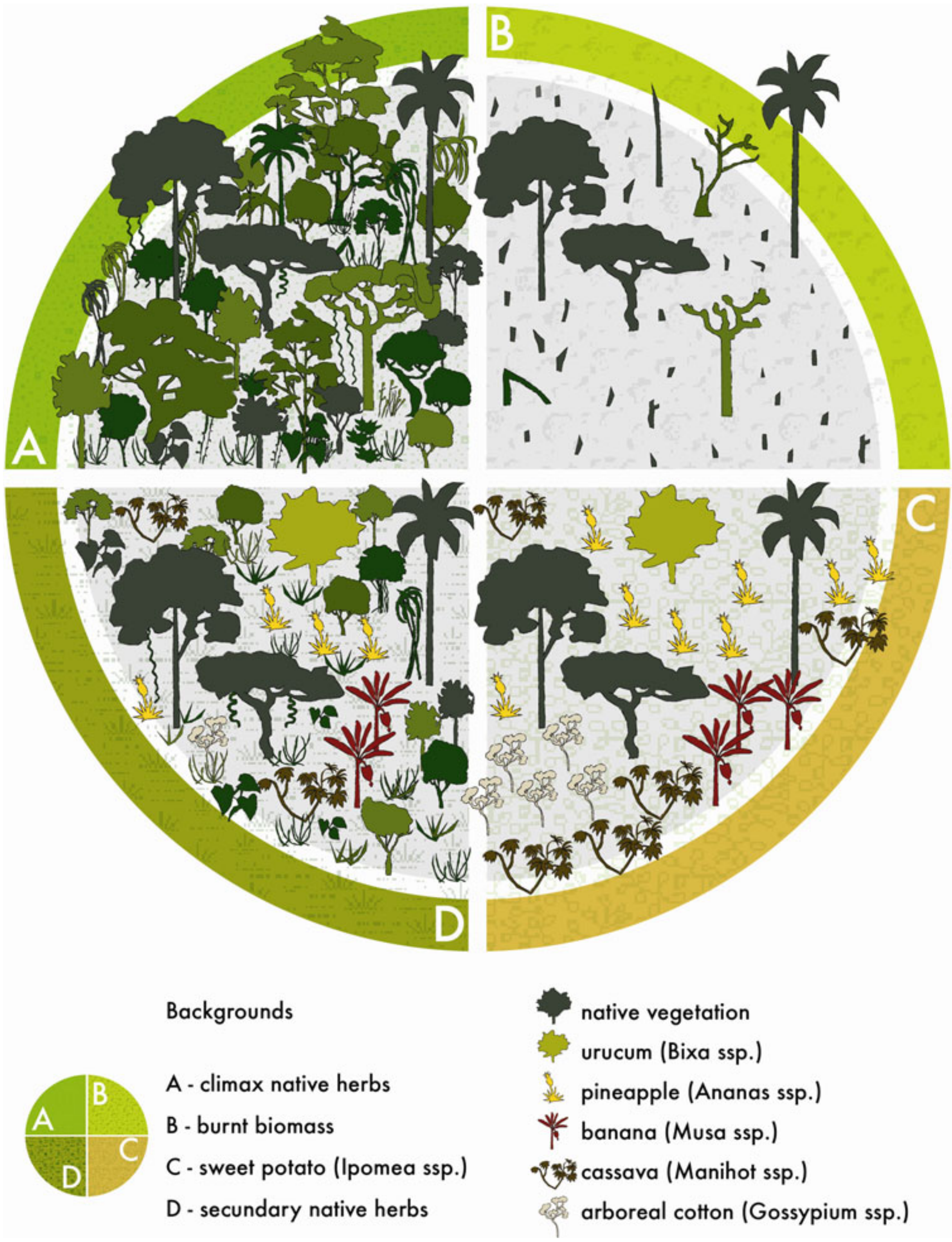
At the end of the nineteenth century, in the travelogues of his travels through the savannas of Brazil, naturalist Karl von den Steinen describes the curious case of an Indian that became fascinated with “matchsticks” and attempted to plant them in a vegetable garden. Perhaps 3,000 years ago, other Indians had the same idea but used branches of wild cassava, and met with success, since using the cuttings of the plant is the most efficient way to establish a cassava plantation. In fact, Carl Sauer, in an extensive review of the subject, affirmed that between Rio de Janeiro and Salvador, thousands of varieties of cassava were cultivated, proposing the simultaneous and independent origin in many points of the coast. Only as an illustrative example, a survey of 1980 showed the Amazonian tribes preserved 19–75 varieties of cassava per tribe and in some cases with the outstanding rate of 2.2 varieties per inhabitant.

Despite the unquestionable nutritional and cultural relevance of cassava, indigenous agriculture systems cannot be understood except as a complex arrangement that is genuinely agroecological. Nothing caused more indignation among the settlers than the apparently chaotic way the Indians organized their plantations. Brazilian agriculture was not only characterized by polyculture but also by multifunctionality. Wild and domesticated species and temporary and permanent varieties in the mixed and companion crops of foods, seasonings, fibers, dyes, drugs, and cosmetics shared the same space. Figure 1c illustrates a real case observed among the Wajãpi rena Indians in this circumstance with the introduction of banana – one of the most exotic plants adopted by the Indians.

Most importantly, this shows a much deeper and more complex dimension of the agrarian systems – the work division and temporary administration, initiated by the choice of a forest fragment. Where science sees only four sequential stages – primary, secondary, late secondary, and climax forest – the Indians see tens of physiognomic and functional types according to the soil, draining, and the flora and fauna. Judging by the social organization of the Kaiapó, the agricultural calendar was dictated by responsible elders and also by the choice of genres to be planted. Shamans were also consulted to establish the ones that would be limited, depending on the needs of the tribes. They indicated the species that should be spared, while the war chiefs recruited men for the clearing of the branches and collection of fruits and honey after cutting down the bigger trees, allowing the clearing areas to dry for a few months. In the *coivara* or “slash-and-burn” system, permission to set fires, generally announced in festive events, is proclaimed by the chief who also announces the transference of agriculture activities to women, who would take over the responsibility to prepare the land, sow, and harvest the production.

The cleaned land for the plantations would be cultivated for 3 or 4 years, by opening regular holes with the help of pointed sticks, each hole receiving a few seeds or transplant branches. Weeds were controlled and manually removed, with the use of stakes and more rarely shovels. This work only stopped when the fruits or tubers ripened, so then they could be harvested and taken to the villages in baskets, inside of which the separation of grains and the cleaning of the roots were carried out. Four years after the planting, a new forest fragment would be put into the cultivated site, which would be set aside for up to five decades in a rotation system.

Agriculture thus provided an efficient source of food. However, the indigenous agricultural system of slash and burn cannot be understood except as it is combined with the systems of collecting and hunting, chiseled by mysticism, and the division of labor. In many tribes, where the agricultural product was not too important, there were still elaborate planting and harvest



Agriculture: Origins of Agriculture in Brazil, Fig. 1 The Brazilian Indian agriculture rotation. (**a**) Forest, (**b**) the tillage preparation from *coivara* or "slash-and-burn" system, (**c**) the companion and multifunctional planting of *roça*, and (**d**) the fruitfully fallow of *capoeira* in an old village (Illustrated by Elisa F. Serafim)

rituals. In other cases, the frequent displacement went along with the search for new forest areas to be exploited. The mobility of these nations caused the function of reinforcing the internal hierarchy of the group. Hunting and the protection of the territory, as signs of courage, sustained men's dominance over the collecting and horticulture being carried out by the women.

One last issue should be clarified. About 35 % of Brazil originally consisted of savanna-field biomes, more than 3/4 of these represented by the Cerrado-Brazilian savannas, where the forest formations are restricted to gallery forest or isolated in small spots known locally as *capões* (*caá pãu* – or in Tupi language "island" of "woods"). Even in the savanna, agriculture was almost exclusively associated with these restricted forest fragments. However, why was planting only done in forests?

Naturalists, traveling the interior of Brazil, asked this same question many centuries ago. The oldest answers are that this was part of the cultural heritage. The natives of the savannas owe their ancestry to the nations arising from the Amazon forest, so that the Indians kept the forested agriculture dependent as a social rule. The oldest human fossil of the American continent, Luzia, a 12,000-year-old woman, was found in the Brazilian savannas. More than this, lithic artifacts from the northeast of the country – another non-forest biome distant from the Amazon – suggest the presence of hominids for at least 30,000 years. Even if we are conservative, we should admit that there was a continual flow of Paleo-Indians from the Amazon to the savanna between the 12,000 years since the arrival of humans in the savannas and the 3,000 years since the development of cassava in this region. This appears to be unlikely.

The second group of answers relies on the microclimate and pedological conditions of the forests. In general the gallery forest soils are more humid and fertile than the savanna soils, especially after the burning of thick vegetation, which adds the minerals of the ashes to the subsistent organic matter. The Bakairí Indians of the savanna told the tale of the stupidity of the deer that tried to cultivate cassava in the savanna. Moreover, savanna soils in Brazil have high contents of aluminum, a great competitor for nutrients, and the ignorance of soil corrective means as a standard between the Indian nations of the Central West would be an additional factor.

Not discarding this hypothesis, I choose an alternative, which was inspired by Ester Boserup concerning labor productivity. With an agricultural system totally dependent on coivara – slash and burn – the Indians noticed that the forests are easily handled as they are more sensitive to fire. Fewer men could open clearings and cultivate them without the need to employ tools or other costly efforts to control the development of herbaceous helophytic species, a limiting factor in the savannas.

Considering the savanna is a pyroclimate biome, the use of fire tends to contribute to the thickening of the herbaceous strata, naturally aggressive and dominating in open physiognomies. The burning system is still used today by commercial cattle breeders in Brazil. The indigenous populations of the time, not having hoes, which are essential for removing meadow grasses, Cyperaceae, and dicotyledonous herbs, probably were not able to meet the production threshold that would make the cultivation sites as an alternative to collecting. Even considering the hypothesis of the advent of such tools, the experience of other agricultures in the world showed it would take large human contingents and exhaustive work to be able to cultivate the soil. We had neither high demographic densities, nor typical tools for the control of herbs in savannas, nor organized specific work that could suggest the agriculture practice in the cerrados.

The convenience of fire and the employment of few men to prepare the forestlands, originally more fertile, led to agriculture over forests, as the most profitable. The forest agriculture of slash and burn became the prevailing agricultural method among the horticulturist people, even in the savannas.

References

Albuquerque, J. A. A., Evangelista, M. O., Mates, A. P. K., Alves, J. M. A., Oliveira, N. T., Sediyama, T., et al. (2014). Occurrence of weeds in Cassava savanna plantations in Roraima. *Planta Daninha, 32*(1), 91–98.

Barbosa, A. S. (2008). A ocupação humana no Cerrado. In H. Gomes (Ed.), *O universo do Cerrado* (pp. 17–41). Goiânia, GO: Editora da Universidade Católica de Goiás.

Bertran, P. (2000). *História da terra e do homem no planalto central: Eco-história do distrito federal: Do indígena ao colonizador*. Brasília, DF: Verano.

Boserup, E. (1965). *The conditions of agricultural growth: The economics of agrarian change under population pressure*. Chicago: Aldine.

Cardim, F. (1980). *Tratados da terra e gente do Brasil*. Belo Horizonte, Brazil/São Paulo, SP: Itatiaia/Edusp (Original work published in 3 vols., 158?).

A

Castelnau, F. (2000). *Expedição às regiões centrais da América do Sul*. Belo Horizonte, Brazil/São Paulo, SP: Itatiaia/Edusp (Original work published in 1840).

Carneiro, R. L. (1997). O uso do solo e classificação da floresta (Kuikúro). In B. G. Ribeiro (Ed.), *Suma etnológica brasileira: Etnobiologia* (3rd ed., pp. 43–56). Belém, PA: Universidade Federal do Pará.

Chernela, J. M. (1997). Os cultivares de mandioca na área do Uaupés (Tukâno) (171–180). In B. G. Ribeiro (Ed.), *Suma etnológica brasileira: Etnobiologia* (3rd ed., pp. 43–56). Belém, PA: Universidade Federal do Pará.

Christoffersen, B. O., et al. (2014). Mechanisms of water supply and vegetation demand govern the seasonality and magnitude of evapotranspiration in Amazonia and Cerrado. *Agricultural and Forest Meteorology, 191*, 33–50.

Cochrane, M. A., & Laurance, W. F. (2002). Fire as a large-scale edge effect in Amazonian forests. *Journal of Tropical Ecology, 18*, 311–325.

Cohen, M. N. (1979). *The food crisis in prehistory: Overpopulation and the origins of agriculture*. New Haven, CT: Yale University Press.

Cohen, M. B., & Armelagos, G. J. (Eds.). (2013). *Paleopathology at the origins of agriculture* (2nd ed.). Gainesville, FL: University Press of Florida.

Cohna, A. S., Mosnierc, A., Havlíkc, P., Valinc, H., Herrerod, M., Schmide, E., et al. (2014). Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. *Proceedings of the National Academy of Sciences of the United States of America, 111*(20), 7236–7241.

Feltran-Barbieri, R. (2010). The other side of agricultural frontier: A brief history on origin and decline of cerrado's agriculture. *Ambiente e Sociedade, 13*(2), 331–345.

Gallois, C. (2002). *Wajãpi rena: roças, pátio e casas*. Rio de Janeiro, RJ: Museu do Índio/Funai.

Gignoux, C. R., Henn, B. M., & Mountain, J. L. (2011). Rapid, global demographic expansions after the origins of agriculture. *Proceedings of the National Academy of Sciences of the United States of America, 108*(15), 6044–6049.

Gray, C. L., Bilsborrow, R. E., Bremner, J. L., & Lu, F. (2008). Indigenous land use in the Ecuadorian Amazon: A cross-cultural and multilevel analysis. *Human Ecology, 36*(1), 97–109.

Gross, D. R., Eiten, G., Flowers, N. M., Leoi, F. M., Ritter, M. L., & Werner, D. W. (1979). Ecology and acculturation among native peoples of Central Brazil. *Science, 206*, 1043–1050.

Hancock, J. F. (2004a). The dynamics of plant domestication. In J. F. Hancock (Ed.), *Plant evolution and the origin of crop species* (2nd ed., pp. 151–173). Oxon, UK/Cambridge, MA: CABI.

Hancock, J. F. (2004b). Origins of agriculture. In J. F. Hancock (Ed.), *Plant evolution and the origin of crop species* (2nd ed., pp. 129–150). Oxon, UK/Cambridge, MA: CABI.

Hoffmann, W. A. (1999). Fire and population dynamics of woody plants in a neotropical savanna: Matrix model projections. *Ecology, 80*(4), 1354–1369.

Hubbe, M., Neves, W. A., & Harvati, K. (2010). Testing evolutionary and dispersion scenarios for the settlement of the new world. *PLoS One, 5*, e11105. doi:10.1371/journal.pone.0011105.

Lévi-Strauss, C. (1997). O uso das plantas silvestres na América do Sul tropical (pp. 19–42). In B. G. Ribeiro (Ed.), *Suma etnológica brasileira: Etnobiologia* (3rd ed., pp. 43–56). Belém, PA: Universidade Federal do Pará.

Magalhães, J. V. C. (1975). *O Selvagem*. Belo Horizonte, Brazil/São Paulo, SP: Itatiaia/Edusp (Original work published 1876).

Marrero, A. R., Silva-Junior, W. A., Bravi, C. M., Hutz, M. H., Petzl-Erler, M. L., Ruiz-Linares, A., et al. (2007). Demographic and evolutionary trajectories of the Guarani and Kaingang natives of Brazil. *American Journal of Physical Anthropology, 132*(2), 301–310.

Mazoyer, M., & Roudart, L. (1997). *Histoire des agricultures du monde: du néolithique à la crise contemporaine*. Paris: Seuil.

Mistry, J. (1998). Decision-making for fire use among farmers in savannas: An exploratory study in the Distrito Federal, central Brazil. *Journal of Environmental Management, 54*(4), 321–334.

Mistry, J., Berardi, A., Andrade, V., Krahô, T., Krahô, P., & Leonardos, O. (2005). Indigenous fire management in the cerrado of Brazil: The case of Krahô of Tocantins. *Human Ecology, 33*(3), 65–386.

Morales, W. F. (2008). *Brasil Central: 12.000 anos de ocupação humana no médio curso do rio Tocantins*. São Paulo, SP/Porto Seguro, BA: Annablume/Acervo-Centro de Referência em Patrimônio e Pesquisa.

Morales-Mateos, J., Perez-Jorda, G., Pena-Chocarro, L., Zapata-Peña, L., Ruíz-Alonso, M., López-Sáez, J. A., et al. (2013). The origins of agriculture in North-West Africa: Macro-botanical remains from Epipalaeolithic and Early Neolithic levels of Ifri Oudadane (Morocco). *Journal of Archeological Science, 40*(6), 2659–2669.

Moran, E. F. (Ed.). (1995). *The comparative analysis of human societies: Toward common standards for data collection and reporting*. Boulder, CO: Lynne Rienner.

Posey, D. A. (1997). Manejo da floresta secundária, capoeiras, campos e cerrados (Kayapó) (pp. 199–213). In B. G. Ribeiro (Ed.), *Suma etnológica brasileira: Etnobiologia* (3rd ed., pp. 43–56). Belém, PA: Universidade Federal do Pará.

Reich, D., et al. (2012). Reconstructing Native American population history. *Nature, 488*, 370–374.

Romero, S. (2014). Discoveries challenge beliefs on humans' arrival in Americas. *The New York Times*, A5. http://www.nytimes.com/2014/03/28/world/americas/discoveries-challenge-beliefs-on-humans-arrival-in-the-americas.html

Ruggiero, P. G. C., Batalha, M. A., Pivello, V. R., & Meireles, S. T. (2001). Soil-vegetation relationships

in cerrado (Brazilian savanna) and semideciduous forest, Southeastern Brazil. *Plant Ecology, 160*(1), 1–16.
Saint-Hilaire, A. (1975). *Viagem à província de Goiás*. Belo Horizonte, Brazil/São Paulo, SP: Itatiaia/Edusp (Compilation of Original work published as report 1857).
Sauer, C. O. (1997). As plantas cultivadas na América do Sul tropical (pp. 57–100). In B. G. Ribeiro (Ed.), *Suma etnológica brasileira: Etnobiologia* (3rd ed., pp. 43–56). Belém, PA: Universidade Federal do Pará.
Silva, L. C. R., Hoffmann, W. A., Rossatto, D. R., Haridasan, M., Franco, A. C., & Horwath, H. R. (2013). Can savannas become forests? A coupled analysis of nutrient stocks and fire thresholds in central Brazil. *Plant and Soil, 373*(1/2), 829–842.
Sommer, B. A. (2008). The forbidden lands: Colonial identity, frontier violence, and the persistence of Brazil's Eastern Indians, 1750–1830. *Ethnohistory, 55*(4), 701–705.
Spix, J. B., & Von Martius, C. F. P. (1981). *Viagem pelo Brasil 1817–1820*. Belo Horizonte, Brazil/São Paulo, SP: Itatiaia/Edusp (Compilation of Original works published as reports 1823, 1828, 1831).
Staden, H. (1974). *Duas viagens ao Brasil*. Belo Horizonte, Brazil/São Paulo, SP: Itatiaia/Edusp (Original work published 1557).
Vogelmann, E. S., Reichert, J. M., Prevedello, J., Barros, C. A. P., Quadros, F. L. F., & Mataix-Solera, J. (2012). Soil hydro-physical changes in natural grassland of southern Brazil subjected to burning management. *Soil Research, 50*(6), 465–472.
Von den Steinen, K. (1894). *Unter den Naturvölkern Zentral-Brasiliens*. Berlin, Germany: Hoefer & Vohsen. Original available on http://biblio.wdfiles.com/local–files/steinen-1894-unter-den-naturvolkern/steinen_1894_unter_den_naturvolkern.pdf
Zimmerman, B., Peres, C. A., Malcolm, J. R., & Turner, T. (2001). Conservation and development alliances with the Kayapo of south-eastern Amazonia, a tropical forest indigenous people. *Environmental Conservation, 28*(1), 10–22.
Zizumbo-Villareal, D., & Marín, P. C. G. (2010). Origin of agriculture and plant domestication in West Mesoamerica. *Genetic Resources and Crop Evolution, 57*, 813–825.

Agroforestry in Africa

Arnold Pacey

Agroforestry is not a new idea; it is merely a new word used by scientists to describe ancient land use practices operated by farmers in many parts of the world. Other names stressing different aspects of the same technique include forest farming, forest interculture, layered gardening, and multistorey farming. The latter word has been used in West Africa to refer to a system where crops are produced from the same area of land at several levels or storeys, ranging from tops of trees (oil palms, for example), to ground crops beneath the trees, and to root crops below ground (yams, cocoyams, cassava).

Rediscovery of such farming methods during the last third of the twentieth century was linked to a realization that imported western techniques in tropical Africa had often led to soil erosion and loss of fertility. Cleared fields planted with single crops in the western manner left the soil acutely vulnerable to damage by heavy seasonal rainfall. By contrast, trees gave protection against erosion during rainstorms, while their leaf litter helped maintain soil fertility.

During the 1980s and 1990s, professionals working on this topic, notably at the International Council for Research on Agroforestry (ICRAF) in Nairobi, came to see agroforestry as a holistic approach to land use, using combinations of trees and shrubs with crops, pastures, or animals. What this means in practice depends on climate and environment, for there are different traditions of agroforestry in semiarid tropical regions, in rainforest areas, and in more temperate zones.

In the West African Sahel, traditional customs of retaining and using sparse tree cover in coordination with livestock raising and cropping tended to moderate the effects of high temperatures and low rainfall and to conserve plant nutrients while making possible a diversity of products, not all of which would suffer when droughts led to crop failure. Whilst many tree and shrub species were involved, one tree in particular, *Acacia albida*, was of such value in the western Sahel that it was often regarded as sacred, and there were severe punishments for its unauthorized felling. Because it is a leguminous, nitrogen-fixing species, yields of millet and sorghum sometimes increased greatly when grown in fields which had a scatter of trees of this type. Its leaves and seed pods were a nutritious fodder

Agroforestry in Africa, Fig. 1 A form of agroforestry in West Africa sometimes known as multistorey farming. The *upper* storeys are represented by oil-palm and banana crops. *Below* that is the cereal crop, maize (corn). Nearer ground level are beans and melons, whilst in the "basement" are the main root crops. *Left* to *right* the latter are yams, cocoyams and cassava. This somewhat compressed view does not reflect realistic spacing, in which maize would be in open glades and more shade-tolerant species under trees (Illustration by Hazel Cotterell based on sketches by Pacey (1990, p. 200))

for livestock. Materials were obtained from it for the preparation of medicines, and its timber was useful in building.

Another species of importance, particularly in Sudan, was *Acacia senegal*, which produced gum arabic, and was grown in conjunction with millet and other crops in a 20-year rotation. With the disruption of this and other cropping systems, sometimes in favor of more "modern" methods, the productivity of the land, and the number of people it could support, was greatly reduced.

In rainforest areas, the retention of tree cover on land where crops are grown is even more important. Oil palm is particularly valuable in West Africa as a tree yielding a valuable crop yet also offering protection of the soil against erosion, and banana may be grown in the same context (Fig. 1). Crops grown at ground level under these trees traditionally include a great variety of beans, squashes, and leafy vegetables, with cereals in more open, sunnier glades.

Many early innovations in agroforestry arose when crops were introduced into new areas. Thus over the last 1,500 years, African agroforestry has incorporated bananas and the Asian yam from Indonesia, then later, cassava and other crops from the Americas. Recently, though, agroforestry has been researched and repackaged by scientists, then taught to farmers by extension workers as if it were something new, with its origins in traditional practice heavily disguised.

One example of an innovation that arose from scientists' observing traditional practices is "alley cropping". This is said to have arisen when an Indonesian scientist working in Nigeria saw farmers planting a tree species on fallow land to speed the regeneration of the soil. He was led to experiment with trees that could be cut back prior to planting a corn crop, but which would grow up again quickly after the crop was harvested. The Alley Farming Network for Tropical Africa (AFNETA) was set up in 1989 to promote sustainable cropping systems based on alley farming and other ideas drawn from agroforestry practice, and in the 1990s it was developing and disseminating such farming methods in 20 African countries.

References

Advisory Committee on the Sahel, U.S. National Research Council. (1984). *Agroforestry in the west African Sahel*. Washington, DC: National Academy Press.

Douglas, J. S., & Hart, R. A. de J. (1984). *Forest farming*. London: Intermediate Technology Publications.

Hart, R. A. de J. (1991). *Forest gardening*. London: Green Books.

Pacey, A. (1990). *Technology in world civilization*. Cambridge, MA: MIT Press.

Richards, P. (1985). *Indigenous agricultural revolution: Ecology and food production in West Africa*. London: Hutchinson.

Rocheleau, D., Weber, F., & Field-Juma, A. (1988). *Agroforestry in Dryland Africa*. Nairobi, Kenya: International Council for Research in Agroforestry (ICRAF).

Scoones, I., & Thomson, J. (1994). *Beyond farmer first*. London: Intermediate Technology Publications (see especially pp. 20, 237).

Shepherd, G. (1992). *Managing Africa's tropical dry forests: A review of indigenous methods*. London: Overseas Development Institute (ODI).

Agroforestry in the Pacific Islands

William C. Clarke

The planting of trees together with the cultivation of annual crops, a combination now generally termed agroforestry, has been strongly promoted in recent years as a way to prevent land degradation and to increase total production of food and useful products from a unit of land. Throughout the Third World, development agencies and government departments of agriculture and forestry have been advocating agroforestry as a way to harmonize forests with farming, or as a way to make up, at least partially, for the destruction of natural forests and their replacement by pasture or by fields of annual crops. In the Pacific these modern, aid-funded attempts to promote agroforestry are ironic, for they take place in a region where agroforestry systems were developed thousands of years ago and where hundreds of species of trees are still used in a be wildering variety of ways.

At least a few trees even have a place in the popular imagination about the Pacific Islands. If asked what particularly characterizes the landscape of the islands, most people would think of a line of coconut palms overhanging a beach beside a coral-reef lagoon. They might also envision the stately and strikingly beautiful breadfruit tree, whose yield of starchy fruit so enchanted Captain Cook and his companions on the first European visit to Tahiti and subsequently led to Captain Bligh's famous voyage to Tahiti in H. M. S. *Bounty* to collect breadfruit cultivars for the West Indies. These conceptions of coconut palms and breadfruit trees in Pacific landscapes are accurate enough, but they only begin to suggest the full significance of trees, both domesticated and wild, in the lives of traditional Pacific peoples.

Recent chromosomal and paleo-botanical studies in the Melanesian islands of the western Pacific reveal that the domestication of plants extends back in time there for thousands of years, thus demonstrating that agriculture evolved endogenously in the Pacific region, rather than being solely or mainly the result of a direct transfer from southeast Asia, as had been believed previously. Plants that may have been domesticated in western Melanesia include – aside from important short-term crops such as *Colocasia* taro and sugar cane – a remarkable number of trees or shrubs. This early emphasis on arboriculture – the cultivation of trees and shrubs – was eventually transported all across the Pacific by the voyaging colonist cultivators, to be incorporated into production systems everywhere and to beget the typical tree-filled environs of human settlements in Polynesia and Micronesia.

Archaeological evidence for a well-developed arboriculture at least 3,500 years ago comes from the Mussau Islands, which are now part of the country of Papua New Guinea. Tree species already in use then included: coconut, two or three species of *Pandanus*, *Inocarpus fagifer* (the "Tahitian chestnut," which remains one of the most important Oceanic arboricultural species), *Canarium indicum* (a nutritionally substantial "almond"-producing tree in Melanesia), *Spondias dulcis* (the vi-apple, now of very wide distribution in the tropical Pacific), and other useful trees such as *Pometia* (which provides edible fruit, medicine, and other products), *Pangium* (seeds edible after treatment to remove the poisonous component), *Terminalia* (edible "beach almond," useful timber), *Burckella* (edible fruit), and *Calophyllum* (timber favored for many uses, sticky sap used for caulking canoes). There is also evidence for the early domestication in the Pacific of several species of sago palm (used in some places to produce starch for food, elsewhere its leaves used as long-lasting house thatching), one kind of banana, and kava (a sprawling shrubby plant, the pounded stems and roots of which are used to make the ritual-social drink long important in many parts of the Pacific).

Over 400 species of trees or tree-like plants have been identified as having widespread or localized economic, cultural, and ecological importance in the Pacific Islands. The adoption of these many kinds of trees for human purposes is the cumulative result of a selection process that occurred over thousands of years and that involved both the domestication of previously unknown species encountered when Pacific voyagers landed on uninhabited islands as well as the deliberate transport from island to island of plants already known to be useful. The trees and their products served Pacific peoples in a great variety of ways. For instance, ecologically, trees provided, among other services, shade, erosion control, wind protection, beach stabilization, soil improvement, and frost protection (at high elevations in New Guinea). Cultural and economic uses included, among many others, house timber, firewood, tools, weapons, fishing equipment, abrasives (for example, the "sandpaper" leaves of some fig species), gums and oils, fiber, beverages (for example, the fluid from coconuts, immensely important for drinking on dry atoll islets), caulking, stimulants, medicines, and love potions and perfumes. Many Pacific trees are also of great importance nutritionally. For example, in various places people depend heavily on one or a combination of staple foods from coconut, breadfruit, bananas, sago palm, or several species of *Pandanus*. Many other species provide supplementary and snack foods. Although many tree foods are energy-rich in carbohydrates or vegetable fats or both, it is in other nutritional essentials that they often excel, compared with the starchy root-crop staples. Several fruits are excellent sources of provitamin A; others provide B-complex vitamins or are rich in vitamin C. Most seeds and green leaves from trees (which are widely eaten) are good sources of plant protein and various micronutrients. Spices and sauces derived from tree products can also be of great nutritional and culinary significance. An oily sauce made from the huge red fruit of a *Pandanus* species in highland New Guinea provides a rich, nutritious condiment for many otherwise bland foods. Or coconut milk or cream (squeezed from the coconut flesh) is widely used in cooking in coastal areas, and in places is aged or fermented with sea water and other flavorings to make a tasty sauce that enhances local cuisines.

The multipurpose nature of many Pacific trees in providing a diversity of different products or services to people is well exemplified by the breadfruit. Its straight trunk is valued for canoe hulls; the inner bark is used to make bark cloth in some areas; the tree's thick, milky sap is used for caulking canoes, as adhesive for bark cloth, and as chewing gum; its large leaves are used as plates and for wrapping food for cooking in earth ovens; the dried inflorescence is burnt as a mosquito repellant; and the fruit is eaten cooked as a staple or important supplementary food in most areas of Polynesia and Micronesia and as a supplementary food in Melanesia, where seed-bearing varieties are often more important than the seedless varieties used as a staple food in Polynesia.

Like most trees, the breadfruit's production of fruit is seasonal, so that people dependent on it for food can expect periods of food shortage recurrently each year. Pacific-Island peoples developed two solutions to this problem. First, high intraspecies diversity had been developed in breadfruit (and most other domesticated crops) by centuries of observation, selection, and transportation of promising varieties from place to place. As only one example of the prolific number of named cultivars that might have been accumulated within a single species, the volcanic island of Pohnpei in Micronesia is reported to have 150 named varieties of breadfruit. Generally, each of the many cultivars followed its own distinct calendar, so that production of breadfruit on atolls and high islands of Polynesia and Micronesia (or, to give another example, the yield of *Pandanus* fruits in highland New Guinea) is staggered over a much longer period than would be available from a single cultivar or individual tree. The second way in which the availability of food from breadfruit was extended over the year was by the pit fermentation of the fruit so that it could be stored. Unlike grains, there were few Pacific-Island indigenous foods except yams (*Dioscorea* spp.) that if unprocessed last long in storage once harvested. Because harvested breadfruit lasts only a few days, a way had to be found whereby the seasonal surpluses could be accumulated for later use. The method developed was pit storage. After the ripe fruit was peeled and cored, it was preserved by a process of semianaerobic fermentation, involving intense acidification, which reduces the fruit to a sour paste that lasted in storage for decades. The pits, which served both as fermentation chamber and storage area, were dug in clay soil to prevent water seeping in and then lined with stones, woven mats, and a variety of leaves to keep soil from mixing with the breadfruit paste. Modern food analysis shows that the fermented product contains more carbohydrate, fat, protein, calcium, iron, and B vitamins than the fresh fruit. The pits of breadfruit paste also provided a reserve food supply after tropical cyclones, or hurricanes, devastated gardens and orchards or during times of warfare. Packages of the baked fermented paste wrapped in leaves also provided a portable, long-lasting food for sea voyages.

Although trees had a great significance in people's lives almost everywhere in the traditional Pacific, the hundreds of species utilized were combined in a great variety of unique agroforestry systems, each distinct to particular locales spread over hundreds of islands, each with a unique environment and each occupied by a distinct group of Pacific peoples, with their own particular history and set of agricultural techniques. In forested areas of low population density where shifting cultivation was practiced, a mixture of certain trees might be planted in old gardens, creating orchards that produced food, fiber, and other products for decades while also serving as a kind of fallow for the gardened soil, which eventually would be reused. The spontaneous secondary forest in such areas came to be everywhere dotted with valuable trees, remnants of past orchards and gardens. Elsewhere, in drier, more heavily populated areas where complex irrigation channels had been built to bring water to permanent plots of taro, there might also be permanent and highly diverse tree gardens surrounding the irrigated plots and shading the villages. On atolls, with their severe environmental constraints, a particularly intensive form of agroforestry had been developed to support the often high population densities. Spread through a matrix of planted coconut palms, which were particularly common and immensely useful on atolls, were a variety of other domesticated trees including species of *Pandanus*, breadfruit, and a native fig. As in much of the Pacific, what might look like an untouched natural forest to an uninformed eye was in reality a managed agroforest in which almost every tree was known and owned by an individual or a family and served at least one valuable purpose if not several. Unfortunately, a variety of present-day socioeconomic factors and changes are leading to a decline of traditional agroforestry in the Pacific region.

References

Budd, W. W., et al. (Eds.). (1990). *Planning for agroforestry*. Amsterdam: Elsevier.

Clarke, W. C., & Thaman, R. R. (Eds.). (1993). *Agroforestry in the pacific islands: Systems for sustainability*. Tokyo: United Nations University Press.

Kirch, P. V. (1989). Second millennium BC arboriculture in Melanesia: Archaeological evidence from the Mussau Islands. *Economic Botany, 43*, 225–240.

Lebot, V., Merlin, M., & Lindstrom, L. (1992). *Kava: The pacific drug*. New Haven, CT: Yale University Press.

Ragone, D. (1991). Ethnobotany of breadfruit in Polynesia. In P. A. Cox & S. A. Banack (Eds.), *Islands plants, and Polynesians: An introduction to Polynesian ethnobotany* (pp. 203–220). Portland, OR: Dioscorides Press.

Vergara, N. T., & Nair, P. K. R. (1985). Agroforestry in the south pacific region? An overview. *Agroforestry Systems, 3*, 363–379.

Yen, D. E. (1974). Arboriculture in the subsistence of Santa Cruz, Solomon Islands. *Economic Botany, 28*, 247–284.

Agroforestry: Agri-Silviculture

Harold Olofson

Agri-silviculture is the intercropping of timber and fuelwood species and/or fruit and other useful trees with vegetables and other crops in a common space, at the same time. It may characterize a harmonic ▶ swidden (see ▶ Agroforestry: Harmonic Swiddens) where fallow periods are sped on their way toward full fertility and a forest architecture by the purposive planting and protection of leguminous and fruit trees in the cropping period or afterwards. Or it may be found in permanent farms. In the first case, we can refer to such swiddens as accelerated swiddens, to be distinguished as a term from the Food and Agriculture Organization's "accelerated fallow" to refer to swidden fallows which, because of population pressure, must be planted to food crops before they have recovered full fertility. In agri-silviculture, the sylvan component of the field is cultivated through practices like weeding and thinning. Agri-silviculture is an example of Alternative Forest-like Structures (AFS) because of the presence of arboreal species which provide some values of the forest. It is also a simultaneous polyculture. Indigenous examples follow.

Within swiddens themselves we frequently find that swiddenists are making efforts to encourage reforestation at a very early stage by interplanting forest trees and tree crops. These are then simultaneously harmonic, polycultural swiddens, as well as examples of agri-silviculture. Agri-silviculture is one type of indigenous agroforestry that seems identical with some of the ideas which modern agroforestry has adopted. From various anthropological sources on the Lingnan Yao of Kwangtung Province, China, which were written in the first third of this century, a summary of their agri-silviculture has been constructed.

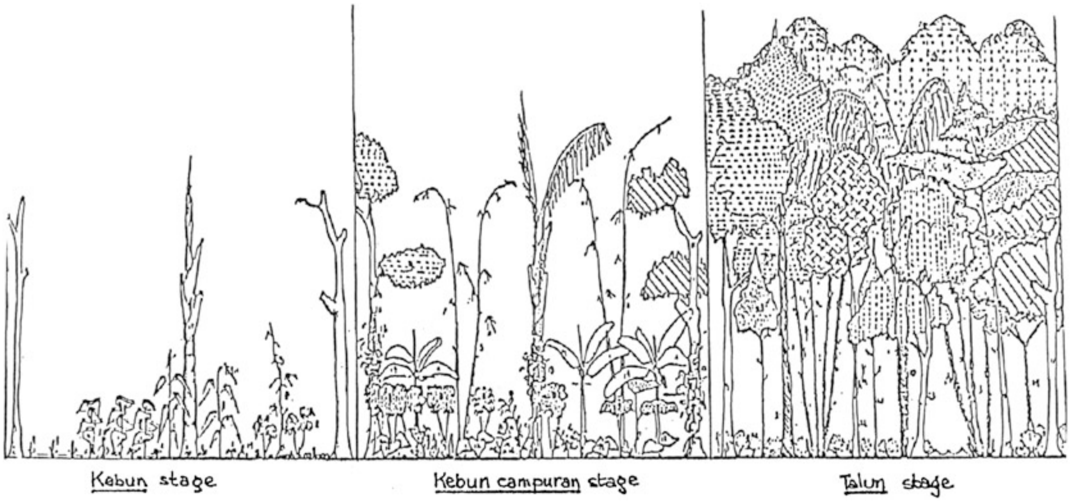
The first year after burning, a swidden is used mainly for mountain rice and maize; the second year for sweet potatoes; and the third year for taro. Simultaneously with the first planting, seedlings of various economically important trees are put in the ground. At the end of 3 years, these are large enough to discourage further growth of weeds and grasses. The swidden is thereafter fallowed for 18 or 19 years until the trees are large enough to be cut for timber (Lebar, Hickey, & Musgrave et al., 1964, pp. 82–83).

They go on to say that cedar and ▶ bamboo are also planted in the swidden. The Lingnan Yao apparently have had a symbiotic relationship with the Han Chinese. The Yao are skilled neither in timber extraction nor in woodwork. In exchange for allowing the Chinese to take most of the timber and other forest products, the Yao receive rice, paper, cloth, salt, guns, and the skilled carpentry of the Chinese. Thus while the Yao grow the timber, the Chinese cut it and transform it into useful shapes (Lebar et al. 1964, pp. 82–83). A search should be made for indigenous agroforestry models among other South China cultural minorities.

Acceleration appears to begin with selective weeding in the swidden so that forest tree seedlings that have established themselves can survive. In his description of the Tsembaga Maring, Rappaport noted that one is chided for stepping on what is called "the mother of the forest" – tree seedlings that are appearing in the ▶ swidden but not recognized by the visitor (Rappaport, 1971, p. 122).

For the Siane of New Guinea, Salisbury provides this description of the importance of *Casuarina*:

> Casuarina trees [*Casuarina equisetifolia*] provide wood for fencing, fuel, and house building, and their growth as a secondary tree cover is facilitated by the weeding of garden sites. This prevents the growth of kunai-grass, which would crowd out young casuarina roots. If the casuarinas are given a chance to establish themselves, their shade often prevents the spread of the sun-loving *kunai*.



Agroforestry: Agri-Silviculture, Fig. 1 Successional stages in the *talun-kebun* agroforest of the Sundanese, West Java (From Christanty, 1982, p. 20)

> The growth of casuarinas is deliberately encouraged, and gardens are often made when a boy is born, with the explicit expectation that this will provide a crop of timber for the boy at the time of marriage, and so enable him to build a house and fence a garden for his wife. Occasionally, too, casuarina seedlings are deliberately planted in areas which no windblown seeds could reach. This happened, for example, in 1941 when Antomona clan of Emenyo tribe returned to their devastated village site, where all trees had been ring-barked following their rout and expulsion in a war. Thus casuarina trees may be considered "cultivated" plants. (Salisbury, 1962, p. 43)

Thus it was considered enough to completely conquer an enemy by ring-barking all of the casuarinas in his territory. This would mean that the vanquished would have to retreat up to the high mossy forests to make their swiddens, while their forest areas lower down might run the risk of grassy invasion, since ghost-fear would prevent these areas from being immediately assimilated into enemy territory (Salisbury, 1962, p. 48).

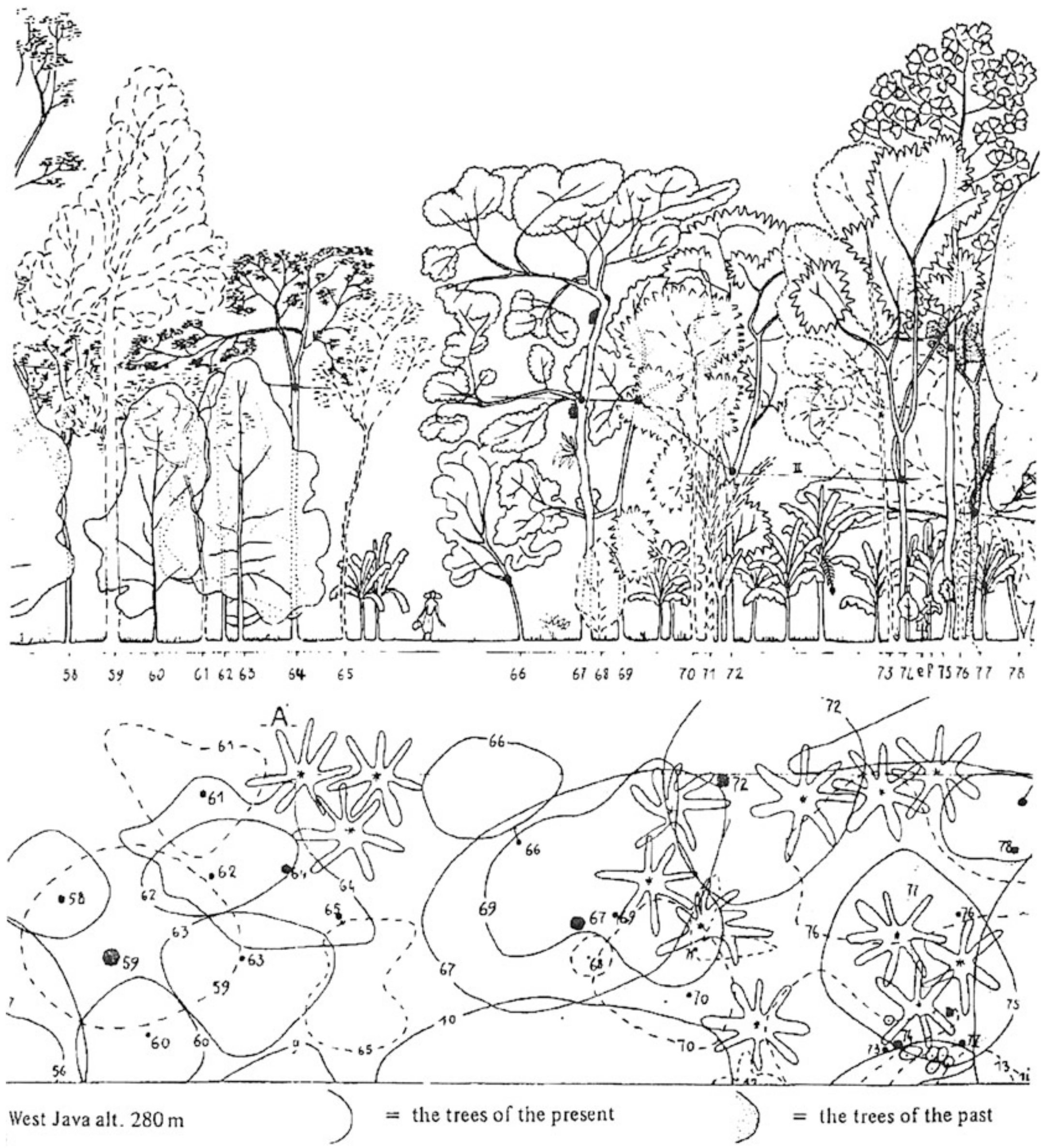
These accounts reveal that traditional swiddenists are frequently capable of long-term future orientation when it comes to forest regeneration, but primarily in the context of viewing the trees that are so protected and preserved as being useful to people.

Given the right economic conditions, this propensity to accelerate swiddens can evolve into a completely stable form of horticulture with the establishment of orchards. This has been described for the Cuyunon of Palawan Island, Philippines. Many of them have made this transition since the 1930s as a response to the flourishing nearby market and port of Puerto Princesa. As an ethnographer describes it,

> Orchards are usually established as an adjunct to swiddening. A farmer systematically intercrops his newly-planted swidden with tree crops and then controls regeneration of herbaceous secondary growth until the tree crops are established (Eder, 1981, p. 95).

The land used for tree crops, which are mostly fruit of many different species, is in this example taken right out of the swidden cycle.

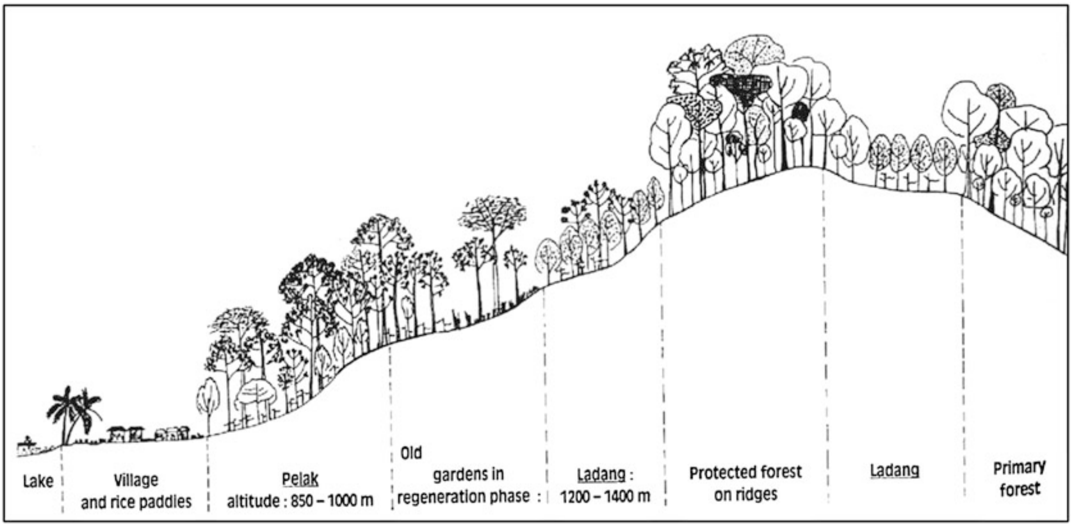
Cairns (ca. 1995) discovered that the nitrogen-fixing (even though nonleguminous) *Alnus nepalensis* (an alder) enables the Angami Naga shifting cultivators of the Himalayan foothills in northeast India to accelerate their swiddens without causing ecological damage. Oral histories collected from village elders revealed that this has been going on for 500 years, ever since alders invaded the originally opened fields and always seemed to enhance the growth of crops planted near them. The Angami came to protect individual alders (which coppice prolifically and thus are good renewable sources of firewood) and their



Agroforestry: Agri-Silviculture, Fig. 2 Partial profile of a *talun-kebun* agroforest of the Sundanese, West Java (From Michon et al., 1983, p. 126 ff)

seedlings, and through the centuries actively to plant them in their fields. This intensification of their agroforestry was probably a response to the fact that the fields had to be clustered near the village due to the hostility of neighboring communities of head-takers. Swiddenists had to be able to retreat quickly to their walled villages.

Over 2 years of cropping, the alders are pollarded for firewood twice, at the reopening of the fallow and again 12 months later. This is to allow sunlight to reach the staple crops of upland rice and pearl millet, and others. The alders are then left to grow and dominate the tree canopy in the next fallow period of 2 years. During that

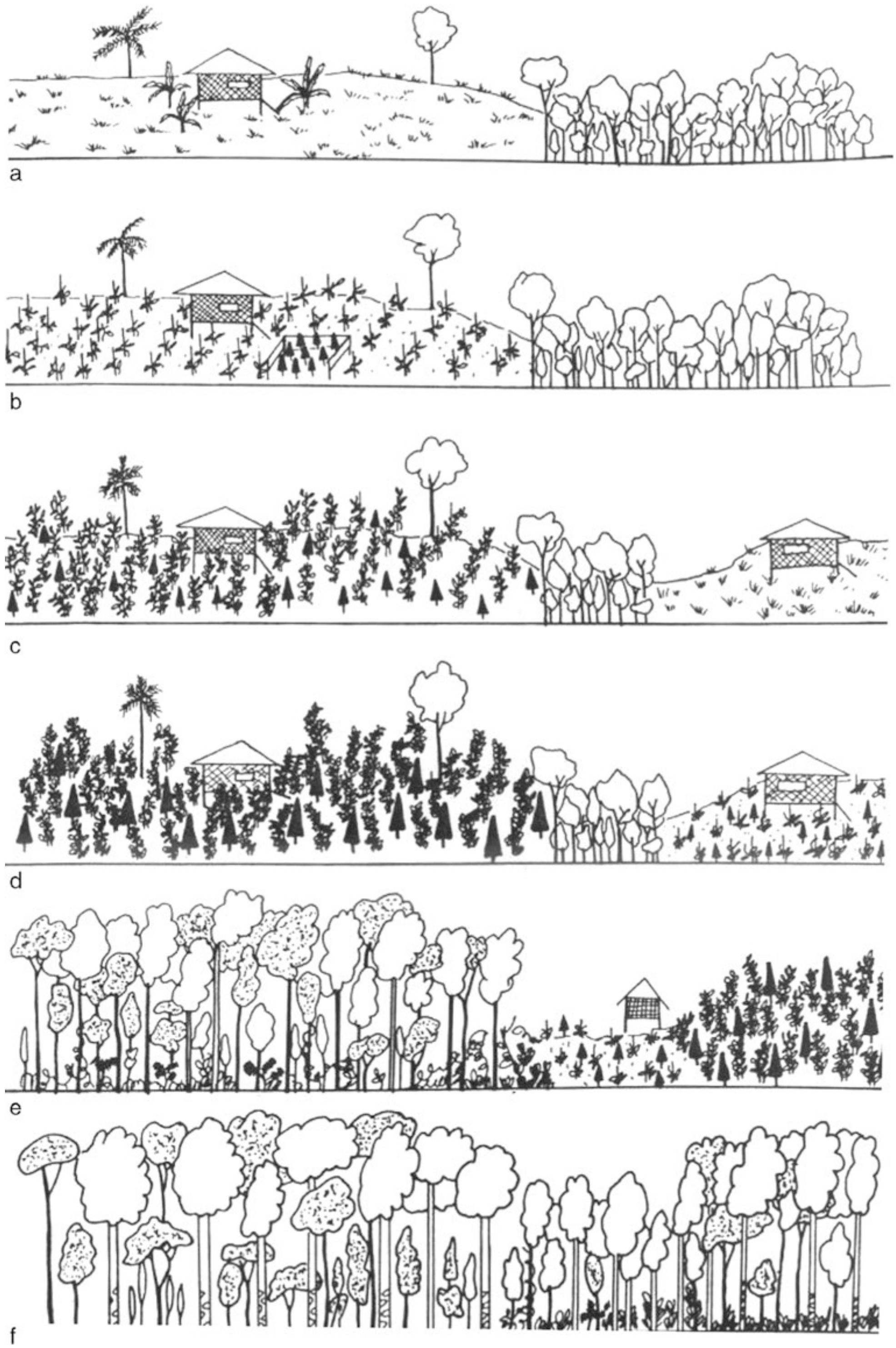


Agroforestry: Agri-Silviculture, Fig. 3 Schematic diagram of land use in Semarang village, at the edge of Kerinci Seblat National Park, Sumatra, Indonesia (*ladang* = swidden) (From Aumeeruddy-Thomas, 1994, p. 22)

fallow, the trees' "extensive roots draw nutrients from a large soil area and return them to the surface in high volumes of nutrient-rich litterfall" (Cairns, 1995, p. 7). As a result, Cairns maintains, the Angami Naga do not remember ever having suffered from this rapid succession of fallow and cropping periods. It is made possible by the presence of the alders, and "without the need of outside technologies, investment capital, or excessive labor inputs." This system is a model for how to stabilize shifting cultivation.

The Huastec Indians of Veracruz State, Mexico, manage stands of forest trees named by them *tel'om* (Alcorn, 1981, pp. 409–410). These are particularly closely managed in communities sited near markets. This can be done by adding shade-loving coffee trees into the forest, in places where some forest trees have been cut down to allow space for them. Those trees and vines which are particularly useful for construction are spared. In the shade of the coffee trees, cassava and chili peppers are planted. Furthermore, a species of valued medicinal palm, mango, and citrus trees may be added. The *tel'om* includes both primary and secondary species, as well as useful species introduced from other plant communities. The managed forest is used by women and children for food gathering and play, and streams running through it are sites for bathing and laundering. Within a range of humanly managed plant associations moving from crop field to natural forest, the *tel'om* approaches the forest in structure, but Huastec culture has turned it into a multiple use artifact which can persist for many years as a stable ecosystem. Having originated as an enriched fallow, it need never be opened again for ► swidden.

Closely related to the *tel'om* conceptually are the "village-agroforests" of the Sundanese in West Java, Indonesia. Named *talun-kebun*, these cover up to 50 % of a village's cultivated land (Christanty, 1982; Michon et al., 1983, see Figs. 1 and 2). Thus they are not to be confused with mixed dooryard gardens, which these farmers also have, for they are found further away from the residences. Architecturally imitative of the tropical forest ecosystem in their structure and bio-diversity, Michon et al. (pp. 118, 120) say that they "should be described in the same way as natural forest ecosystems" as well as "in terms of an agricultural lay-out." As in the *tel'om* of the Huastec, the Sundanese *talun-kebun* preserves wild vines, bananas, and trees. Annuals and perennials are mixed with wild and domesticated plants and livestock (chickens, sheep, and goats)



Agroforestry: Agri-Silviculture, Fig. 4 From rice field to coffee plantation to damar (*Shorea javanica*) agroforest in Krui, Sumatra (From Michon et al., 2000, p. 184)

Agroforestry: Agri-Silviculture, Fig. 5 Profile of an agroforest showing an association of timber, legume, and cinnamon tree crops, Jujun, Kerinci, Sumatra (From Aumeeruddy-Thomas, 1994, pp. 28–29)

as well. Crop species can reach up to 250 in number. This richness prevents the spread of plant pests and diseases and "represents an invaluable gene pool on an island [Java] where original forests have about disappeared" (Michon et al., pp. 118–119). Like the *tel'om*, the *talun-kebun* evolved out of the fallowing phases of an older shifting cultivation, no doubt in response to increased population pressure.

Much study has been done recently of indigenous agroforestry in Sumatra, Indonesia that has been able to restore biodiversity to the forest by incorporating cash tree crops into village forest gardens (Aumeeruddy-Thomas, 1994; Michon et al., 2000; see Figs. 3, 4, and 5).

In the agri-silvicultural form of accelerated swidden, crops may sometimes support the trees. This can occur if some of the crops are nitrogen fixing. But more importantly, food crops that are interplanted with tree seedlings have the function of giving the farmer quick returns, which he may require before he is willing to go into the venture of a long-term investment in the form of trees interplanted with his crops.

References

Alcorn, J. B. (1981). Huastec noncrop resource management: Implications for prehistoric rain forest management. *Human Ecology, 9*(4), 395–417.

Aumeeruddy-Thomas, Y. (1994). *Local representations and management of agroforests on the periphery of Kerinci Seblat National Park, Sumatra, Indonesia*. Paris: UNESCO. Also at http://www.rbgkew.org.uk/peopleplants/wp/wp3/index.html.

Cairns, M. (1995). *Profile of [an] Alnus nepalensis-based swidden system: A working paper*. Bogor, Indonesia: International Centre for Research on Agroforestry, Forest Research and Development Centre.

Christanty, L. (1982). *Traditional agroforestry in West Java, Indonesia*. Honolulu, HI: Environment and Policy Institute, East-West Center. Unpublished paper.

Eder, J. F. (1981). From grain crops to tree crops in the Cuyonon swidden system. In H. Olofson (Ed.), *Adaptive strategies and change in Philippine swidden-based societies* (pp. 91–104). Los Baños, Philippines: Forest Research Institute.
Lebar, F. M., Hickey, G. C., & Musgrave, J. K. (Eds.). (1964). *Ethnic groups of mainland Southeast Asia*. New Haven, CT: HRAF Press.
Michon, G., et al. (1983). Tropical forest architectural analysis as applied to agroforests in the humid tropics: The example of traditional village agroforests in West Java. *Agroforestry Systems, 1*, 117–129.
Michon, G., et al. (2000). The Damar agroforests of Krui, Indonesia: Justice for forest farmers. In C. Zenner (Ed.), *People, plants and justice: The politics of nature conservation* (pp. 159–203). New York: Columbia University Press.
Rappaport, R. A. (1971). The flow of energy in an agricultural society. *Scientific American, 225*(3), 116–132.
Salisbury, R. F. (1962). *From stone to steel*. London: Cambridge University Press.

Agroforestry: Field-and-Grove Systems

Harold Olofson

This is the most interesting, complex, and varied form of indigenous agroforestry. The fields can be either harmonic or disharmonic swiddens, accelerated swiddens (agrisilviculture or agroforestry rotations), irrigated or nonirrigated permanent fields, or combinations of these. But they are interspersed with groves of trees that may vary along a range from predominantly wild forest species that are consciously conserved to groves largely composed of domesticated tree species planted by people. These two components may alternate or be scattered in a highly productive mosaic across the landscape of a village, district, or watershed. There may also be a tendency over a long period for some fields to become groves, and some groves to become fields, with both components thus slowly migrating across the landscape, producing in effect a very long-term agroforestry rotation. I was able to find four different types of field-and-grove systems in the literature available to me.

The Field-and-Forest

In some countries having temperate climates, these have been a feature of indigenous agroforestry. In England, patches of trees are known as copses when they are composed of species that can be managed by coppicing (cutting back trees regularly to encourage more growth). Larger woodlots and forests have been preserved for centuries as a source of game, deadwood for fuel, honey, and visual pleasure (see Rackham, 1985). But in more definite examples of the "field-and-forest," forest resources may be more consciously pulled into the support of agriculture than they usually are in swiddening systems, where the forest tends to take on the passive role of a growing fertilizer reserve. The forest becomes more markedly a component of an agroecosystem.

In many areas of Japan, it is the custom to maintain a forest adjacent to wet-rice fields so that litter from the forest floor can be annually incorporated into the pondfield soils. This may in some measure account for the traditional high productivity of Japanese rice farmers. But the groves are subject to premature aging as a result of the fact that they are not allowed to reabsorb their own litter as food (Kira, 1976, pp. 36–37).

Some fascinating examples of field-and-forest relationships are described by Wilken (1977) for Mesoamerica. As in Japan, in western Guatemala and Mexico he observed the "transfer of the forest floor to the fields." Leaf litter is scattered onto the fields and turned into the soil to improve its structure and moisture retention. The litter may first be placed on the stable floor, where it picks up nitrogen content from the urine of livestock. Also, forest materials may be transported to the field to provide protective microclimates, in the form of mulches to reduce radiation and evaporation from the soil and absorb the impact of raindrops, or actual shelters in the form of leaves and branches to perform similar functions and to allow cash crops to become gradually attuned to the open field. Wilken uses the term "forest structure mimicry" to describe the protective uses of litter and also the custom of letting leguminous trees or pines to simply invade the fields, leading to an eventual replacement of the field by a grove.

Wilken, like Kira, points out that the practice of forest litter removal may have deleterious effects on the forest. However, one could easily imagine long-term experiments to determine the best system of leaf-litter removal management so that no section of the forest floor is harvested year after year, thereby at least prolonging the life of the grove.

The Field-and-Sacred Grove

A second variant of the field-and-grove type of indigenous agroforestry is found primarily among shifting cultivators who maintain forests, which they believe are inhabited by spirits or deities. These are thought of as fiercely defending their homes by visiting illness on human intruders. An excellent example is found in the Philippines among the Tagbanuwa on the island of Palawan, described by Fox (1982, pp. 163–76; for India see Gadgil and Vartak, 1976). When a Tagbanuwa selects a site in the forest for making a ▶ swidden, it must be first determined by a religious practitioner (the shaman) whether there are malevolent spirits (*panya'in*) who claim the place. He or she enters the forest alone, makes an offering, and perhaps experiences a trance or dream in which an answer is received from the spirits. If the results are negative, the area becomes untouchable, and swiddens cannot be opened in it for the lifetimes of the shaman and the shaman's spouse. Another way of testing a potential site is described by Katherine Warner.

> . . .A potential site was further tested for the presence of a *panya'in* by sticking a piece of ▶ bamboo into the ground. The next day when the bamboo was pulled out, if there was dirt sticking inside it, it was said that it was a *panya'in*'s area and that sickness would come if it was planted. Interestingly, the test that showed the presence of the forest spirit on another level gave information on the texture and suitability of the soil. If the soil is hard and stays in the bamboo, it is not quite ready to be planted, whereas if it is soft and fine textured it will fall out, indicating not only the absence of *panya'in* but also the suitability of the soil for planting. (Warner, 1981, p.. 20)

The result in Tagbanuwa country has been a patchwork effect of swiddens, fallows, secondary growth, bamboo groves, useful grasses, and sacred groves, which has led to a harmonic and productive system that allowed the Tagbanuwa to live in what for swiddenists are quite large villages without depleting the nearby land. The numerous ecotones (well-defined boundaries typical of closed communities) also have insured the abundance of wildlife and game. But unlike the systems described by Wilken, forest material cannot be moved to the field, as sickness and death might follow the breaking of the taboo against trespass. However, the groves provide seed, which can reach the centers of swiddens easily since the Tagbanuwa do not arrange their swiddens in clusters. With the death of the shaman or the migration of his village, his taboo would be forgotten, and a later shaman might come in and determine the former sacred patch to be safe for swiddening. The long-term effect of this again was an agroforestry rotation between fertile sacred groves and cultivated areas.

In field-and-sacred grove systems, forest resources are not used consciously in support of agriculture. But the existence of the grove is preserved so that it can be truly available to play eventually its integral role in shifting cultivation along with all forest vegetation as the "beginning and end" of the swidden cycle, as Warner has expressed it in a nice way (1981, p. 27).

Apel (1996) describes the complex forest management of the villages of the Dai minority people in Yunnan Province, China. The bulk of their forests are "amenity forests," which provide an aesthetic setting for each village, an expression of a value rare in tropical Asia. Watershed forests are "used forests," recognized as providing construction timber and an adequate supply of water for each village and its rice pondfields. "Forests without special functions" are another kind. All types of forest have high species diversity. About 5 % of forests are considered sacred. There are three kinds of these. "Sacred natural woodlands" are wild and have been considered sacred since animist, pre-Buddhist times and are situated on hilltops adjacent to villages. Hunting, tree felling, and collecting are all forbidden there.

"Sacred groves," purposively planted near Buddhist temples, are biodiverse, providing sanctuary for rare plants, and yield fruits for Buddhist monks. "Forest cemeteries" must be kept separate from the village at an elevation well below it. Conceptually distinct from all of these are individual "sacred trees," especially the strangling fig (*Ficus altissima*) with its many striking features, which can be planted in sacred Buddhist groves, found wild on hilltops as the homes of spirits and sites of sacrifice to them, or scattered throughout the "used forest." In the latter case, there is a taboo against felling the *Ficus* for use, and they serve a positive ecological function in assuring that frugivores (birds and mammals) have a food supply available to see them through periods of wider food scarcity, thanks to the characteristic of figs to bear fruit at different times. Apel claims that the taboo against cutting down the strangling fig thus prevents local degradation of the forest through overexploitation.

McWilliam (2001) has gathered significant evidence to say that probably all communities on the Island of Timor historically recognized, and many still do recognize, within the districts belonging to them, sacred (*lulic*) forests or groves, existing within government forest land, which they protect against shifting cultivation. Today, much of Timor's forest has been denuded of vegetation, and sacred groves remain as relicts of the wider forest. Depending on the traditions of the varied cultures concerned, sacred groves may have been preserved as the "mythic origin places of local clan groups" and sites of religious sacrifice to those founding ancestors (McWilliam, 2001, p. 97). McWilliam makes a case for East Timor government support of these "forest custodial communities" as entry points for "negotiated reforestation activities," the responsibility for which can be shared between Timorese government and villages. The basis for this survival of sacred groves, he contends, is a tradition of "rural land management and protection" which "provides a powerful source of moral authority and ecological knowledge" that could lead to sustainable conservation programs. This bold suggestion could be true for places other than Timor, as well.

The Field-and-Woodlot: The Ifugao Pinugo

The most striking example of a field-and-grove system is that of the Ifugao of the Cordillera Central mountain range in northern Luzon, Philippines. This system, which may be 1,000-years old, has been described by Harold Conklin (1980; for a review article on this see Olofson, 1980). The Ifugao are best known for their wet-rice terraces and irrigation technology on steep terrain. But few know that their woodlots, or *pinugo* as they call them, among pondfields, or at higher elevations, are almost as interesting. Sweet potato swiddens, too, are found at high elevations of a watershed. The most instructive aspect of the Ifugao woodlot is that it is made out of grassland (and secondary forest) through an intermediate ► swidden stage. To the Ifugao, making a swidden is the logical first step in reforestation. In the swidden stage, the land being used is not owned by the one making the swidden; he only has the right to use its products. But when a family member decides to grow a woodlot on this swidden, it becomes recognized by all families in the watershed that it is now owned, as a piece of land, by that individual, and its boundaries will be clearly demarcated for all to see.

The Ifugao woodlot is itself an agrisilvicultural system. The only kind of economic plant not grown appears to be vegetables and tubers, if Conklin in his account has mentioned everything. But there are plantings of trees for firewood and for the provision of building materials, utensils, furniture, tools, and religious figurines; fruit trees and grove crops such as betel nut; bamboos and rattans; and medicinal plants. According to Conklin, the species diversity exceeds that of the natural forest. The woodlot is weeded, pruned, and thinned as it grows. It has in fact grown out of an accelerated swidden. And, it might be added, that as a woodlot is harvested and ages, it reaches a later stage in its cultural successional sere.

Oftentimes, the Ifugao cluster their swiddens together, perhaps to defend them better from wild pigs by digging trenches on the edges of the cluster. When the swiddens are converted into woodlots, the cluster is more ecologically sound as a forested expanse than would be a single cluster alone.

Besides supplying the Ifugao with numerous products, which make woodlots second only to pondfields in economic value, the woodlots are overtly recognized by the Ifugao as supportive of the terraces, though not by the use of tree litter as fertilizer (this comes from the floor of the public forest). They are well aware, rather, of the fact that they aid crucially in conserving the water needed in irrigation, and in preventing soil erosion and land slippage. Conklin found that even children could talk about this. In addition, when the woodlot becomes aged and completely harvested it can be reconverted to swidden, at which time its soil should be particularly fertile for sweet potato.

The Field-and-Mixed Home Garden

Of some importance as indigenous agroforestry are field-and-grove systems in which the grove component is the mixed tropical "dooryard," "kitchen," or "home" garden. The dooryard garden represents a distinct agricultural enterprise with its own integrity and often with crucial connections to the farm component. Such gardens are similar to harmonic, polycultural swiddens, except that more important in them are fruit trees, which provide a protective canopy under which other plants are grown, and that perhaps as a result of the need for closed nutrient cycling as in forests, have become permanent. Stuart Schlegel (1979) in his description of the home gardens of the Tiruray of Mindanao finds that they are in fact a terminal stage in swidden. They would thus in Tiruray be an equivalent to the Ifugao woodlot, which also develops out of ▶ swidden, except that the Ifugao woodlot may be some distance from the house.

Home gardens are of great significance on the world's most densely populated island, Java, where they are called *pekarangan*. First of all, this is due to their ability to protect the soil through forest mimicry. Among the first to note this was the geographer Karl Pelzer (1945, pp. 43–47) drawing on the work of Ochse and Terra in Indonesia. Then, according to an economic anthropologist, who was also including *talun-kebun* (village-agroforests) in her statistics,

> [For Java] . . . garden land . . . makes up anywhere from 15 % to 75 % of the cultivable land area, may provide more than 20 % of household income, and more than 40 % of a household's caloric requirements. (Stoler, 1978, pp. 86–87)

Another interesting statistic comes from Terra (1966), who found that once well established and continuously producing throughout the year, the home garden grove in Java requires only five-man days of labor per year for its upkeep. Finally, Indonesian ecologists, noting that dooryard gardens in some overfarmed areas of Central Java "look like green oases in a desert of eroded hills," have characterized them as the last line of defense against ecosystem degradation (Soemarwoto et al., 1976, p. 194). These same observers go on to suggest that they could be expanded spatially to become *talun-kebun* and begin a rehabilitation of these same uplands. In this last regard, Central Javanese home gardens are fulfilling the same function as has been reported for sacred groves in western India (Gadgil & Vartak, 1976) by representing the last patches of forest-like cover in the landscape.

Pelzer believed that mixed home gardens were not well developed in the Philippines. But recent work by Sommers (1978) has shown that they are rather widespread there, and the problem remains of diffusing them further to the many households where they are yet nonexistent or underdeveloped.

From descriptions such as Stoler's, it is clear that Javanese home gardens are an alternative forest structure (AFS).

They often lack the orderly appearance of other forms of cultivation. They seem a haphazard array of scattered trees, untended plants, crawling vines, and decaying vegetation. In fact the lack of orderly rows and clean swept vegetation is precisely what allows *pekarangan* to produce its own natural fertilizers, and remain erosion-free even in critical watershed areas of poor land use. The multileveled "disorder" functions in part to prevent unnecessary organic waste found under other systems of cultivation (Stoler, 1978, pp. 88–89).

She goes on to mention timber trees as one of their products.

By viewing home gardens as part of a field-and-grove system, we throw them into a wider context. The ways in which they are related to the staple field, livestock, and other gardens are probably many and varied, but not covered systematically in the literature in any one place. One thing that stands out from putting together scattered references on the dooryard garden, especially in the context of shifting cultivation combined with stable residences, is its role as an experimental site for new varieties of vegetables and even staples borrowed from neighboring people or visitors. If these do well in the dooryard, they may be grown on a wider scale and even tried out in the main field. For example, among the wet-rice growing Bontok in northern Luzon, Philippines, where sweet potato grown in swiddens is calorically more important than rice grown in mountain terraces, new varieties of sweet potato are planted first in the *doran*, which is found around the house. This area acts as a reserve for all kinds of cuttings, and also has fruit trees, green vegetables, and other root crops. From the *doran*, the cuttings may be transplanted to swiddens or fed to pigs (Yen, 1974, pp. 92, 95, 96).

This brings us to the connection between home gardens and livestock. Among the Ikalahan of northern Luzon, papaya, chayote, and sweet potato vines from the dooryard go into the special pig's cauldron in the kitchen where cooked food is prepared for them daily (Olofson, 1984). The Ikalahan pig, however, is allowed to roam freely to hunt for mast on the forest floor during the day, so it cannot contribute collectible manure for the maintenance of the dooryard plants. Among the Bontok, however, pigs are kept near or under the house and their manure can be collected and added to compost which goes into rice fields and which helps to account for the high productivity of Bontok wet rice without capital inputs (Sajise & Omengan, 1981).

In the entry on harmonic swiddens, we noted that a number of South American Amazonian Indian groups have experimented with swiddens of much-less-than-expected species diversity, swiddens often polyvarietal in nature, to perhaps find other ways of providing some of the values of the tropical rainforest to the cropped field. Among the Siona-Secoya, one of these groups, Vickers (1983) found that home gardens had sparse and discontinuous canopies; they are also not the best examples of the AFS. However, it is important to note that Lathrap earlier (1977, pp. 729–736) had much to say about highly diverse mixed-home gardens among people like the Shipibo and Desana and found that they may have been very significant in the evolution of agriculture among South American Indians. It is worth quoting from him at a little length.

The house garden functioned as an experimental plot. New species of plants brought in from the forest or received through contact with other ethnic groups would be introduced into the house garden in a conscious effort to evaluate their potential as useful cultigens. The composition of the house garden was dynamic; . . .the potential of [new] species was constantly being investigated. . .. I would argue that the important food crops of Amazonia were ennobled in the context of these experimental plots. . .. Under the artificial growing conditions and a degree of artificial selection, they were genetically modified so as to become the supremely efficient food producers of the tropical forest system at the time of the contact period (Lathrap, 1977, p. 733).

See Also

▶ Environment and Nature in Buddhism
▶ Environment and Nature in Buddhist Thailand: Spirit(s) of Conservation
▶ Forestry in Japan
▶ Swidden

References

Apel, U. (1996). Traditional village forest management in Xishuangbanna, South-West China. *Plant Research and Development, 44*, 7–22.

Conklin, H.C. with the special assurance of P. Lupeih and M. Pinther, Cartographer-Ethnographic Atlas of Fuyao

(1980). A study of Environment, Culture and Society in Northern Luzon. New Haven and London: Yale University Press.
Fox, R. B. (1982). *Tagbanuwa religion and society*. Manila, Philippines: National Museum. Monograph No. 9 (1954).
Gadgil, M., & Vartak, V. P. (1976). The sacred groves of the Western Ghats in India. *Economic Botany, 30*(4), 152–160.
Kira, T. (1976). Man's place in natural ecosystems. In Secretariat, HESC Organizing Committee, Science Council of Japan (Ed.), *Science for a better environment* (pp. 31–39). Tokyo: The Asqhi evening News.
Lathrap, D. W. (1977). Our father the Cayman, our mother the Gourd: Spinden revisited, or a unitary model for the emergence of agriculture in the new world. In C. A. Reed (Ed.), *Origins of agriculture* (pp. 713–751). The Hague, The Netherlands: Mouton Publishers.
McWilliam, A. (2001). Prospects for the sacred grove: Valuing *lulic* forests on Timor. *The Asia Pacific Journal of Anthropology, 2*(2), 89–113.
Olofson, H. (1980). Review article: An ancient social forestry. *Sylvatrop: The Philippine Forest Research Journal, 5*(4), 255–262.
Olofson, H. (1984). Towards a cultural ecology of Ikalahan dooryards: A perspective for development. *Philippine Quarterly of Culture & Society, 12*(4), 306–325.
Pelzer, K. J. (1945). *Pioneer settlement in the Asiatic tropics*. New York: American Geographical Society. Special Publication No. 29.
Rackham, O. (1985). Ancient woodland and hedges in England. In S. R. J. Woodell (Ed.), *The English landscape: Past, present, and future* (pp. 68–105). Oxford, UK: Oxford University Press.
Sajise, P.E., & Omengan E. (1981). *Ecological study of the Bontoc rice paddy system: A case study of human-environment interaction*. Paper presented at the Thursday seminar of the International Rice Research Institute. 26 Mar. Los Baños, Philippines.
Schlegel, S. (1979). *Tiruray subsistence*. Quezon City, Philippines: Ateneo de Manila University Press.
Soemarwoto, O., et al. (1976). The Javanese home-garden as an integral agro-ecosystem. In Secretariat, HESC Organizing Committee, Science Council of Japan (Ed.), *Science for a better environment* (pp. 193–197). Tokyo: The Asahi Evening News.
Sommers, P. (1978). The traditional Filipino *halo-halo* garden. Paper presented at the thursday seminar of the International rice research institute. 17 Aug. Los Baños, Philippines.
Stoler, A. (1978). Garden use and household economy in Rural Java. *Bulletin of Indonesian Economic Studies, 14*(2), 85–101.
Terra, G. J. A. (n.d.). Home gardens for improved human nutrition. Paper presented at the reunion Interactional Problems se La Agriculture en Los Tropicos Humedor de America Larina, 22 May ar Lima and June ar Belem.
Vickers, W. T. (1983). Tropical Ferrer mimicry in swiffens: A reassessment of Geprz's model with Amozomian Oara. *Human Ecology, 11*(1), 35–46.
Warner, K. (1981). Swidden strategies for stability in a fluctuating environment: The Tagbanua of Palawan. In H. Olofson (Ed.), *Adaptive strategies and change in Philippine swidden-based societies* (pp. 13–28). Los Baños, Philippines: Forest Research Institute.
Wilken, G. (1977). Integrating forest and small scale farm systems in middle America. *Agro-Ecosystems, 3*(4), 291–302.
Yen, D. E. (1974). *The sweet potato and Oceania: An essay in ethnobotany*. Honolulu, HI: Bishop Museum Press.

Agroforestry: Field-and-Interstitial Support Trees

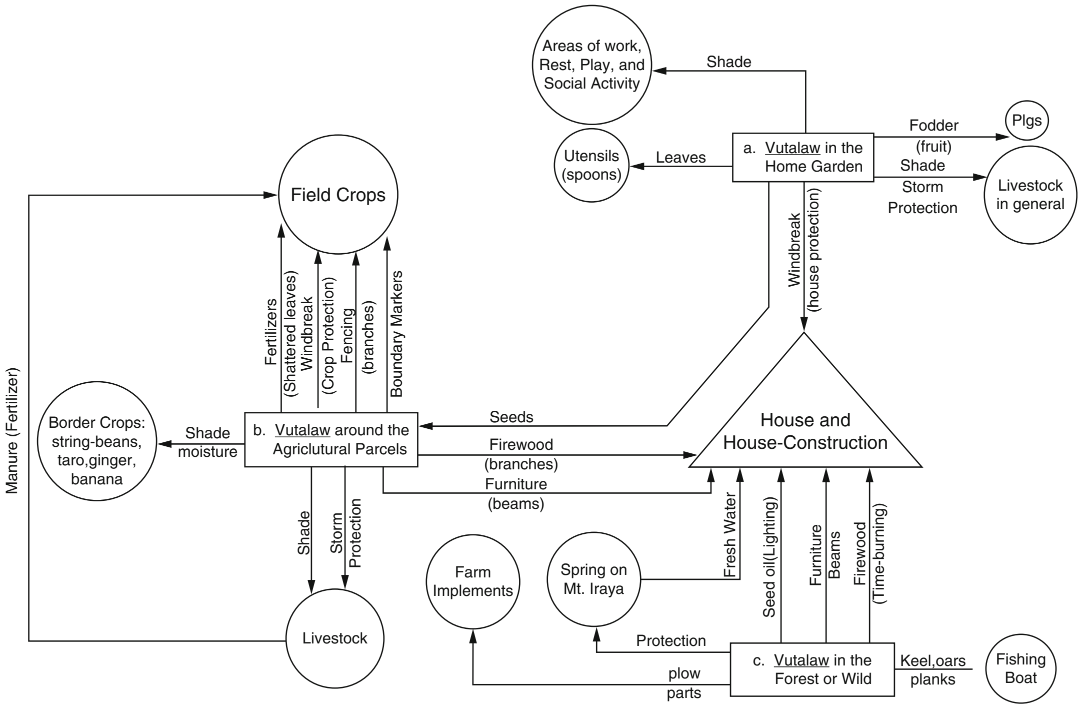
Harold Olofson

In this type of agroforestry, trees in groves or rows are separated spatially from crops, but are in a common field with them. The trees may be planted in arrangements interstitial (with small openings or gaps) to crop fields, for example, as field borders, or along the contours of a slope. In a variation, the trees and crops may be rotated in a field. In this agroforestry rotation, the trees interplanted in a mixture with crops may be cut back (coppiced) to allow crops to grow in the sun, and in a later phase allowed to take over and dominate the field for a period when their products are needed. This last essentially entails a rotation or alternation – or "separation" – of trees and crops through time. In all variations, the trees support the crops, as well as yield products of their own.

Spatially Interstitial Trees

There are many examples of trees that are spatially interstitial:

1. The planting of Osage orange in the American Great Plains as a hedge to protect fields from



Agroforestry: Field-and-Interstitial Support Trees, Fig. 1 The participation of the *vutalaw* (*Calophyllum inophyllum*) in the Ivatan agroecosystem (From Rede-Blolong and Olofson (1997, p. 115). By permission of *Philippine Quarterly of Culture & Society*. Thanks to Fr. Herman van Engelen for his help in constructing this illustration)

animals and then, as they grew, as a windbreak (Smith & Perino, 1981);

2. The growing of ipil-ipil for fertilizer or firewood on rice bunds in Pangasinan, Philippines (interview data);
3. A living fencerow of *Cestrum nocturnum*, guava, and forest trees to prevent the passage of pigs from a pigsty into a swiddening area among the Ikalahan of northern Luzon, Philippines (personal observation);
4. The use of ipil-ipil in contoured rows to prevent erosion on steep corn farms in Cebu (National Academy of Sciences, 1977, pp. 72–73);
5. The planting of teak on fallow boundaries by the Yoruba of Nigeria to claim ownership of the fallow (John Wyatt-Smith, personal communication), and thus probably prevent premature cropping by others; and
6. The planting in Batanes, Philippines of palo maria (*Calophyllum inophyllum*) as living fencerows on parcel borders to mark boundaries, provide shade for cattle, windbreaks for crop protection in a typhoon-battered region, firewood, fencing material, and moist soil for plantings of ginger and beans (Rede-Blolong & Olofson, 1997, pp. 110–102; see Fig. 1).

Of special interest is the use of trees to reclaim soil to fixate sand dunes, thus adding to the total arable land. A good example is the construction of living fencerows in seasonal floodplains by the Indians of Sonora, Mexico. These are arranged in such a way that they are able to capture arable soil from seasonally torrential watercourses that would otherwise erode away the area in which the fencerows have been planted. The trees are planted so as to impede the flow of water, allowing soil particles in the water to sink to the bottom of the stream (Nabhan & Sheridan, 1977). While this type of agroforestry involves the use of residual, leftover, or boundary spaces, such trees can be of the utmost importance; they can be used to reverse the deleterious forces of nature.

Interstitial arrangements involving livestock occur where spatially interstitial trees provide fodder. A case in point occurs in Jalajala, Rizal, Philippines, where native ipil-ipil growing between (and within) upland parcels is collected and brought down to sites situated on a level lakeside plain in order to stall- or force-feed milch cows (Olofson, 1985, p. 322).

Temporally Interstitial Trees, or the Agroforestry Rotation

An interesting system that falls into this rubric has been described for the Atoni language speakers in the province of Amarasi in southwestern Timor. The system is a relatively recent innovation, but originated within and has been strongly supported by traditional institutions. It is a many-faceted response to famines caused by slash-and-burn on poor soils in a climate with a 9-month dry season, and to the spread of *Lantana camara*, which was interfering with the attempt to develop a livestock industry in the resulting savannahs, because it is poisonous to cattle:

> With the systematic use of [*Leucaena leucocephala*], which had been known in Timor for centuries as a fallow plant, a significant agro-ecological change took place in Amarasi. An *adat* regulation pronounced in 1932 by the local ruler (*raja*) in accordance with his council obliged every farmer in Amarasi to plant rows of this leguminous plant with at least 3-m spacings along the contour lines on his shifting plot before abandoning it. This was intended to reduce erosion, to encourage new plant growth, and to improve soil fertility by making use of the nitrogen-fixing properties of this legume. In order to put the necessary pressure behind these regulations, each farmer was threatened with a heavy fine for failing to comply. (Metzner, 1981, p. 96)

In 1948 the government officially adopted this custom law as its own, and by 1951 *Lantana* had been significantly reduced by the ipil-ipil (*lamtoro* in Atoni), so that land-use zoning, also originating in *adat* decisions taken by the raja in 1938, could be most efficiently implemented to aid in the separation of farming and grazing areas (Metzner, 1981, pp. 96–98).

It can be assumed that the ipil-ipil was planted late into the ► swidden because of its rapid growth, so that a succession of food crops and ipil-ipil took place, rather than a mixture, in the initial phase. In one area this use of ipil-ipil led to a situation where the farmers could make a labor-saving innovation that eventually resulted in almost permanent cultivation.

Once the *lamtoro* poles and leaves are cut they are not burnt but left on the field as mulch. Into this mulch layer maize and other crops are planted. Weeding is limited to cutting off the fresh shoots growing from the roots of the legume left in the ground. Similarly the cut-off shoots remain on the field as mulch. Since the soil is neither hoed nor turned the thin layer of topsoil is hardly disturbed. According to the farmers. . .even after 7 years of continuous cultivation yields were not lower than those expected from newly cleared *lamtoro* plots (Metzner, 1981, p. 100).

In this system, the growth of the trees and crops alternate over time in the same space. In most swiddens, the forest stage of the swidden cycle primarily functions as a source of fertilizer to be released by the next burning, of shade to eliminate weeds, and of seed for reforestation of fallow areas. Here the fast growth of the ipil-ipil as well as the soil enrichment caused by nitrogen fixation adds significantly to these functions, making the next cultivation of the plot possible much sooner as well as extending the cropping period. This last, in turn, makes it possible to delay fallow and to allow adjacent ipil-ipil fallows to grow more. For this reason, agroforestry rotations of temporally interstitial trees that nourish the soil could be called forms of accelerated swidden.

It is important to note here that while the tree component is kept "submerged" or cut back during the cropping phase, so that we cannot speak of a mix of growing trees and crops, this example is still one of a simultaneous polyculture. The underground portions of the ipil-ipil still play a positive role in generating nitrogen and holding the soil.

References

Metzner, J. (1981). Innovations in agriculture incorporating traditional production methods: The case of Amarasi (Timor). *Applied Geography and Development, 17*, 91–107.

Nabhan, G. P., & Sheridan, T. E. (1977). Living fencerows of the Rio San Miguel, Sonora, Mexico: Traditional technology for floodplain management. *Human Ecology, 5*, 96–111.

National Academy of Sciences. (1977). *Leucaena: Promising forage and tree crop for the tropics*. Washington, DC: National Academy of Sciences.

Olofson, H. (1985). Traditional agroforestry, parcel management, and social forestry development in a pioneer agricultural communing. The case of Jala-jale, Rizad, Philippines. *Agroforestry Systems, 3*, 317–337.

Rede-Blolong, R., & Olofson, H. (1997). Ivatan agroforestry and ecological history. *Philippine Quarterly of Culture and Society, 25*(1–2), 94–123.

Smith, J. L., & Perino, J. V. (1981). Osage orange (*Maclura pomifera*): History and economic uses. *Economic Botany, 35*(1), 24–41.

Agroforestry: Harmonic Swiddens

Harold Olofson

Forest swiddens are clearings made in a forest by shifting cultivators, to be planted to crops. They are generally of two types, depending on the cultural traditions of the cultivators: harmonic and disharmonic.

Harmonic swiddens are found among many indigenous cultivators, and are essentially a form of agroforestry. In fact, when they are designed and managed in such a way as to enable rapid recovery of the forest after a brief period of use during which their soil fertility is depleted, they are good models for modern agroforestry. As integral agroforestry paralleling Conklin's (1961) famous classification of types of shifting cultivation, they are embedded in cultures into which members of a society are born, as part of their plan for survival. Making harmonic swiddens is learned as part of growing up in indigenous societies where they are integral to the tradition of cultivation. One of the effects of harmonic swiddens which is often "in the awareness" of their practitioners is to accelerate the recovery of the forest structure which was eliminated in the process of making a ▶ swidden in the forest, once they have to leave the swidden. This is done by paralleling or imitating in the swidden that forest structure which they have felled, or one which exists nearby. They attempt to harmonize the structure of the swidden with the nature of the environmental context in which they live. Such swiddens can be called Alternative Forest Structures (AFS). The AFS can have up to five characteristics that aid in identifying it as forest alternatives. The first three were clearly described by the anthropologist Geertz (1963) and Harris (1971).

1. There is a high diversity index of plant species in the swidden, as in the natural forest. In contrast to monoculture, which specializes in one species only, there are many species and varieties planted in the field. Thus, a swidden is a simultaneous polyculture (coined by Kass, 1976, p. 6), but a complex, not a simple one. This term covers patterns involved in mixed cropping, intercropping, interculture, interplanting and relay-planting. Also in contrast to monoculture, there are relatively few representatives of any species.
2. The vegetation is stratified into soil-protecting canopy layers, two or four in number, but usually less than in a tropical forest climax.
3. As in the natural forest ecosystem, the tight cycling of nutrients within the bounded agroecosystem is quite rapid. As has been said for the tropical forest, the AFS cannibalizes itself by quickly reabsorbing its own litter into its root systems. While this is widely believed to be true for some of the AFS described below, there is a need to confirm this through detailed agroecological studies.
4. Oldeman nicely analyzes the fourth analogy. According to him, especially in older forests, "the death of forest patches is a perfectly natural mechanism which constitutes the motor of all vegetational dynamism" (Oldeman, 1981, p. 79). Numerous accidents through time, such as earthquake, exposure to storm

winds, or the formation of goblet-shaped clearings or *chablis* by the falling of single, large, old trees cause the forest to take on the appearance of a mosaic of points on a successional sere. As Rambo (1981, p. 36) has put it, man may purposefully and systematically manipulate the forest – through an eco-catastrosphe of felling and burning – to deflect the natural succession on a site back to more open conditions and thus cause a patch to enter a succession which he himself designs. Geertz called this "putting the forest through its paces." Thus, like patches in the forest many AFS will be located on some point along a sere. Oldeman points out how it requires a good deal of art and science to preserve with some stability the analogical relationships between the cultivation cycle and the natural cycle, and to replace the wild species by domesticated ones that fill the "same functional and structural niche as their wild precedents" (Oldeman, p. 81). Like the forest, swiddens also have phases in their histories.

5. The overall effect is one of resonance between the AFS and the surrounding natural forest. The structure of the forest is imitated, planting materials may actually be brought in from the forest, and forest wildlife may flourish at the ecotone (boundary) with the AFS. In these ways, the AFS may act to reinforce the forest ecosystem.

Disharmonic swiddens may have evolved from harmonic ones, with the farmer learning to specialize to the point of monoculture or near-monoculture, with one species such as sweet potato, upland rice, or corn dominating in the field. In this process, the ► swidden loses its stratified canopies and there is a dangerous reduction of plant cover in the clearing during the cropping stage. Or, disharmonic swiddens may be cleared by land-hungry, lowland migrants to the hills or forests who may be people who have little knowledge of indigenous practices, who did not grow up in cultures traditionally skilled in forest farming.

Disharmonic swiddens have no resonance with the surrounding forest other than attracting wildlife; they bring on the threat of soil erosion through heavy rainfall impacting on the bare soil, grassy intrusion, and a decrease of nutritional diversity in the family diet. The harmonic swidden is much more capable than the disharmonic of regenerating into natural forest during the fallow period.

Swiddens can be found on a continuum of incipient to advanced indigenous agroforestries. In the first, trees may not be a major component of the swiddens, but species of fruit trees are usually present. These incipient agroforestries may be seen as evolutionary precursors to indigenous agroforestries which put more stress on trees, usually always to support the crops. Swiddens of this nature have been reported widely for traditional peoples. For the T'boli of Mindanao, Rice has made this observation:

> Usually there are three or more different crops on a given piece of land at all times and as each crop ripens and is harvested its place is taken by another. A well-developed system of inherited agricultural knowledge governs which seeds are to be planted together and in which months they can be planted for most effectiveness. This . . . tends to maintain the soil fertility longer since at least one legume is usually in the soil to stimulate nitrogen fixation. Second, the land is covered more continuously and heavily, and erosion and weed control are thus more effective. . . (Rice, 1981, p. 77)

For the Tsembaga Maring of New Guinea, one anthropologist has described the forest-like structure of their swiddens.

In the garden as in the forest, species are not segregated by rows or sections but are intricately intermingled, so that as they mature the garden becomes stratified and the plants make maximum use of surface area and of variations in vertical dimensions. For example, taro and sweet potato tubers mature just below the surface; the cassava root lies deeper and yams are the deepest of all. A mat of sweet potato leaves covers the soil at ground level. The taro leaves project above this mat; the hibiscus, sugarcane and [*Setaria palmaefolia*] stand higher still, and the fronds of the banana spread out above the rest. This intermingling does more than make the best use of a fixed volume. It also discourages plant-specific insect pests, it allows advantage to be taken of slight variations in garden habitats, it is protective of the thin tropical soil and it achieves a high photosynthetic efficiency (Rappaport, 1971, pp. 121–122).

The Tiruray of Mindanao have been described as having another kind of what I call resonance between the forest and the cultivated areas. This involves a virtual exchange of planting materials between the two sites. Four ▶ bamboo species, the fruit tree *Averrhoa carambola*, narra, and *Gendarussa vulgaris* are taken from the forest and planted in swiddens, gardens, at the edge of watercourses, or right at the forest boundary, while the candlenut (*Aleurites moluccana*) is planted directly in the forest (Schlegel, 1979, pp. 171–179, 194–205).

In harmonic swiddens, trees support the domesticated plants grown in the clearing by first bringing about more fertile soil conditions and then by being sacrificed through burning for fertilizer. It is difficult to see, however, how nutrients from the clearing do much in their turn to make the forest prosper. Perhaps on the edges of swiddens, where some slash or crop residues may be thrown from the ▶ swidden into the forest, or where rainwater is eroded down from the swidden, nutrients may re-enter the nutrient cycle of a small section of forest. On the field itself, only crop residues remain to act as a source of nutrients for the returning forest. It may be that young trees are able to make incredibly efficient use of such small amounts of nutrients, for on soils in which domesticated plants no longer flourish, secondary growth will oftentimes thrive.

The Lacandon Maya of Chiapas, Mexico plant numerous varieties of fast-growing root and tree crops prior to the planting of corn in their *milpas* (swiddens); these prevent soil erosion and nutrient leaching in the newly cleared field. During the rains, many other species of tubers, trees, cereals and vegetables are planted. Of great interest is the observation that the Lacandones have learned to plant several of these crops only when certain "indicator" species in the primary forest begin to flower. For each planted species, the corresponding flowering forest species is called the "foot" of that crop. "Such a system coordinates the agricultural cycle with current environmental conditions, rather than with a fixed calendar that makes no provisions for annual variations in temperature and precipitation" (Nations & Nigh, 1980, pp. 9–11, see Table 1). Thus the Lacandones tune in to what ecologists would call the forest's information flow. This could also be described as the dispersion of crop cycles through time.

There is also, among the Lacandones, dispersion of plants in space through their swiddens. This prevents large clusters of single species and so emulates the high species diversity index of the forest, ensuring that the ▶ swidden "becomes a living mass of food-producing plants which occupy the entire cleared area both above and below the soil." These dispersions in space and time enable the plants to escape their herbivorous predators, and make possible a sustained yield of food throughout the year (Nations & Nigh, 1980, p. 11).

The Lacandones have evolved a swidden system wherein a swidden is only cultivated for short periods, and few weedings are done. This allows secondary species to establish themselves quickly on sites that are abandoned, so that re-opening of that space to cultivation can take place after only 2 or 3 years of fallowing, since forest growth will have been enough to provide sufficient ash fertilizer after burning. Not only that, but wild species are encouraged, and a variety of other useful plants are deliberately seeded into the *acahual* (fallow) to accelerate the reappearance of the forest (Nations & Nigh, 1980, p. 15).

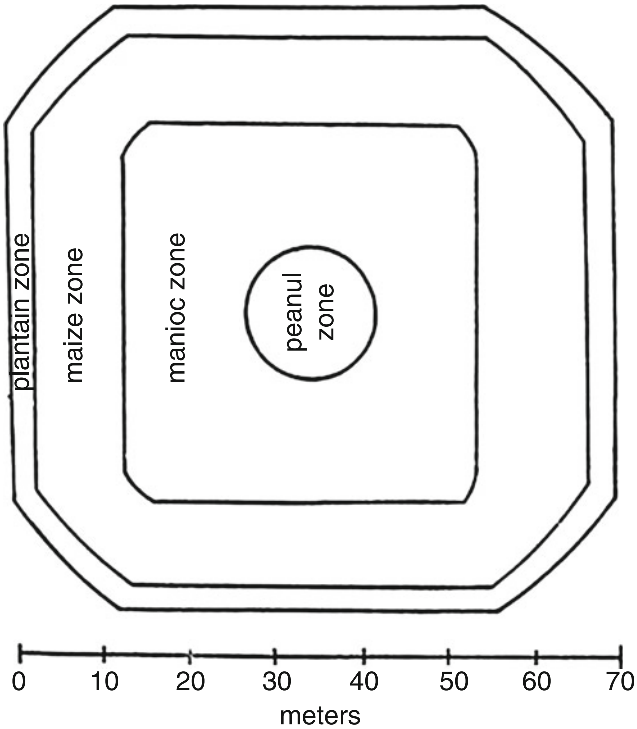
The Lacandones recognize the forest as the principle factor in regulating itself. The strategy is thus to "farm" in the forest. . . not to replace the forest in order to farm (Nations & Nigh, 1980, p. 20).

All of the above is not to imply that all shifting cultivators have harmonic swiddens, as defined previously. Newcomers to forest farming do not have the required knowledge for managing forest-friendly swiddens. But traditional, integrated swiddenists also may not have swiddens that are Alternative Forest-Like Structures. Anthropological research prior to 1983 among Amazonian Indian groups living near the Equator

Agroforestry: Harmonic Swiddens, Table 1 "Foot" indicator plants: wild forest species whose flowering provides information flow to the Lacandon Maya (From Nations & Nigh, 1980, p. 12)

Crop				Indicator species		
Month	Region	English	Latin	English	Latin	Lacandon
January	South	Corn	Zea mays	Barbasco	Paullina pinnata	mäsh ak'
February	North	Watermelon	Citrullus vulgaris	Corkwood	Heliocarpus donnell-smithii	halo
	North	Corn	Zea mays	Corkwood	Heliocarpus donnell-smithii	halo
March	–	–	–	–	–	–
April-early	South	Corn	Zea mays	"White rope" vine	Unidentified	säk su'um
April-late	North and South	Corn	Zea mays	?	Bucida buceras	pok te'
May-late	North and South	Corn	Zea mays	Mahogany	Swietenia macrophylla	punah
June-early	North and South	Corn	Zea mays	Mahogany	Swietenia macrophylla	punah
	North	Rice	Oryza sativa	Mahogany	Swietenia macrophylla	punah
	North	Peanuts	Arachis hypogaea	Mahogany	Swietenia macrophylla	punah
July	–	–	–	–	–	–
August	North	Tobacco	Nicotiana tabacum	Black bache	Guatteria anomala	ek'bache
	North	Black climbing beans	Phaseolus vulgaris	Black bache	Guatteria anomala	ek'bache
September-late	North	Sweet potato	Ipomoea batatas	?	Nectandra sp.	ek'onté
October	North	Tobacco	Nicotiana tabacum	Wild tamarind	Dialum guianese	wäch
	South	Jícama	Pachyrrhizus erosus	Water vine	Vitis tillifolia	yuhi
	South	Corn	Zea mays	?	Unidentified	k'uwan
November-early	South	Corn	Zea mays	?	Unidentified	piskinin
November-late	North	Corn	Zea mays	Barbasco	Paullina pinnata	mäsh ak'
December-late	North	Corn	Zea mays	Corkwood	Heliocarpus donnell-smithii	halo

in South America found a number of tribes without them, interspersed among those who do. In 1983, the journal *Human Ecology* published a symposium of papers on these groups, wherein the authors attempted "appropriate descriptions" of them, which were summarized by Beckerman (1983a). The research found, instead of harmonic features, monocropping, planting of different monocrops in concentric circles around the swidden (in one culture, the family house was always cited in the center of the swidden), and polyvarieties of the staple cultigen (usually many varieties of cassava [manioc] mixed together). In the symposium, attempts were made to explain how these arrangements were able to perform some of the functions of the Alternative Forest-Like Structure. For example, the different varieties of cassava planted in Jivaroan gardens have a "variation of branching pattern, leaf shape, and growth period . . .promoting effective vertical and lateral exploitation of available light, warmth, and



Agroforestry: Harmonic Swiddens,
Fig. 1 Idealized plan view of ring-planting in a Candoshi ▶ swidden (From Stocks, 1983, p. 77. Permission pending)

moisture" (Boster, 1983, p. 62) that would be much the same as that achieved by the mixture of distinct species. Beckman notes that the simultaneous monocrops planted in an annular fashion among the Bari (Beckerman, 1983b) and the Candoshi (Stocks, 1983, see Fig. 1) are done so that the tallest plants are in the outer ring and the shortest in the center ring, creating a downward gradient of crop elevations from the edge to the center – a "funnel-like" effect in the garden. Stocks suggested that this arrangement reduces the shading of a shorter crop by a taller one; protects interior crops from pests by placing crops that are valued less by people but which taste best to pests on the outer rim, thus preventing satisfied pests from continuing on into the center; nourishes the crops on the edge better by placing them next to the forest; and/or disperses crops across a range of "micro-edaphic variation". Beckerman suggested that these and other hypotheses needed agronomic field testing before they could be accepted.

Another possibility springs to mind. In the evolution of agriculture there must have been people who initiated the practice of planting whole fields to one or a few favored staples. The first experimental monocultural fields could have been forest swiddens. Could these Amazonian Indian groups have been among the first to move in this direction? Their heavy reliance on the cassava as their staple food could have supplied a motive. The Amazonian swiddens discussed above may well represent a frozen stage in that transition, a stage continuing on today in those societies.

Swiddens of the South American rain forest which are Alternative Forest-Like Structures happened to be among the earliest studied, particularly by geographers, for example those of the Yanomamo people found in the Upper Orinoco of Venezuela (Harris, 1971). Treacy (1982) has also written of them among the Bora in southern Colombia. He makes the following very nice point for them: "…the notion that shifting cultivation fields are 'abandoned' with fallowing needs reassessment" because fruit trees, planted in the Bora swidden, continue to grow for a long period of time after final crop harvesting and the ground around them is regularly weeded to prevent competition with fast-growing secondary forest species (Treacy, p. 16).

See Also

► Swidden

References

Beckerman, S. (1983a). Does the swidden ape the jungle? *Human Ecology, 11*(1), 1–12.

Beckerman, S. (1983b). Bari swidden gardens: Crop segregation patterns. *Human Ecology, 11*(1), 85–101.

Boster, J. (1983). A comparison of the diversity of Jivaroan gardens with that of the tropical forest. *Human Ecology, 11*(1), 47–88.

Conklin, H. C. (1961). The study of shifting cultivation. *Current Anthropology, 2*(1), 27–59.

Geertz, C. (1963). *Agricultural involution*. Chicago: The Free Press.

Harris, D. R. (1971). The ecology of Swidden agriculture in the upper Orinoco rainforest. *The Geographical Review, 61*(4), 475–495.

Kass, D. C. (1976). *Simultaneous polyculture of tropical food crops with special reference to the management of sandy soils of the Brazilian Amazon*. Ph.D. Thesis, Cornell University.

Nations, J. D., & Nigh, R. B. (1980). The evolutionary potential of Lacandon Maya sustained-yield tropical forest agriculture. *Journal of Anthropological Research, 36*(1), 1–30.

Oldeman, R. A. A. (1981). The design of ecologically sound agro-forests. In K. F. Wiersum (Ed.), *Viewpoints on agroforestry* (pp. 75–121). Wageningen, The Netherlands: The Agricultural U of Wageningen, The Netherlands.

Rambo, A. T. (1981). *Orang Asli adaptive strategies: Implications for Malaysian natural resource development planning*. Honolulu, HI: East-West Center. EAPI Preprint. Environment and Policy Institute.

Rappaport, R. A. (1971). The flow of energy in an agricultural society. *Scientific American, 225*(3), 116–132.

Rice, D. (1981). Upland agricultural development in the Philippines: An analysis and a report on the Ikalahan programs. In H. Olofson (Ed.), *Adaptive strategies and change in Philippine swidden-based societies* (pp. 73–90). Los Baños, Philippines: Forest Research Institute.

Schlegel, S. (1979). *Tiruray subsistence*. Quezon City, Philippines: Ateneo de Manila UP.

Stocks, A. (1983). Candoshi and cocamilla swiddens in eastern Peru. *Human Ecology, 11*(1), 69–83.

Treacy, J. (1982). Bora Indian agroforestry: An alternative to deforestation. *Cultural Survival Quarterly, 6*, 15–16.

Agroforestry: Special Systems

Harold Olofson

Certain indigenous agroforestry systems do not fit easily into a Western-science classification of such systems because, anomalously, they do not have as major components either a field of agricultural food crops or grazing livestock. Instead they involve, on the one hand, specific conserved species of forest vegetation, or sizeable conserved sections of forest, and on the other, such animal food sources as fish or bees in the place of domesticated animals or plants (although other agricultural or even agroforestry types may be found elsewhere in the village or district under consideration). Bee culture, however, is considered a branch of agriculture in some places (Commonwealth Agricultural Bureaux, 1980). Existing forest species are simply maintained as a support for either aquaculture or apiculture. These systems are not well known.

Aqua-Silviculture

The evidence for an indigenous aqua-silviculture, or combination of aquatic resources with managed forest vegetation, is thin. One possibility is a system described by Joly (1981) for a mixed Hispanic and Indian group living along rivers in upland Panama. These people train a species of riverine fish (*Brycon chagrensis*) to feed on the leaves of *Piper auritum* placed as bait in a system of stockades in family-owned pools during periods of low water. The fish absorbs the pleasant flavor of the leaves and the stockades facilitate the trapping of the fish.

It is somewhat questionable whether the plant *P. auritum* can be included in a discussion of silviculture, which pertains primarily to trees. Although Joly's discussion is unclear, it seems that this herb is not a part of the gallery forest found adjacent to the pools. It is apparently gathered from secondary forest vegetation growing away from the river and brought to the feeder devices. It is, however, at the very least a conserved forest resource, for when clearings are made for ▶ swidden, "clumps" of the plants are left untouched. If it requires shade, then other forest trees are involved in its conservation.

The Uanano Indians in the Uaupes River Basin in the Brazilian Amazon rainforest provide another example of indigenous aqua-silviculture. They take care to preserve particularly the forests along major rivers, by prohibiting the practice of shifting cultivation on the river margins. They know that if they interfere with those trees, they will harm the rivers' fish populations, their major source of protein.

A Western science explanation can be made for what the Uanano perceive in doing this. The rivers in the Uaupes Basin are all blackwater rivers, full of tannins produced by the rainforest plant species as a protection against herbivores. Rains wash these tannins from the litter on the forest floor into the drainage system, where they prevent the growth of microflora which fish feed upon. These rivers generally have low levels of nutrients and primary phytoplankton. But during rainy seasons of high water in the rivers, the fish are able to swim into the forest with the rising river waters and feed on the vegetable matter (leaves, fruits, flowers, seeds, and microflora) and small animals (insects and their larvae, arachnids, crustaceans, and worms) that they can find there as "floating and decomposed matter and mud." Observing this, the Uanano are "acutely aware" that preservation of the forest will save for them the fish as well (Chernela, 1982).

Another example of aqua-silviculture has been noticed in a lakeside community in the Philippines, where the finally branching tree *Streblus asper* is maintained in farmers' parcels. Branches are cut and submerged in the lake water for a time necessary to capture shrimp which come to shelter among them (H. Olofson, fieldnotes, Jalajala, Rizal, Philippines).

Api-Silviculture

When forest resources in the form of nectar-producing flowering trees and other plants are consciously conserved in order to support domestic beekeeping and honey production, we have what could be called an indigenous api-silviculture. Essential to the recognition that api-silviculture exists is the knowledge that a beekeeping people can name flowering forest species important in honey production and also conserve them by, for example, not cutting them for swidden.

The protection of nectar-producing forest trees occurs among the swiddening Iraya of northern Mindoro Island, Philippines. Another aspect of their traditional conservation is the restriction of honey collection to the waxing period of the moon, thus forcing bees to swarm and to build up new hives with honey in the waning of the moon. Such customs may be stimulated by the fact that the Iraya look upon honey as a shamanic medicine (Revel-Macdonald, 1971). But the Iraya are "honey hunters," not beekeepers, having to look for such new hives by observing the flight directions of bees after those bees partake of river water. (The term "honey gatherers" would be most properly reserved for those people who know of permanent hive sites, such as those located on known cliff faces, to which they can return year after year.)

It would seem logical that if honey-hunters protect relevant trees, so also there must be examples of indigenous beekeepers who do. A good description of ritualized domestic beekeeping among the Yucatecan Maya is given in Weaver and Weaver (1981) but only the plant *Gymnopodium antigonoides* is mentioned as a recognized nectar source; they do not say whether it is protected. However, Chemas and Rico-Gray (1991) say that the Yucatecan Maya are able to identify 12 species of wild trees and weeds that are good sources of nectar foraged by bees to produce honey. They can rank these in terms of quantity, odor, flavor, color, and viscosity of the honey produced, as well as the quality of their pollen and nectar. They have a good knowledge of the flowering phenology of these trees, and know how very dry and very rainy seasons, very humid and very cool years, affect the honey produced by bees. They find that the management of honey and pollen-producing vegetation need be only minimal. In their area, forest cutting has led to the forest being composed of mainly young trees. But this may have done little damage to the annual honey production cycle, since bees prefer to visit younger successional stages of forest growth anyway, as well as roadside plants.

The conservation of interstitial trees or of bee pasture useful to bees would be essential to growing populations who combine farming and beekeeping, since otherwise the nectar sources would give way to the spread of crop land (see Editorial, 1981).

References

Chemas, A., & Rico-Gray, V. (1991). Apiculture and management of associated vegetation by the Maya of Tixcacaltuyub, Yucatán, Mexico. *Agroforestry Systems, 13*, 13–25.

Chernela, J. M. (1982). Indigenous forest and fish management in the Uaupes Basin of Brazil. *Cultural Survival Incorporated Quarterly, 6*(2), 17–18.

Commonwealth Agricultural Bureaux. (1980). *Perspective in world agriculture*. Slough, UK: Commonwealth Agricultural Bureaux.

Editorial. (1981). Endangered honey sources. *Bee World, 62*(1) 3–4.

Joly, L. G. (1981). Feeding and trapping fish with *Piper auritum*. *Economic Botany, 35*(4), 383–390.

Revel-Macdonald, N. (1971). La Collecte du Miel. In J. Barrau (Ed.), *Langues et Techniques Nature et Société: Tome II: Approche Ethnologique et Naturaliste* (pp. 73–90). Paris: Éditions Klincksieck.

Weaver, N., & Weaver, E. C. (1981). Beekeeping with the stingless bee *Melipona beecheii*, by the Yucatecan Maya. *Bee World, 62*(1), 7–19.

Agroforestry: Systems with Animals and Grasses

Harold Olofson

Silvipasture

Silvipasture is an agroecosystem which involves a necessarily precise combination of forest trees, livestock, and selected grasses.

It is difficult to locate references on indigenous communities which have achieved the combination of forest-grazing consciously involving silviculture. For example, one would not expect to find this among pastoralists, who have in the course of cultural evolution branched off from a way of agricultural life involving both domesticated animals and plants to concentrate on domestic animals alone – full-time pastoralists are not usually planters. They are known to graze their animals among forest trees, and to use those trees for shade for their livestock, but it is difficult to find reference to their actually having planted those trees. This type of agroforestry appears to be a very recent conception.

If they can be accepted as a people who are now, in this day, "indigenous" to their homeland, some nth-generation Caucasian New Zealanders are a good example of temperate-climate silvipastoralists (Stover, 1979). Silvipasture, interestingly enough, was discovered almost accidentally and simultaneously by imaginative, private farmers and private company employees in the 1960s, not by scientific research. Observations of their schemes led to serious consideration of silvipasture in the Forestry Development Conferences of that country in the 1960s and 1970s and silvipasture was then realized as a way of reversing the historical depletion of timber resources caused by clearing land for cattle and sheep. As a response to increased timber prices, and to the lowering prices for meat and wool,

> Farmers . . . have come to see trees not only as shelters for livestock both winter and summer and as sources of fuel and locally needed posts, but as another potential cash crop, albeit, a slow-growing one, that might share growing space with grass. (Stover, 1979, p. 441)

The New Zealanders' view of the role of livestock is reminiscent of the rationale for the food crops in accelerated ► swidden or food-tree crop interplantings. In the latter, the crops provided the short-term returns necessary to stimulate the willingness to plant and wait for trees on the same space, as among the Ifugao in Northern Luzon, Philippines. In New Zealand, the farmers see that the animals provide income to cover interest costs during the period before the trees can be harvested. Silvipasture in New Zealand involves allowing livestock into well-established forest, once the potential relationships are well understood; planting trees into well-established pasture; or sowing grass among tree-seedlings on run-down land.

Agri-Silvipasture

A remarkable indigenous system involving the mix of three components – livestock, trees, and a staple crop, is found among the Fur of Sudan. This permanent system is made possible by the unique characteristics of the savannah tree *Acacia albida* (Radwanski & Wickens, 1967). Unlike almost all other trees, this legume sheds its leaves at the start of the rainy season, and plots of millet or sorghum placed directly under the trees quickly benefit from the rapidly decaying leaves, at a time when sunlight is able to reach the crop through the tree canopy. In the dry season, the trees are in leaf, providing shade for the plots below, and keeping down the temperature of the soil which is able to retain more water than otherwise. During this fallow period, livestock may be allowed to graze and rest in the shade under the trees, especially when a storm blows down the nutritious fruits of the acacia. The livestock in turn fertilize the area. They are also fed with the leaves and fruits of the tree especially collected by the Fur as fodder. And the combination of animal manure and *Acacia albida* leaves makes nitrogen plentifully available under the trees.

References

Radwanski, S. A., & Wickens, G. E. (1967). The ecology of *Acacia albida* on mantle soils in Zalingei, Jebel Marra, Sudan. *The Journal of Applied Ecology, 4*(2), 569–579.

Stover, S. L. (1979). Grazing and exotic forestry: The development of an intercultural experiment in New Zealand. *Agricultural History, 53*(2), 438–450.

Aida Yasuaki

Shigeru Jochi
Osaka Kyoiku University (Osaka University of Education), Osaka, Japan

Aida Yasuaki, also called Aida Ammei, was born in Yamagata, Japan on February 10, 1747 (March 20, in the present calendar). Aida studied mathematics under Okazaki Yasuyuki, a mathematician of the *Nakanishi-ryu* school, from the time he was 15 years old until he reached the level of the *Tianyuanshu* technique (Chinese Algebra system).

Then he went to Edo (now Tokyo), in September 1769 and became a son-in-law of SUZUKI Seizaemon, a Samurai of the Shogun. Aida changed his name to SUZUKI Hikosuke and worked as a *Fushin' yaku*, a civil engineer. Here he came to know KAMIYA Teirei, a student of FUJITA Sadasuke (1734–1807). Fujita was a mathematician of the *Seki-ryu* school who wrote the *Seiyo Sampo* (Exact Mathematics, 1781) which was one of the best mathematical textbooks of that time.

Aida decided to become a mathematician, retired from his work, changed his name back to Aida Yasuaki, and asked Fujita if he could teach mathematics. Fujita did not accept Aida's offer because he was concerned about mistakes in Aida's *Sangaku*. (*Sangaku* is a picture board with mathematical drawings, mostly of geographical problems. They were hung on the walls of shrines and temples for praying for mathematical progress.) Aida grew angry with Fujita and wrote the *Kaisei Sampō* (Counter-argument with Seiyo Sampo, 1785).

He then founded the *Saijō-ryū* school, and both schools disputed mathematics with each other for about 20 years. This encouraged Japanese mathematics to progress to a high level. Aida published eight books, nearly 2,000 chapters of manuscript. He taught mathematics to WATANABE Hajime (1767–1839), SAITO Naonaka (1773–1844), ICHINOSE Korenaga (fl. 1819), and KANDO Seii (nineteenth century).

Aida died at Edo (Tokyo) on October 26, 1817 (December 4 in the present calendar).

The strong point of the *Saijo-ryu* school was in systematic algebraic symbols. Aida created the original symbol for "equal," which was the first use of equal in Eastern Asia. He wrote the *Sampo Tensei-ho Shinan* (Mathematical Instruction of "Tensei-ho" (or the Tenzanjutsu technic in the Seki-ryu school)), which is one of the most systematic books describing the Japanese algebraic system.

Aida's mathematical method was similar to SEKI Kowa's. Aida studied the characteristics of irrational numbers. First, Aida computed the approximate value of irrational numbers by a sort of "Horner's method" (Horner, 1819); then he computed the value of the continued fractions. An example of the root 2 is as follows:

Aida then calculated the continued fractional value of prime numbers smaller than 100. He also used the inductive method.

Approximate value	Continued fraction
$\sqrt{2} \approx 1.4142$	1, 2, 2, 2, 2, 2, 1...
$\sqrt{2} \approx 1.414213$	1, 2, 2, 2, 2, 2, 2, 2, 1...
$\sqrt{2} \approx 1.41421356$	1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, ...

References

Aida's works are discussed in vol. 4 of Fujiwara Matsusaburo 1956. One of the more complete works is Hirayama and Matsuoka 1966. Most of his works are kept at the Yamagata University Library http://www.lib.yamagata-u.ac.jp/rarebooks/sakuma_1-1280.html#anchor1150321

Aida's Publications

Kaisei Sampo (Counter-arguements with Seiyo Sampo). (1785). Edo.
Kaiwaku Sampo. (1788). Edo.
Sampo Hi-hatsuran. (1801). Edo.
Sampo Kakujo. (1797). Edo.
Sampo Kokon Tsuran (Mathematics for All Ages). (1797). Edo.
Sampo Tensei-ho Shinan (Mathematical Introduction of "Tensei-ho"). (1811). Edo.
Kaisei Sampo Kaisei-ron (Kaisei Sampo; new edition). (1787). Edo.
Tosei Jinko-ki (Today's Jinko-ki). (1785). Edo (Tokyo).

Secondary Sources

Akira, H., & Motohisa, M. (1966). *Aida Sanzaemon Yasuaki*. Tokyo: Fuji Junior College Press.
Gakushiin, N. (Ed.). (1956). *Fujiwara Matsusaburo. Meiji-zen Nihon Sugaku-shi (History of Japanese mathematics before the Meiji Era)*. Tokyo: Iwanami Shoten.
Horner, W. G. (1819). A new method of solving numerical equations of all orders by continuous approximation. *Philosophical Transactions of the Royal Society, 109*, 308–335.

Ajanta

Rajesh Kumar Singh
Baroda, Gujarat, India

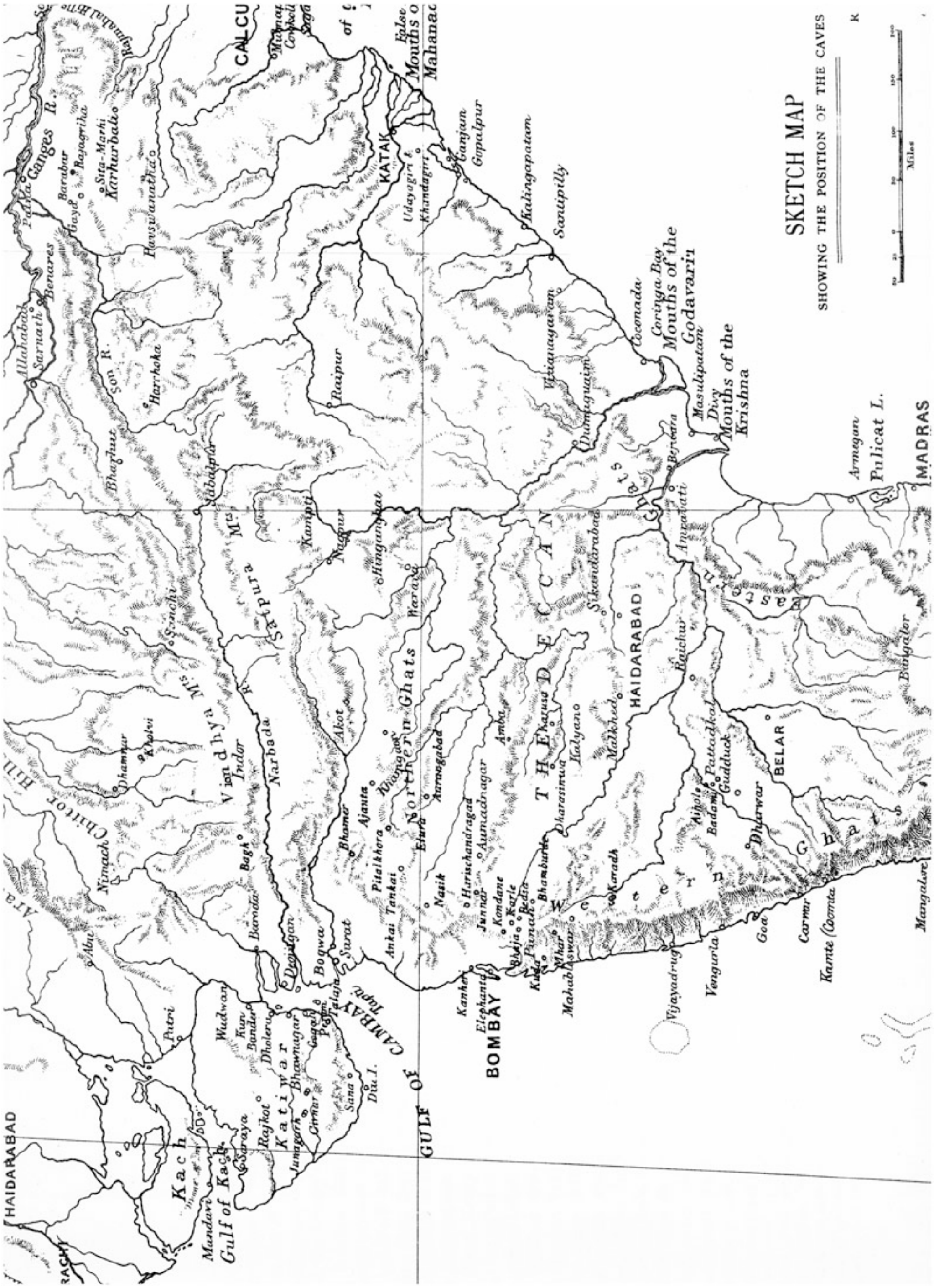
Introduction

Location. The ancient *saṅghārāma* (Buddhist monastery) of Ajanta is located in the Aurangabad district of Maharashtra state in India (latitude 20°33′9.94″N and longitude 75°42′0.69″E). There are nearly 30 rock-cut edifices.

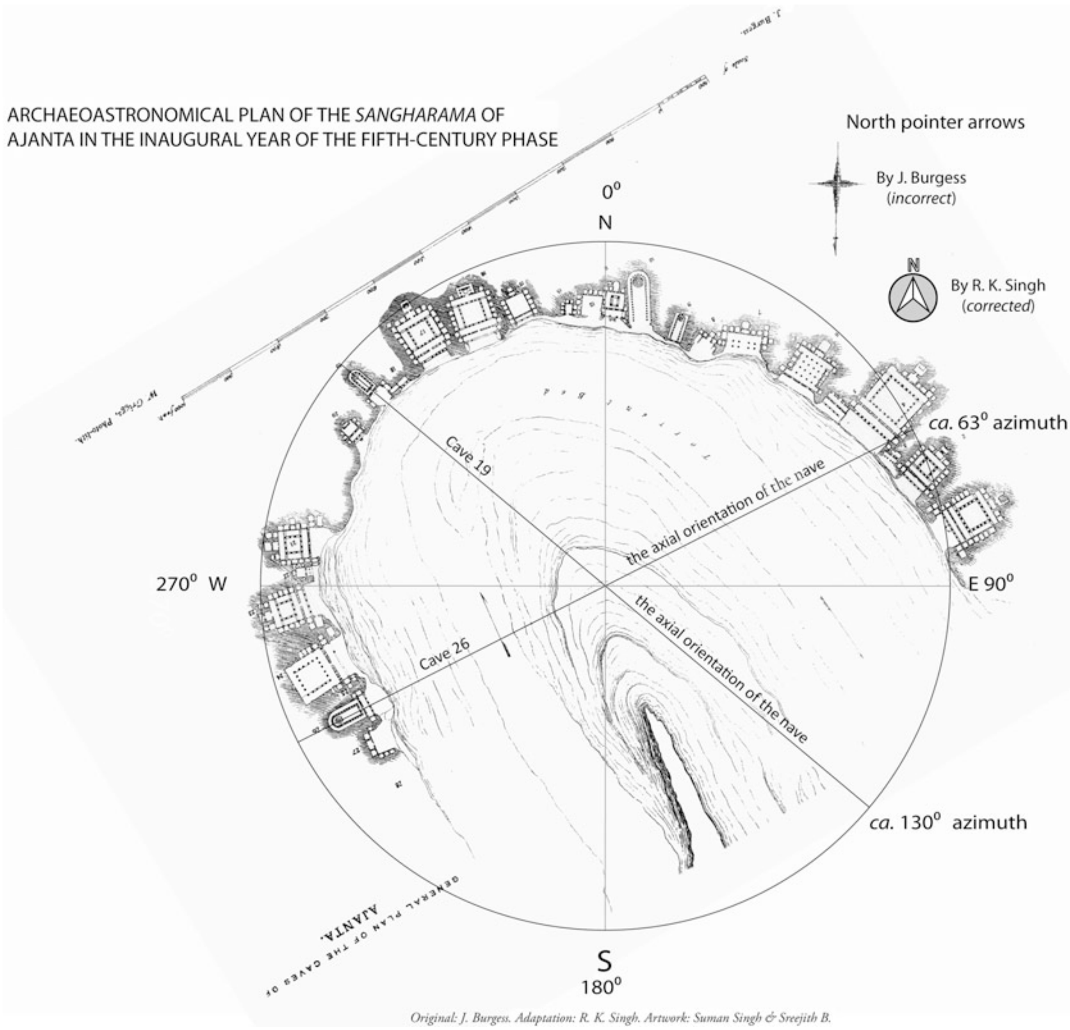
Geography. The geographical setting of the *saṅghārāma* is typical. It is near a waterfall, recessed deep into the glen of a ravine. The entire *saṅghārāma* is carved out of a monolithic stretch of scarp, which is in the shape of a horseshoe. The particular stretch of the scarp belongs to the Sahyādri range of the Western Ghats (*ghāṭ* = slope), recently listed in UNESCO's World Heritage list as an eco-sensitive zone.

Antiquity. Chronologically, the caves are divided into two groups. The first group of five caves is dated between the third and first centuries BCE (Nagaraju, 1981). The second group of some 26 caves has been dated recently between circa 462 CE and circa 480 CE (Spink, 2009, Fig. 39).

Political background. During the first phase, the region of Ajanta fell within the dominion of the powerful Sātavāhana dynasty whose direct involvement at Ajanta is not yet known. The period of the second phase of Ajanta developed within the reign of Maharaja Hariṣeṇa (ca. 460–477 CE) of the Vākāṭaka dynasty.



Ajanta, Fig. 1 Map showing rock-cut cave sites in India (Source: Fergusson and Burgess 1880)



Ajanta, Fig. 2 Caves 26 and 19 (the only two temples in the original plan of the fifth-century phase of Ajanta) show revealing astronomical connections. If Cave 26 is oriented to ca. 63° E-NE so as to receive the first rays of the sun on the Dhamma Day and on the first day of the varṣā ćaturmāsa, Cave 19 is oriented to ca. 130° E-SE so as to receive the precise alignment of the morning sun, every day, during the entire period of the subsequent, winter, ćaturmāsa (which spans from Kārttika Pūrṇimā to Phālguna Pūrṇimā)

Classification of the Ajanta edifices. Conventionally the *layaṇas* or *śailagṛhas* (both meaning rock-cut edifices) of Ajanta are classified under different categories: *Hīnayāna* (Lesser Vehicle), *Mahāyāna* (Greater Vehicle), *ćaityagṛha*, and *vihāras*. These categories now appear to be dubious. Frontier researchers are in the process of formulating a new criteria of classification that reflects the current and advanced understanding about the monastic complex.

Architecture

Rock-Cut Architecture

Rock-cut architecture is one of the most peculiar ways in which the history of arts and architecture evolved in India. All the ancient religions of India including Hindu, Jain, and Buddhists adopted the science or art of excavating rock-cut temples, monasteries, and pilgrimage sites (Fergusson & Burgess, 1880).

Ajanta, Fig. 3 A view of the Ajanta caves from the “Viewpoint”

Ajanta, Fig. 4 The Satavahana-period temples, Caves 9 and 10 (seen in the *center*)

Plans

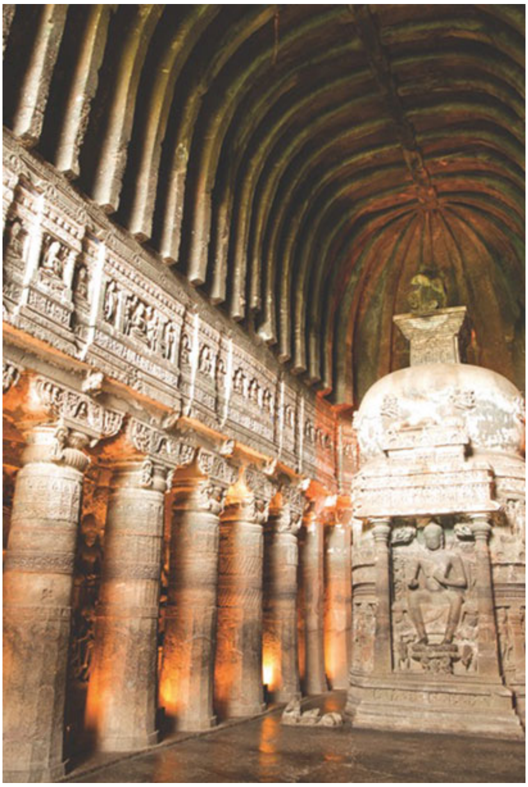
Stupa temples. *Stupas* were initially burial mounds that gradually came to be worshipped in ancient India. The Buddhists adopted the practice, for the earliest Buddhist stupas contained the relics of the Buddha. These were opened up in later times and the relics redistributed for and kept in many later stupas that were generally made of stone and bricks. In the context of rock-cut architecture, monolithic stupa temples were excavated, which could not of course contain any relic but were worshipped with equal faith. The history of stupa temples evolved in a variety of ways in different regions. However, the most characteristic of the evolved types, as at Ajanta Caves 9, 10, 19, and 26, contain a frontcourt,

Ajanta, Fig. 5 Cave 9, interior

a high enclosure wall, a nave, the stupa at the back of the nave, a circumambulatory path divided from the nave by a colonnade, and the vault. Further evolved types may also include porches (as in Ajanta Cave 26), musicians' galleries (as in Cave 19), terraces (as in Cave 26), and even adjunct *upāśrayas* (as in Cave 26) or *maṇḍapas* (as in Caves 26 and 19) (Singh, 2012a).

Upāśrayas. The word *upāśraya* in Ajanta inscriptions denoted a place of lodging for monks. The word is still used in India in similar contexts. *Upāśrayas* of Ajanta form one of the two major varieties of architecture, the other being the temples. Therefore, lodging and worship halls were two distinct types, demanding two different types of architectural requirement. This was so in the first group of the Ajanta caves in the Sātavāhana period, and it was so even during the first few years of the site's planning and development in the fifth-century phase. Soon, however, in circa 466 CE, a revolutionary idea changed everything; the old categories were discarded, for the *upāśrayas* were converted into *maṇḍapas* or *stupavihāras*, which combined the stupa and

Ajanta, Fig. 6 Cave 10, interior



Ajanta, Fig. 7 Cave 26, interior

the *upāśraya* setting allowing the monks to dwell in the interiors of the temple. Thus, a new variety emerged when the edifices that were begun as *upāśrayas* later began to add Buddha shrines in the interiors and also created *vithikās* (picture galleries) with other elaborate decorations (Singh, 2012b).

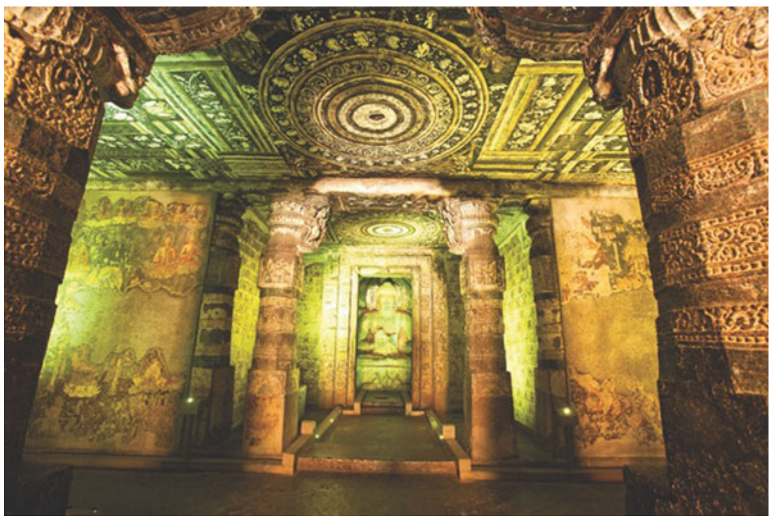
The plan of the *upāśrayas* is simpler. The main features included a congregation hall surrounded with residential cells, many of which have rock benches and pillows. Some larger *upāśrayas* were provided with pillars in the hall, windows on the front wall, and a porch. Occasionally porticos were excavated too. They often had front-courts. Sculptural or painted decoration was generally not the rule or requirement.

Maṇḍapas. The word *maṇḍapa* means a pavilion, still used in India. However, in Ajanta inscriptions the word is used variously to imply the presence of the Buddha. Thus, a *maṇḍapa* is not simply an *upāśraya* (hostel). Shrines of the Buddha were excavated in them (Cave 16), which were also called *caityamaṇḍapam*. Often, the plan of the *maṇḍapas* had a flight of steps for the riverbed, an ornate central gate (*torṇa-dvāra*), a frontcourt with

Ajanta, Fig. 8 Cave 7, the facade with the double portico

Ajanta, Fig. 9 Cave 2, interior

Ajanta, Fig. 10 Cave 2, the shrine area



an enclosure wall (*prākāra*), a pillared porch, and cubical hall with or without pillars, cells, and at least one Buddha shrine. The distinction of *maṇḍapas* from upasrayas may be gleaned from the fact that in the context of the *maṇḍapas* (with the anthropomorphic Buddha figures in the shrines), the word *upāśraya* has never been used in inscriptions. Instead, the words *ćaityamaṇḍapam*, *stupavihāram*, and *munirājaćaityam* are used (Yazdani, 1952), as in Ajanta Caves 16 and 17 (Mirashi, 1963) and the contemporaneous Ghaṭotkacha Cave not far from Ajanta, indicating that these are Buddha temples and not just *upā-śrayas* or halls. The *maṇḍapas* that are excavated at Ajanta and depicted in the Ajanta paintings give us enough clues as to what they are, and how to interpret or classify them. In Ajanta paintings, the Buddha is often seen seated in a pavilion type of architectural setting. Actually, the architectural scheme, layout, and planning of several Ajanta caves most closely resemble the pavilion type. Such pavilions are characterized

A

by a pillared portico, a porch, a hall, and subjoined cells. These are, thus, elaborate pavilions. And, they are not just pavilions. Because of the presence of the Buddha, the pavilions are effectively transformed into temples. It is for this relationship between the semantics and the syntax of the architecture of the *maṇḍapa* that the word *maṇḍapa* was used in the sense of a Buddha temple rather than a simple pavilion devoid of the Buddha's presence.

Ajanta, Fig. 11 Cave 1 interior rear wall, left of shrine depicting the Bodhisattva King in a Mountainous Landscape

Cisterns. Because the caves are at various levels of elevation at the cliff, there was a need to excavate cisterns at the cliff. Most of the edifices have a cistern. The water harvesting technology, the method and excavation technique, and the challenges faced by the planners in their creation are seldom explored. Some Ajanta cisterns are several dozen cubit feet in measure that are capable of storing a great volume of drinking water for the daily needs of the expected residents and pilgrims. Obviously, water harvesting at such altitudes of the monolithic cliffs of the amygdaloidal traps of the Western Ghats involved special engineering and experience. Some cisterns are open to the sky, some are inside the porches (Cave 6), some are inside the outer cells on front-courts (Caves 4 and 21), and at least one was so specially treated as to require an exclusive pillared edifice (Cave 18).

Architectural Components

Staircases. Most edifices were separately approached from the riverbed through a flight of steps, which were long for high elevation (as Cave 26) and shorter for those on the lower

Ajanta, Fig. 12 Cave 17, porch rear wall depicting the narrative of Kalodayin elevation (as Cave 6). Most staircases were open to the sky, while some were also tunneled (Caves Upper and Lower 6, Cave 16 and 17). Most of them have perished or been notably damaged in the course of time.

Gates and doorways. There are many types of doorways. First, the main gates (*torṇa-dvāra*) permitted access into the precincts of the edifices which have mostly perished now, except for the bare traces of a few. They evidently had sculpted guardian figures and other carved and painted decorations. Second, there are the main doorways permitting entry into the interiors of the edifices, which are often carved with figures of humans and other creatures. Geometric, ornamental, and vegetative decorations are also included with equal charm and beauty. Third, many edifices have side doorways permitting access into the interior, many of which have decorations with various carved or painted motifs. They provide extra lighting for the interiors when the hall is larger requiring proper lighting for the painted walls. Fourth, there are shrine doorways at the hall's rear, which received special treatment, because the shrine is symbolically and structurally the center of the temple. Each shrine doorway displays unique thematic, iconographic, and aesthetic treatment. Lastly, there are the cell doorways that are bereft of sculpted decorations, for the resident monks did not require decorations. Some cell doorways have painted decorations around the frame.

Prākāras. *Prākāras* are enclosure walls around the frontcourts of some edifices (Caves 19 and 26). Whether other edifices had *prākāras* cannot be confirmed, since the front parts of many frontcourts have perished in gradual rockslides.

Frontcourts. Most edifices have exclusive frontcourts. Of the earlier group of *upāśrayas*, Cave 12 probably had one. The other two (Caves 13 and 15A) are too small to permit any frontcourt. Of the fifth-century *upāśrayas*, the earliest inaugurated ones had shallow frontcourts (Caves 8, Lower 6, 26, and 19), while those inaugurated in subsequent years were provided with wide and deep frontcourts (Caves 21, 23, 24, 1, and 2). Even the adjunct *upāśrayas* or *maṇḍapas* had frontcourts (Caves 25, 27, and the lower wings of Cave 26).

Porticoes. Only few edifices have porticoes, e.g., Caves 1, 7, and 19. Cave 1 had a small double-pillared portico (now perished) and Cave 19 has a similar double-pillared portico. However, Cave 7 has the unique arrangement of two multi-pillared porticoes indicating that the edifice was special.

Porches. Both the *upāśraya* and temple types often have porches. While the stupa temple Cave 26 has a spacious pillared porch, the other stupa temple of the same fifth-century phase, Cave 19, does not have any porch. In the earlier phase, none of the two temples (Caves 9 and 10) seems to have had any porch. However, in the *upāśraya* category the larger ones were ideally provided with porches whether of the earlier period or of the fifth-century period. This is because Cave 12 of the earlier phase possibly had a pillared porch whose traces are all gone. As regards the later phase, it was the rule to provide every *upāśraya* or *maṇḍapa* with a porch, as there is no exception.

Halls. The halls of the earlier period, not only at Ajanta but also elsewhere, are smaller. Notably, the concept of the hall was rather related to the *upāśraya* type (residential). The word, *upāśraya*, itself implied a hall whose usage is not found in the inscriptions of the stupa temples wherein the Buddha was worshipped symbolically in the form of the stupa. Halls, therefore, can be said to belong to the *maṇḍapa* (literally, pavilion) type of architecture at Ajanta that has the Buddha shrines.

Cells. *Apavaraka* was the word used for the monks' cells. In earlier periods, as even today, the interior of a sacred place was never the ideal place for lodging. It was at least so by circa 466 CE in the context of Buddhist rock-cut architecture. A survey of Buddhist archaeology would reveal, as suggested earlier, that the *upāśrayas* and temples were excavated apart from each other even if physically adjoined to each other. However, a revolutionary experiment was carried out at Ajanta in circa 466 CE (Spink, 2009, Figs. 40–41) when the ideas of the *upāśraya* and the temple were combined into one architectural composition. The earlier duality was eliminated. The two types of architecture now coexisted within one layout, within a single program. The historical invention, for it was indeed the invention of a new idea, was created right at Ajanta in that catalytic year of circa 466 CE, as noted first by Spink. The new idea was to convert the *upāśrayas* into temples. A majority of the *upāśrayas* were already underway – some halfway into the porch or some had barely exposed the hall, but some had already completed the larger part of excavating the hall, and even the interior cells – when the idea of converting the *upāśrayas* (hostels) into temples suddenly gripped the site. What followed then was the challenging process of making difficult adaptations, redesigning the whole layout; each edifice presented unique opportunities for new schemes as well as new types of difficulties.

Cells were removed at places, extra cells were carved in other places, and blank areas were utilized for excavating more cells, such as those on the porch ends, and even on the left and right outer walls flanking the frontcourt. Thus, everything was overhauled, and the cells (or the cells' inmates) remained witness to the dramatic developments. Evidently, some cells were used while the excavation work was still underway, and some were used after the main Buddha shrines were dedicated and put to worship, and some cells were never used at all for various reasons. Some of the cells were plastered from inside, and some were even painted, as in Cave 27.

Door fittings. Spink has unlocked a great mystery of Ajanta by suggesting that the cell door fittings contain a credible corpus of physical data whose analysis alone is enough to reveal the internal chronological structure of the Ajanta caves of the second phase. He has classified the door fittings into four modes: A, B, C, and D. Then, there are also A+, B+, and C+, which are advancements over the earlier types. The door modes suggest a story of internal evolution at the site, across different caves. They suggest the gradual advancement of technology, the effort of grappling with the new medium of rock-cut architecture, and the trial and error process. It was indeed a new medium for the workers, planners, and other stakeholders, as it was after centuries that such architectural projects were started again in the monolithic medium. A survey of rock-cut architecture in India reveals that in the centuries immediately preceding the fifth-century phase of Ajanta, there was hardly such an edifice excavated in the Indian subcontinent. If there was a preexisting technology available regarding how to fix wooden doors in the monolithic doorframe of a shrine, or a main door, or a cell, the masters of Ajanta at least were not aware of them. They tried a variety of ways. The earlier efforts were really not very technological and also impractical, but the later ones are more sophisticated and sensible.

Pillars. Before the Ajanta examples, the rock-cut *upāśrayas* seldom had pillars in them. Even at Ajanta, the earlier *upāśrayas* do not have pillars. Ajanta Cave 12 that has a spacious hall does not have any pillar. In the fifth-century phase, when nearly 17 edifices were planned together in circa 461–462 CE, the plan seems to have been to provide the pillars in stupa temples alone, and not in the *upāśrayas*, which were dwelling halls. It was probably for this custom that the earliest of the fifth-century halls (e.g., Caves 27 and 15) do not have any pillar in the interiors even though the halls are reasonably larger. Soon, however, the planners felt the need of pillars in the *upāśrayas*. Accordingly, Cave 11 had four pillars added although the hall does not seem to require pillars because of its smaller size. In no time, it became a custom at Ajanta to add pillars in the halls of every *upāśraya*. The earliest pillars were octagonal without any decoration. The later pillars have 16, 32, or even 64 sides in them carved in various permutations of designs and decorations. Some such octagonal pillars were reworked in later years to suit the emerging aesthetic norms, as the site developed rapidly within a tight chronological framework of about 18 years during the reign of Hariṣeṇa.

As regards the pillars of the stupa temples, they have a long history of association and gradual development. At Ajanta, the earlier group of stupa temples (Caves 9 and 10) have a row of colonnades on either side of the nave, which goes around the stupa at the back, thus separating the nave from the aisles as well as permitting the creation of a *pradakṣiṇā-patha* (circumambulatory path). These pillars in both the caves are octagonal without any carvings. The flat surfaces were used for paintings. However, in the fifth-century stupa temples (Caves 19 and 26), the pillars while having been arranged for defining the circumambulatory path are lavishly carved with a variety of motifs and designs. Later, they were also painted.

Shrines. Prior to the fifth-century phase of Ajanta, the shrines were to be found only in the temples where the Buddha was worshipped in the symbolic form of the stupa. The symbolic structure of the stupa was itself the shrine; it carried the presence of the Buddha. However, it was not customary to have a shrine in the *upāśrayas* (residential halls). Only isolated examples are found in the Western Deccan where stupas are seen in the *upāśrayas*.

As regards the anthropomorphic Buddha image, it is not found in the *upāśrayas* prior to the fifth-century phase of Ajanta except for the solitary example of Kanheri where a portable wooden Buddha image was found in a *maṇḍapa* type of edifice. This has been dated just before the fifth-century phase of Ajanta. Thus, it appears that the Buddha shrines of Ajanta, wherein full-sized and even larger than life-size images of the Buddha are excavated in the monolith, are really the inventions of Ajanta in the fifth century CE – a fact seldom noted in art history (save for the works of Spink). The invention, however, did not start all of a sudden; it was not, evidently, the plan in the beginning.

From circa 466 onwards, when the idea of converting the *upāśrayas* (dormitories) into temples gripped the site, every possible residential hall then was added with a shrine at the rear of the hall, no matter how many adaptations had to be made for the purpose. Studies show that such Buddha shrines have a history of their own at Ajanta, beginning from the simple to the complex, from the smaller to the larger. Even iconographically, sociologically, and politically, the shrines underwent multiple phases of significant adaptations. For example, the Bodhisattva images were added later in them; the *upāsakas* (lay worshippers) were carved or painted, which were never a part of the original plan. Images of the donors who were either kings, queens, ministers, famous monks, or wealthy merchants or their family members were carved inside the shrine as *upāsakas* – a fact largely unnoticed in Ajanta studies.

Geology

Ajanta is geologically important too. The scarp bearing the cliff that has the caves punctured in them was actually created by the rivulet Wāghur (Tiger River) flowing down below. In fact, the seasonal river has cut out the whole gorge. Wāghur River originates from the waterfall at Ajanta and flows down to the plain of Tāpī for hundreds of miles across the fields. Near the plunge of the waterfall, there is a continuous process of head cut creating backward recession of the rock surface. Thus, the place of the head cut is receding, which can be clearly observed from the "Viewpoint" up above the *ghāṭs*.

The basalt of the amygdaloidal trap rock of the Deccan is relatively soft and has porous fissures, cracks, and flaws at places. The ancient lava flow now solidified has layers in between, which created difficult conditions for the excavators. Crystal formations in the trap were also a problem especially if they occurred at places earmarked for sculptures. Evidently, due to geological flaws the carvers had to make notable adaptations. Due to rock fall, scarp recession, and seepages, the monuments are endangered. Geologists, scientists, and archaeologists are working in tandem to find ways to preserve the heritage of Ajanta for posterity.

Paintings

Ajanta paintings have long been misunderstood as frescoes, which employ different sets of pigments, processes, and methods. They are now

Ajanta, Table 1 Identification of pigments at Ajanta

Color	Pigments	Location
White	Kaolin	All around
	Pure calcium carbonate	Dresses, architectural depictions, and figures
	Shell white	Lips, necklace, and decorations on women figures
Red	Red ochre	All around
	Red lake	Brighter red pigments all around
	Cinnabar (rare)	Identified at one place only
Yellow	Yellow ochre	Background, animals, dresses, and figures
	Orpiment and/or realgar	Decorations, tools, dresses, and animals
Green	Green earth	Leaves, dresses, background
	Orpiment with blue or organic black	
Blue	Lapis lazuli	All around (not present in the earlier group of caves of third-first centuries BCE)
Black	Lamp black	All around

Source: Singh, M. (2011), p. 90

best called murals. The paintings display a wide range of themes, which have now been fully and correctly identified by Dieter Schlingloff and Monika Zin after some attempts by earlier scholars. Broadly, there are narrative and non-narrative themes. The narrative themes deal with episodes from the life of the Buddha and the Jatakas that are the stories of the Buddha in his previous lives (Schlingloff, 2013). The non-narrative themes are either devotional or ornamental (Zin, 2003).

Pigments (by coauthor M. Singh). The pigments of Ajanta paintings have now been identified using the destructive and nondestructive methods of analysis of micro-samples (Table 1).

Some colors have been obtained by mixing the pigments, e.g., pink has been obtained by mixing white (kaolin or calcium carbonate) with red (red ochre or red lake). Orpiment or realgar is added to the pink to obtain a flesh complexion. The pigment layer is applied on dry plaster with an organic binder, which is probably vegetable or animal glue. The carrier of the painting is a thick plaster made up of silt, vegetable fibers, dung, ground rock powder (containing quartz, feldspar, pyroxene, olivine, iron oxide, etc.), and very little mud which is about 3 to 2.5 mm thick on a rough basaltic rock support.

Over the silt plaster, a calcium carbonate layer with thickness ranging from 80 to 200 μm was applied probably to render the pictorial surfaces flat and homogeneous in color to better receive the pigment layer. The adhesive material might have been animal or vegetable glue that has all disappeared now due to its being organic.

The paintings are under serious threat due to rising humidity conditions with the influx of tourists as well as because of the microbiological and microclimatic conditions.

Plaster (by coauthor M. Singh). Ajanta paintings were executed on a layer of plaster. There are various speculations about the composition and technique of the plaster. Recently, however, the Science Branch of the Archaeological Survey of India carried out detailed scientific investigations. The mud plaster samples were analyzed using XRF, FTIR, and SEM-EDX. The samples were observed using an electron microscope, which revealed a coarse substrate with casts even larger than 200 mm. This was followed by a second layer of fine-grained finishing.

The elements present in greater quantities in the sample are calcium, silicon, aluminum, and iron. Calcium is located in the inner most layer, silicon and aluminum in the layer immediately above, and iron associated with silicon and aluminum is in the outermost layer.

The elemental map with energy dispersive microprobe indicates a layer of calcium carbonate and a layer of kaolin due to the presence of aluminum. However, a clear line of demarcation between the calcium-containing layer and the kaolin (silicon and aluminum)-containing layer is not evident.

Particle size analysis of Ajanta mud plaster shows that the plaster is nonplastic with an average distribution of silt 70–75 %, sand 9–14 %, and clay around 12–15 %. The mud plaster shows specific gravity around 2.75. From this, it can be seen that low clay soil was used for the preparation of Ajanta mud plaster, which also contains a high amount of silt. Since such high-silt soil can be found on the bank of the Wāghur River at Ajanta, the question of its use during the preparation of Ajanta mud plaster cannot be ruled out, as there is more than 70 % silt found in this soil. This is in consonance with ancient canonical texts on the arts and architecture, viz., *Samarāngana Sūtradhāra*, where they recommend collecting soil from riverbanks for the preparation of mud plaster. It appears that sand and aggregate were mixed in the collected soil of riverbeds for the final preparation of mud ground. The present author attempted to prepare the mud plaster of Ajanta as per the recipes of the ancient text, and the results were rewarding.

References

Fergusson, J., & Burgess, J. (1880). *The cave temples of India*. London: W. H. Allen.

Mirashi, V. V. (1963). *Inscriptions of the Vakatakas: Corpus inscriptionum indicarum series* (Vol. V). Ootacamund: Government Epigraphist for India.

Nagaraju, S. (1981). *S. Buddhist architecture of western India, c. 250 B.C. – c. A.D. 300*. Delhi: Agam Kala Prakashan.

Schlingloff, D. (2013). *Ajanta: Handbook of the paintings*. New Delhi: Indira Gandhi National Centre for Arts.

Singh, M. (2011). Microclimatic condition in relation to conservation of cave no. 2 murals of Ajanta. *Current Science*, 89–94.

Singh, R. K. (2012a). The early development of the cave 26-complex at Ajanta. *South Asian Studies, XXVIII*(1), 37–68.

Singh, R. K. (2012b). *An introduction to the Ajanta caves: With examples of six caves (1st paperback edition)*. Baroda: Hari Sena Press.

Spink, W. M. (2009). In J. Bronkhorst (Ed.), *Painting, sculpture, architecture year by year: Ajanta, history and development series – Handbuch der Orientalistik (HDO) series* (Vol. V). Leiden: Brill.

Yazdani, G. (1952). *Ajanta: Monochrome reproductions of the Ajanta Frescoes based on photography, with an explanatory text by G. Yazdani and appendices on the painted and incised inscriptions by N.P. Chakravarti and B.Ch. Chhabra* (Vol. 6). London: Oxford University Press.

Zin, M. (2003). *Guide to the Ajanta paintings: Devotional and ornamental paintings* (Vol. 2). New Delhi: Munshiram Manoharlal Publishers.

Ajima Naonobu

Shigeru Jochi
Osaka Kyoiku University (Osaka University of Education), Osaka, Japan

Ajima Naonobu (1739–1796), also called Ajima Chokuen, was born at Edo (now Tokyo) in 1732. Ajima's father was earning 80 *pyo* (*pyo* was an annual salary of 60 kg of rice, and 80 *pyo* was the same salary as a landlord of an 80-person village would earn, or *koku*) and a samurai warrior of Lord Shinjo (Lord Shinjo belonged to the Tozawa family) in Dewa (now Yamagata Prefecture). Ajima studied mathematics first under Irie Masataka, a mathematician of the *Nakanishi-ryu* school, then under Yamaji Nushizumi (also called Yamaji Shuji (1704–1772)), who was the third president of the *Seki-ryu* school and an astronomer at *Bakufu Temmongata* (Shogun's Astronomical Observatory). Then Ajima became an accountant of Lord Shinjo, at the rank of 100 *koku*.

Yamaji made the *Horeki* (*Kojutsu*) *Reki* calendar (Calendar Made in Horeki Era 1754), which was used from 1755 to 1797; however, this calendar was not very accurate. In order to make a new lunisolar calendar, in 1762 he started to observe the sky with Fujita Sadasuke (1734–1807), his assistant. When Fujita was appointed *Sangaku Shihan* (Professor of Mathematics) of Lord Arima (1714–1783) in 1768, he retired from the Shogun's Observatory. After that, Ajima helped Yamaji to observe the sky and taught astronomy at Yamaji's astronomical school. Ajima wrote four astronomical manuscripts: *Jujireki Bimmo* (Introduction of the "Works and Days Calendar"), *Anshi Seiyo-reki Koso* (Professor Ajima's Studies for Western Calendars), *Ajima Sensei Bemmo no Jutsu* (Intoroduction of Professor Ajima's Metods), and *Koshoku Mokyu Zokkai* (Introductions of Eclipses (of the Sun and Moon)). These manuscripts were probably students' notes of Ajima's lectures.

Ajima Naonobu, Fig. 1 Ajima Naonobu's grave

The lunar crater of "Naonobu" (4.6S 57.8E) commemorated him and was named in 1976.

Ajima's works for pure mathematics were studies for logarithms, computing the values of spheres, and series. Ajima and other Japanese mathematicians studied Western mathematics indirectly, that is to say, through Chinese books such as the *Shuli Jingyun* (Mei Juecheng (1681–1763), 1723, China). Ajima studied logarithms from this book and then made a table of logarithms whose values are from 0.9 to 10^{-12}, 108 items. When Ajima used this table and these formulae

$$\log = \log X + \log Y \qquad \text{and} \qquad \log 0 = 1,$$

he could compute all logarithmic numbers up to 12 decimal places.

Ajima expanded Japanese mathematicians' traditional method *Tetsu-jutsu*, which uses a sort of inductive method. (*Tetsu-jutsu* was created by Takebe Katahiro (1664–1739), the second president of the *Seki-ryu* school.) Ajima computed the value of a sphere. In this case, he solved a sort of integral equation using *Tetsu-jutsu* twice.

Ajima also wrote the *Sansha San'en Jutsu* (Methods of Three Diagonals and Three Circles).

After Yamaji died, Ajima became the fourth president of the *Seki-ryu* school (or fifth, because Fujita was sometimes counted as the fourth). Ajima died in Tokyo, April 5, 1798 (May 20, 1798, current calendar) (Fig. 1).

References

Hirayama, A., & Matsuoka, M. (Eds.). (1966). *Ajima Naonobu Zenshu*. Tokyo: Fuji Junior College Press.

Nihon, G. (Ed.). (1954). (FUJIWARA Matsusaburo). *Meiji-zen Nihon Sugaku-shi*. Tokyo: Iwanami Shoten.

Hayashi Tsuruichi 林鶴一 (1937). *Hayashi Tsuruichi Hakushi Wasan Kenkyu Shuroku* 林鶴一博士和算研究集録 (Collected Papers on the old Japanese Mathematics) (2 vols., Vol. 2. p. 42). Tokyo: Tokyo Kaiseikan 東京開成館.

Nihon Gakushiin 日本学士院 (Japanese Academy) (Ed.) (Fujiwara Shozaburo 藤原松三郎). (1954). *Meiji-zen Nihon Sugaku-shi* 明治前日本数学史 (History of Pre-Meiji Japanese Mathematics) (5 vols., Vol. 4, p. 199). Tokyo: Iwanami Shoten 岩波書店.

Hirayama Akira 平山諦, & Matsuoka Motohisa 松岡元久 (Eds.). (1966). *Azima Naonobu Zenshu* 安島直円全集 (Collection of Azima Naonobu) (pp. 56). Tokyo: Fuji Tanki Daigaku Shuppanbu富士短期大学出版部 (Fuji Junior College Press).

Al-Battānī

Julio Samsó

Abū ʿAbd Allāh Muḥammad ibn Jābir ibn Sinān al-Raqqī al-ḥarrānī al-ṣābiʾ was an extremely important Islamic astronomer of the ninth to tenth centuries. He was probably born in ḥarrān before 858, and had Sabian ancestors. He lived most of his life in Raqqa (Syria) where he made most of his observations, but there is also evidence that he visited Baghdad and Antioch.

Apart from a few astrological tracts which have not been studied so far, he compiled (after 901) his *al-Zīj* (astronomical handbook with tables) also called *al-Zīj al-ṣābiʾ* (Sabian *Zīj*), a work which marks the stage of full assimilation of

Ptolemaic astronomy in Islam. This process had produced its first results ca. 830 with the *zījes* which were the consequence of the program of observations undertaken in Baghdad and Damascus under the patronage of Caliph ▶ al-Maʾmūn. Al-Battānī's ▶ zīj contains a set of instructions for the use of the numerical tables which have an essentially practical character. We do not find in them careful descriptions of the Ptolemaic models implied in the tables, and the author makes surprising simplifications, such as not describing Ptolemy's model for Mercury or not mentioning the equant point around which the mean motion of the center of the epicycle takes place. Nevertheless he describes, sometimes very carefully, the observations he made in Raqqa between 887 and 918, which allowed him to establish new and more precise mean motion parameters, a new eccentricity (0;2,4,45°) for the Sun and Venus, the longitude of the apogee (82;17°) of these two celestial bodies, a very accurate determination of the obliquity of the ecliptic (23;35°) (the band of the zodiac through which the Sun apparently moves in its yearly course), measurements of the apparent diameters of the Sun and the Moon, and their variation in a solar year and anomalistic month, respectively. These new parameters show a clear improvement over those of Ptolemy and led al-Battānī to establish some important corrections on Ptolemaic theory such as the mobility of the solar apogee, the fact that the obliquity of the ecliptic is not a fixed value, and the possibility of solar annular eclipses.

Apart from the *Almagest* and the *Planetary Hypotheses* (used by Battānī to determine the geocentric distances of the planets), Theon's *Handy Tables* constitute a major Ptolemaic influence in the *zīj*: the planetary equation tables (with the obvious exception of those for the equation of the center of Venus), for example, derive from Theon, and al-Battānī's work constitutes one of the important instruments for the diffusion of the *Handy Tables* during the Middle Ages. The *zīj* was translated twice into Latin (by Robert of Ketton and Plato of Tivoli) in the twelfth century, as well as into Spanish (thirteenth century) under the patronage of ▶ Alfonso X. It influenced strongly the Latin version of the *Alfonsine Tables*, was known in Jewish circles through the summary made in Hebrew by Abraham bar ḥiyya (d. ca. 1136), and was quoted by European astronomers until the seventeenth century. Al-Battānī died in 929.

See Also

▶ Abraham bar Ḥiyya (Savasorda)
▶ *Almagest*: Its Reception and Transmission in the Islamic World
▶ al-Maʾmūn
▶ *Zīj*

References

Abu Abdallah al-Battani (858–929 A.D). (1998). *Hamdard medicus 41*(2), 4–5.
Bossong, G. (1978). *Los Canones de Albateni. Herausgegeben sowie mit Einleitung, Anmerkungen und Glossar versehen*. Tübingen, Germany: Max Niemeyer Verlag.
Hartner, W. (1970). Al-Battānī. *Dictionary of Scientific Biography* (pp. 507–516, Vol. I). New York: Charles Scribner's Sons.
Kennedy, E. S. (1956). A survey of Islamic astronomical tables. *Transactions of the American Philosophical Society (Philadelphia), 46*(2), 32–34.
Maeyama, Y. (1998). Determination of the sun's orbit: Hipparchus, ptolemy, al-Battani, copernicus. Tycho Brahe. *Archive for History of Exact Sciences, 53*, 1–49.
Nallino, C.A. (1969). *Al-Battānī sive Albatenii Opus Astronomicum* (3 vols). Milan, Italy: Publ. Reale Osservatorio di Brera, Milano, 1899–1907. Rpt. of Frankfurt, Germany: Minerva G.M.B.H.

Al-Bīrūnī

Abdul Latif Samian

Abū Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī was born on Thursday, 3rd of Dhū al-Hijjah, 362 H (4th September A.D. 973) at Madīnah Khwārizm. His exact birthplace is still a matter of controversy. It is conjectured that he was born in the outskirts (*bīrūn*) of Kath, at al-Jurjāniyah, Khwārizm or at a place called Bīrūn, as implied by his nickname al-Bīrūnī. The only clue given by al-Bīrūnī was that he was born in a city in Khwārizm. The name Abū Rayḥān was given to him because of his love for sweet fragrance. Al-Bīrūnī died on 443 H (A.D. 1051).

He knew Persian but preferred Arabic, because the latter was more suitable for academic pursuit. Most of his numerous books and compendia were written in Arabic. He received some of his early education under the tutelage of the astromathematician Abū Naṣr Manṣur b. ʻAlī b. Īrāq al-Jilāni (d. ca. 427 H) and ʿAbd Al-Samad b. ʿAbdal Samad from Khwārizm. This is in addition to his formal elementary religious education at the *madrasah*, an institution where Islamic sciences are studied.

Al-Bīrūnī's first patron was the Sāmānid Sultan Abū ṣālih Manṣūr II, who reigned in Bukhara until the city was invaded by the Ghaznavid Sultan Maḥmūd in 389 H (A.D. 999). Later al-Bīrūnī went to Jurjān to the court of Abu'l Haṣṣan Qābūs b. Washmjīr Shams al-Ma'ālī (r. A.D. 998–1012), under whose patronage he wrote *al-Āthār al-bāqiya min al-qurūn al-khāliya* (Chronology) which was completed in 390 H (A.D. 1000). Al-Bīrūnī found the Sultan indiscriminate and harsh. His next sojourn was in Khwārizm and Jurjāniyah, in the service of the Sāmānid Prince Abu'l Abbas al-Ma'mūn ibn Muḥammad II. Under his partonage, al-Bīrūnī received great respect. It was during this period that al-Bīrūnī met the physician ʻAbu Sahl ʿIsa b. Yaḥaya al-Jurjāni. His *Taḥdīd nihāyāt al-amākin li taṣḥih masāfāt al-masākin* (Determination of the Coordinates of Cities) was completed in A.D. 1025.

His *Kitāb fī taḥqīq ma li'l-Hind* (Book on India) was finally published in 421 H (A.D. 1030). The Ghaznavid Sultan Maḥmūd invaded and conquered the city in 407 H (A.D. 1017). Al-Bīrūnī's other book, *Kitāb al-tafhīm li-awā'il sināʿat al-ṭānjīm* (The Book of Instruction in the Art of Astrology), which was dedicated to Rayḥānah, daughter of al-ḥassan, was written in Ghaznah, A.D. 1029. Al-Bīrūnī's *magnum* opus, *al-Qānūn al-Masʿūdī fī al-hay'ah wa'l-tanjīm* (Canon Masudicus), an astronomical encyclopedia comprising 11 treatises divided into 143 chapters, was completed at a later date, in 427 H (A.D. 1035) and was dedicated to the son of Maḥmūd, Masʿūd. Apart from emphasizing the importance of astronomy, he gave accurate latitudes and longitudes and also geodetic measurements. His *Kitāb al-jamāhir fī maʿrifat al-jawāhir* (Mineralogy) was completed less than a decade later (about 435 H/A.D. 1043) and was dedicated to the Ghaznavid Prince Sultan Shihāb al-Dīn Abu'l Fatḥ Mawdūd b. Masūd, Sultan Maḥmūd's grandson. His *Kitāb al-ṣaydanah fi'l-ṭibb* (Materia Medica or Pharmacology) was written toward the very end of his life.

Al-Bīrūnī lived during a period of intense scientific activity. Among his contemporaries were Ibn al-Haytham (A.D. 975–1039) and Abu ʿAli al-Husayn ibn ʿAbd Allāh ibn Sīnā (370 H/A.D. 980–428 H/A.D. 1027). Others include Abū Nasr Mansūr ibn ʿAli ibn Irāq who was one of al-Bīrūnī's patrons, Abū al-Hassān ʿAli ibn Sāid ʿAbd ar-Raḥmān ibn Aḥmād ibn Yūnus who was an astronomer of distinction (d. A.D. 1009), and Abū Sahl ʿIsa ibn Yaḥya al-Masīhi al-Jurjāni (d. A.D. 1000) who was a close associate of al-Bīrūnī's and wrote 12 books under his name.

Al-Bīrūnī was a philosopher-scientist, but science prevailed over philosophy and he appeared not to have identified himself with any school of philosophy. It was reported that he started doing astronomical observation as early as 18-years old.

In addition to his *Kitāb al-tafhīm* (Astrology) and his *Kitāb fī ifrād al-maqāl fī amr al-Ẓilāl* (The Exhaustive Treatise on Shadows) we can also find remarks which reflect his conception of nature in his other works. As an example, the introduction to his *Kitāb al-jamāhir fī maʿrifat al-jawāhir* consists of 15 *tarwīhāh* (philosophical reflections) which give his view on the attitude of man toward nature. It is more than a book on pearls and precious stones.

According to al-Bīrūnī, God creates nature from nothing (*creatio ex-nihilo*). Concerning his views on the relationship between man and nature, in his introduction to *Taḥdīd nihāyat* *al-amākin* (The Determination of the Coordinates of Cities), al-Bīrūnī explicitly refers to the *Qur᾿ānic* verse, "And contemplate the wonders of the creation in the Heavens and the Earth," "Our Lord: Not for naught hast Thou created (all) this" (Ch. 3: 191). Moreover, al-Bīrūnī contends, "This noble verse contains the totality of what I have explained..." In other words, this particular *āyāt*, out of all the other *Qur᾿ānic* verses, is of paramount importance to his scholarly life.

The element of transcendence is evident in al-Bīrūnī's outlook on nature. One of his major postulates is that God creates nature; al-Bīrūnī envisages from the very beginning the affinity between natural phenomena and their metaphysical causes. God creates nature through the *Qur᾿ānic* injunction of *kun fayakun* (Ch. 17: 163). Nature and her phenomena are nothing but the manifestation of God's initial creative act that is verbal. But God's creative act is also continuous. God always intervenes. It is different from the Cartesian worldview where God stops to intervene after the initial act of creation.

The laws of nature (*sunnat* '*Allah*), which are the laws of God and which to al-Bīrūnī warrant examination, are possible because of the appearance of permanency in them. The affinity between nature, the created, and God who is the Creator points also to the element of the sacredness of nature. The study of nature through contemplation and action ought to be done within the parameters of religion, which to al-Bīrūnī is Islam. Therefore there is an esoteric and exoteric utility to religion in studying nature. In addition to the esoteric utility of studying nature, al-Bīrūnī emphasizes the exoteric aspect too. Again, in *Kitāb ṭāḥḍīḍ* (The Determination of the Coordinates), he states, "The Jews also need a direction, because they turn in their prayers to the Temple in Jerusalem... The Christian need the (direction of) true East because their elders...prescribed to them that they should turn to Paradise in their prayers."

Prayer (*ṣālat*) is one of the fundamental principles of Islam. It is well known that Muslims offer their prayers facing the *qibla* in Mecca. The problem for Muslims all over the world is to ensure that they are facing the correct direction in their prayers. This is an example of what can be viewed as the exoteric aspect which al-Bīrūnī attempted to solve.

Another example is determining the time for prayer. Al-Bīrūnī devoted a whole chapter in his *Kitāb fī ifrād al-maqāl fī amr al-zilāl* (The Exhaustive Treatise on Shadows) to this problem. Studying nature should not be for the sake of studying nature; there must be a greater purpose sanctioned by religion, and in this case it is to solve the problem faced by Muslims in offering their prayers.

Al-Bīrūnī places truth as one of the noble aims of contemplating nature. "I must assay all aspects of this statement, because I do not refuse to accept the truth from any source, wherever I can find it" (*Taḥdīd*). Studying nature is akin to an investigation to find out the truth. The external world can provide truth. Thus al-Bīrūnī maintains, "There is a great difference between an investigator of truth [who studies nature] and a follower of tradition." God says: "Are those equal, those who know and those who do not know" (*Taḥdīd*).

Al-Bīrūnī never uses the word "science" in the sense that the word is understood today – that knowledge which is exact, objective, verifiable, deductive, and systematic. The closest term that he ever used is the Arabic word *ʿilm*, which also means knowledge. *Al-ʿilm* in the language of the *Qur᾿ān* and Sunnah (traditions of the Prophet) implies knowledge which makes man conscious of God, of His attributes, of the eternals, of the next world, and of the return to Him.

Science, to al-Bīrūnī, is a problem-solving activity. Scientists seek solutions to problems. Solving problems, which to al-Bīrūnī is analogous to "untying knots," (*Kitāb fī ifrād al-maqāl*), is the main activity of scientists. That science is a problem-solving activity and a scientific problem is a problem circumscribed by the Holy *Qur᾿ān* and Sunnah which needs to be solved in order for a Muslim to improve his *taqwa* (God consciousness) can be discerned by examining, in particular, the Introductions of his major books. We can see in these cases that this concept of religion is fundamental in shaping his attitude toward science as a problem-solving activity. His *India*, for example, was written "as a help to those who want to discuss religious questions with them, as a repertory of information to those who want to associate with them."

In another work, *Taḥdīd nihāyat al-amākin* (The Determination of the Coordinates), he clearly states another aspect of a scientific problem. "Geography is very essential for a Muslim for knowing the right direction of *qibla*." Finding the direction of the *qibla* is an example of a scientific problem which is circumscribed by the *Qur'ān* and Sunnah.

The evaluation of the problems tackled, except in the *Taḥdīd*, is not given post hoc or ad hoc. It is not the case that al-Bīrūnī solved scientific problems before thinking of their necessity, their worthiness for the *society*, viz., their legitimacy from the *Qur'ānic* and Sunnah point of view. Concerning geography and astronomy, he states: "...For whoever determines the longitude and latitude of this country with precision will thereby enable him to find out...times which are needed...for fasting." Realizing the comprehensiveness of Islam as a complete way of life, he adds, "...the usefulness here exceeds specific religious matters and extends to worldly affairs." Clearly, there is a sacred orientation in scientific problems. Scientists *qua* scientists should solve problems in a manner which brings them closer to God that can "yield His satisfaction (*riḍā*)."

In yet another book, *The Exhaustive Treatise on Shadows*, we can see very clearly his orientation toward scientific problems. In studying shadows, not only did he analyze shadows of this world, but also shadows in the Hereafter. He investigated in detail their differences, similarities, and the nature of their existence. He differentiated between shadows in Heaven and shadows in Hell. Thus al-Bīrūnī showed that there is a "revealed perspective" on scientific problems which the scientist should take into account. The scientist should always be mindful of the connection that the problems have to this world and to the Hereafter. The science of astronomy, for example, has its origin from the prophet Idrīs. These are examples of scientific problems in the Holy *Qur'ān* and Sunnah that from al-Bīrūnī's point of view merit investigation.

There is an element of transcendence in seeking scientific solution. Al-Bīrūnī is always conscious of God while solving problems. He strives to be among those who "...remember Allah, standing, sitting and reclining and consider the creation of the heavens and the earth, (and say): O Lord; Thou created not this in vain." Examples are abundant in his writings where he invokes God's help. In *India*, he beseeches God to "help him to a proper insight into the nature of that which is false and idle, that he may sift it so as to distinguish the chaff from the wheat."

Generally speaking, within the schema of contemplation, al-Bīrūnī solves problems mathematically. He considers himself a mathematician more than anything else. In *al-Qānūn al-Masūdī*, he says: "...I belong to a branch of mathematics (*riyāḍhi*),...and have been known by it and may intention never exceeded it..."

There are two complementary aspects of his problem solving: one is the "external" and the other is the "internal." The "external" aspect involves more of the external senses as opposed to the "internal" aspect. The "internal" aspect heavily involves the processes of mathematical abstraction by the internal senses.

Man has to look for information, for evidence, in nature. This is an external aspect of his problem solving. "Human reason needs data and no human being can be an exception from the need of phenomena in which the mind functions" (*Kitāb al-Taḥdīd*). Al-Bīrūnī's statement urging his readers to observe and collect data about observables shed some light on his approach to mathematical inquiry: that the process of mathematization, from the external aspect that is, should have empirical import. There are two parts related to his external aspect of this problem solving (as an act of contemplation) that warrant elaboration. First is al-Bīrūnī's view on the manner in which one arrives at a theory and second in his perspective on theory choice.

Al-Bīrūnī attaches great importance to intense observation and putting exhaustive effort into procuring, comparing, analyzing, and synthesizing data (which includes both oral and written reports) in arriving at a theory. In fact in his *Kitāb fī ifrād al maqāl* (The Exhaustive Treatise on Shadows), he cautions people against "ignoramuses" who do not spare much effort but simply "attribute to God's wisdom all that they do not know of the physical sciences." The physical world is out there to be studied in order for us to internalize the greatness of God. Observation is essential to all scientific endeavors, including medicine. Al-Bīrūnī says, in the *Kitāb fī ifrād*, "through the frequency of observations he will gain in resource, both intellectual and intuitive."

To begin with, one has to define his object of study. In the case of geology, he needs to focus his observation on "the rocks and vestiges of the past." Observation involves seeing. Unlike Aristotle, who believed that vision was made possible by emitting rays from the eyes, al-Bīrūnī believed that rays were emitted to the eyes by the object themselves. Images are then formed in the eyes. There is no objective observation. Seeing is an experience. It is a not physical state. A retinal reaction is a photochemical excitation, a physical state. Scientists-and not their eyes-see. Al-Bīrūnī admits the possibility of the observation made by his contemporary, the astronomer Abū Saʿid of Sistan, even though al-Bīrūnī preferred the geocentric theory. Unlike al-Bīrūnī, the latter was a proponent of the heliocentric (the sun is the center of the universe) theory. Al-Bīrūnī saw the sun rising but Abū Saʿid saw the horizons of the earth changing in the East at dawn.

Al-Bīrūnī underscored the importance of observation not only in studying geology, but also in mineralogy. One should have keen eyesight, more so than others. Without good eyesight, it would be difficult for them to observe the minute differences and similarities in metals and precious stones.

It is through sight that mathematicians can observe nature and contemplate. Observation, which is an integral part of al-Bīrūnī's problem solving, is not only for the sake of accumulating information. Observation is done within the schema of contemplation. For example, in his *Kitāb ifrād al-maqāl* (The Exhaustive Treatise on Shadows), he quotes a *Qurʾānic* verse (Ch. 77: 31) and states: "If one meditates on the verse, he will find two of the attributes of the shadow in the masculine form…" In his *Kitāb al-jamāhir* (Mineralogy), he says: "Sight connects what we see to the signs of Divine Wisdom in creatures and demonstrates the existence of the Creator from his creation."

Sight and hearing are two of the most important sense perceptions for gathering data for scientific inquiry insofar as observation is concerned. Both are integrated "in the heart, which is the seat of intelligence."

Reports are equally important as observation. The scientist gathers his data from documented reports. Reports are written in several languages. Al-Bīrūnī's preference for Arabic is not without a strong reason. Through etymological examination of the names of things, the scientist can be more informed about them. For example, there is the word *falāk* in his explanation about celestial motion. He writes in *Kitāb al-tafhīm* (Astrology), "The celestial sphere…is called *falāk* on account of its circular movement, like that of a whirl of a spindle…"

It is interesting to note that in so far as history of science is concerned, al-Bīrūnī preferred written tradition to immediate observation and he recommended *comparing* reports. Al-Bīrūnī lamented his predecessors who did not scrutinize their data.

After focusing on the problem, al-Bīrūnī collects data which are then compared and analyzed or synthesized, mainly through experiment or verbal verification (questioning the transmitters) or both, depending upon the field of study. In al-Bīrūnī's pattern of problem solving, the stage of theorizing comes only after one has exhausted all reasonable efforts in procuring data and in comparing the results of previous or contemporary researches. It is only after he is satisfied with the amount of information relevant to the problem that he goes "from the known to the unknown, from the near distant to the far" – to wit, the inductive and deductive process.

Examples are abundant throughout his works which demonstrate this exhaustive effort. In his study of astronomy, after procuring data, he examines solutions offered by others. His study entitled "A Number of Topics Dealing with Shadows" is a case in point. In it he discusses methods for computing the length of daylight at any time of the year used by ▶ Brahmagupta, Vijayanandin, and Yaʿqūb ibn Tāriq besides three other methods of Babylonian and Persian origin.

In the fourth chapter of *al-Qānūn al-Masʿūdī* (Canon Masudicus), he compared results obtained by Ptolemy and one Yaʿqūb al-Sehri and thereafter made the trenchant remark, "Both the methods give results correct to the second order but Ptolemy understood what he did, whilst Yaʿqūb did not known what he was doing." In mineralogy, there were extensive etymological considerations in his analysis of minerals. He revised the findings of others. He did the same in his studies of medicine in his *Kitāb al-ṣaydanah* (Materia Medica or Pharmacology).

In his analysis of societies such as in *Kitāb fī taḥqīq ma li'l Hind* and *al-Āthār al-bāqiya* (India and Chronology), in subtopics where experiments could not be conducted, where most of the data is not in the form of direct observation but through oral and written reports, he examines witnesses to remove distortions in addition to comparing reports to ensure that they are as correct and accurate as possible. His emphasis is on the comparative method. In his *al-Āthār al-bāqiya*, he writes on most, if not all, of the festivals of various creeds and religions found in the regions of the Caliphate. In *Kitāb fī taḥqīq* he compares the beliefs and lifestyles of the Hindus with Buddhists, Manicheans, and Zoroastrians to what others wrote about them. Similarly in his study of the circumference of the earth, al-Bīrūnī examines the previous results obtained by astronomers under the patronage of Ma'mūn al-Rashid (A.D. 813–833), the Abbāsid Caliph. He discovers that they reached different results. Dissatisfied, he conducted experiments in the area of Ghazz, Turks, and Jurjān.

In the external aspect of al-Bīrūnī's pattern of scientific problem solving, the problem of theory choice from his view occurs when there are several possible theories (as viable solutions) to a specific problem. In particular, the problem arises when al-Bīrūnī compares possible explanations in order to find a good one. Al-Bīrūnī does have some criteria which determine his choice and these criteria help him in formulating a good theory. What is more interesting is that these criteria reflect his scientific acumen and his conception of God (as the "perfect scientist").

An important criterion to al-Bīrūnī is accuracy. That accuracy dictates the choice of one theory instead of another is partly because accuracy is less equivocal compared to other characteristics such as simplicity or fruitfulness. The predictive and explanatory power of theories depends on their accuracies. Al-Bīrūnī knew that accuracy is almost synonymous with exactness which certainly involves measurements. The finer the measurement, the higher the degrees of accuracy. Al-Bīrūnī's treatment on measurements, on inventing measuring instruments such as the *Yamīni* ring, the *Ustuwani* which he used "to measure the height of heavenly bodies, their apogees, time, depth of well or rivers and heights of walls, towers and hills..." His expertise with *al-dahj*, *sarqālah al-ma'*, *Sirāj al-Khādim*, and *naqshah*, and a particular machine that found the exact prayer times which he constructed for the mosque in Ghaznah, points to the importance of accuracy to him. More important than that, the striving for accuracy on the part of the scientist reflects al-Bīrūnī's understanding that perfect scientific knowledge belongs to no other but God because it is only He that measures perfectly.

In addition to accuracy, another criterion is novelty. Al-Bīrūnī believed that a good theory should be able to disclose new relationships of previously unnoted phenomena. A theory should help the mathematician to discover "new" aspects of God's creation, increasing his awareness of God as *al-Khāliq*, the Creator who creates everything unceasingly. An example to illustrate this is al-Bīrūnī's study of the variation in the length of the year related to the motion of the apogee where he gives the theorem "that the apogee and the perigee are the points at which the apparent velocity reaches its extreme values."

However the most important criterion is truth. Truth to al-Bīrūnī is more than a regulative principle; it is *the* regulative principle. The notion of truth is central to his conception of problem solving. We can find that truth permeates at all stages in his pattern of problem solving outlined above. Al-Bīrūnī did not view truth as an illusive notion which, construed as such, is irrelevant to science. After focusing on a particular problem, he begins his inquiry in *al-Āthār al-bāqiya* (Chronology) by asking God to "help [him in] perceiving and realising the Truth, and facilitate its pursuit and lighten its courses…" In collecting as much relevant information as possible to the problem, he states in *Taḥdīd* (The Determination of the Coordinates): "I do not scorn to accept truth from whatever source I can find it." He even reminded himself in *India* to "speak the truth, even if it were against yourselves." In *Chronology*, al-Bīrūnī perceives truth as that which is "enjoined by the holy scriptures on mankind [and] possesses its own intrinsic beauty just like justice…"

Al-Bīrūnī's notion of truth is not equivalent to the popular conceptions of truth. It cannot be construed as correspondence theory of truth favored by realists. Neither can it be categorized under the coherence theory nor the pragmatic theory of truth per se. These are the reductive approaches to truth. Truth, to al-Bīrūnī, must be seen from the perspective of the *Holy Qurʾān dan Sunnah* since the *Qurʾān* is revealed as a "guidance" (*huda*). Therefore it is interesting to note that whenever a theory which is a result of his rigorous approach is not consistent with a new discovery of an "irregularity" of nature, it points not so much to its falsity but more so to Divine Wisdom.

In light of the importance of contemplation to al-Bīrūnī, it needs to be emphasized that although al-Bīrūnī construes science as an activity of problem solving, the scientist himself is not obsessed with the problems. Rather he is obsessed with the relationship between himself and God. It is God that is central in this problem-solving activity. Therefore solving scientific problems is only a consequence of his consciousness and conception of God.

To recapitulate, nature to al-Bīrūnī is the handiwork of God. The activity of deciphering nature, of solving scientific problems, can be an act of ʻ*ibādah*, a "sacred" act which can raise the status of the scientist in the eyes of God. Scientific activity to al-Bīrūnī is an activity bounded by the parameter of religion. In his quest to gain understanding of nature, he believed that one should be conscious of Divine Wisdom, which is manifested in nature and all its intricacies. It is both a theoretical and practical activity of solving problems. As a very prolific and multidimensional scholar, al-Bīrūnī did serious work in almost all branches of science in his time and his 146 treatises range from 10 to 700 pages each.

References

Primary Sources

al-Āthār al-bāqiya min al-qurūn al-khāliya (The Chronology of Ancient Nations). (1879). (E. Sachau, English Trans.). London: Minerva GMBH.

al-Qānūn al-Masʿūdī (Canon Masudicus). (1954–1956). Hyderabad, India: Osmania Oriental Publications Bureau.

Krenkow, F. (Ed.). (1936). *Kitāb al-Jamāhir fī marifat al-jawāhir (Mineralogy)*. Hyderabad, India: Osmania Oriental Publications Bureau.

Kitāb al-ṣaydanah fiʿl-tibb (Materia Medica). (1973). (Hakim Mohammed Said, et al., Ed. & Trans.). Pakistan: Hamdard Academy.

Kitāb al-tafhīm li awāʾil ṣinā ʿat al-ṭanjīm. (1940). Tehran, Iran: Jalal Huma'l. (R. Ramsay Wright, English Trans.). *The book of instruction in the art of astrology*. London: Luzac, 1934.

Kitāb fī ifrād al-maqāl fī amr al-zilāl. (1948). Hyderabad, India: Osmania Oriental Publications Bureau. (E. S. Kennedy, Ed. & Trans.). *The Exhaustive Treatise on Shadows*. Syria: University of Aleppo, 1976.

Kitāb fī taḥqīq ma liʿl Hind (Alberuni's India). (1888). (E. Sachau, English Trans.). London: Trubner.

Taḥdīd nihāyat al-amākin li-taṣḥiḥ (The Determination of the Coordinates of Cities). (1967). (Jamil Ali, English Trans.). *al-Bīrūnī's Tahdid al-Amakin*. Beirut, Lebanon: American University of Beirut.

Secondary Sources

Boilot, D. J. (1955). L'oeuvre d' al-Bīrūnī: essai bibliographique. *Mélanges de'l Institut dominicain d'études orientales, 2*, 161–256.

Kennedy, E. S. (1970). al-Bīrūnī. In C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 2, pp. 147–158). New York: Charles Scribner's Sons.

Khan, A. S. (1982). *A bibliography of the works of Abū'l Rāiḥān Al-Bīrūnī*. New Delhi, India: Indian National Science Academy.

Nasr, S. H. (1993). *An introduction to Islamic cosmological doctrines* (Rev. ed.) Albany, NY: State University of New York Press.
Nasr, S. H., & Chittick, W. C. (1975). *al-Bīrūnī: An annotated bibliography of Islamic science*. Tehran, Iran: Imperial Iranian Academy of Philosophy.
Said, H. M., & Khan, A. Z. (1979). *Al-Bīrūnī – His times, life and works*. Karachi, Pakistan: Hamdard Foundation.

Al-Bīrūnī and Geography

Akhtar H. Siddiqi

The geographical knowledge of the Muslims, in part derived from the Greeks and others, and contemporaneously developed and advanced by themselves, had reached a very high level of development by the tenth century. It is in this development that the work of ► al-Bīrūnī is significant. Al-Bīrūnī presented a critical summary of the total geographical knowledge up to his own time. He made some remarkable theoretical advances in general, physical, and human geography. Al-Bīrūnī did not confine himself to a simple description of the subject matter with which he was concerned. He compared it with relevant materials and evidence, and evaluated it critically, offering alternative solutions.

George Sarton identifies al-Bīrūnī as one of the great leaders of this period because of his relative freedom from prejudice and his intellectual curiosity. Although his interests ranged from mathematics, astronomy, physics and the history of science to moral philosophy, comparative religion and civilization, al-Bīrūnī became interested in geography at a young age. He is considered to be the greatest geographer of his time.

In the area of physical geography, he discussed physical laws in analyzing meteorology and climatology. He wrote of the process of streams development and landscape evolution. He introduced geomorphological enquiry to elucidate a history of landscape. He developed the mathematical side of geography, making geodetic measurements and determining with remarkable precision the coordinates of a number of places. Some of his noteworthy contributions to geography include: a theory of landform building processes (erosion, transportation, and deposition), proofs that light travels faster than sound, explanations of the force of gravity, determination of the sun's declination and zenithal movement, and discussion of whether the Earth rotates on its axis. He described various concepts of the limits for which he seems to have had recourse to contemporary sources not available to earlier geographers. He made original contributions to the regional geography of India.

In the study of physical phenomena, including landforms, weather, and geology, al-Bīrūnī adopted the methods of the physical sciences and drew conclusions with scientific precision. Al-Bīrūnī developed a schema for physical geography: (a) terrestrial conditions, describing the shape and size of the Earth; (b) cosmic concepts, dealing with the measurement of the circumference of the Earth and the establishment of the exact location of places; and (c) classification of natural phenomena either in accordance with their nature or with their position in time and space. He studied phenomena in time (chronological science) and also tried to study them in space. In his view, geography was an empirical science.

Based on available knowledge concerning the surface of the Earth, he deduced and described the shape and forms of land surface. Al-Bīrūnī examined questions concerning the Earth's shape, size, and movement.

He explained running water as the most effective agent by which the surface of the land is sculpted. He further asserted that as the rivers of the plains of India approached the sea they gradually lost their velocity and their power of transportation, while the deposition process along their beds increased proportionately. ► Al-Bīrūnī considered the changes in the course of a river a universal phenomenon. He also recognized the influence of the sun upon the tide and suggested that heavenly bodies exert a gravitational effect on the tides.

Al-Bīrūnī recognized that the heat of the atmosphere and the Earth's surface is derived from the sun through the transfer of energy by rays, and that it varies with the length of time that the Earth is exposed to the rays. He recognized the wind's force and velocity and argued that the wind, in all its phases, is determined by certain causes.

Al-Bīrūnī noticed the peculiarities of the Indian monsoon, observed the time of its breaking, and described its westward and northward movements and the unequal distribution of rain in different areas of India.

Finally, he added that the habitable world does not reach the north on account of the cold, except in certain places where it penetrates into the north in the shape, as it were, of tongues and bays. In the south it reaches as far as the coast of the ocean, which in the east and west is connected with what he calls the comprehending ocean (*India*, Vol. I, p. 196).

In short, al-Bīrūnī recognized geography as an empirical science, and he dealt with the terrestrial globe as a whole. He stressed its nature and properties. He also tried to investigate the causes of global phenomena and described them as they existed.

See Also

- ▶ Geography in India
- ▶ Maps and Mapmaking in India

References

Ahmad, S. M. (1965). Djughrafia (Geography). In *The encyclopedia of Islam* (Vol. II, pp. 575–587). Leiden, Netherlands: E. J. Brill.

Barani, S. H. (1951). Muslim researches in geodesy. In *Al-Bīrūnī commemorative volume* (pp. 1–52). Calcutta, India: Iran Society.

Kazmi, H. A. (1974). Al-Bīrūnī's longitudes and their conversion into modern values. *Islamic Culture, 49*, 165–176.

Kazmi, H. A. (1975). Al-Bīrūnī on the shifting of the bed Amu Darya. *Islamic Culture, 50*, 201–211.

Kramer, J. H. (1951). Al-Bīrūnī's determination of geographical longitude by measuring the distance. In *Al-Bīrūnī commemorative volume* (pp. 177–193). Calcutta, India: Iran Society.

Memon, M. M. (1959). Al-Bīrūnī and His contribution to medieval Muslim geography. *Islamic Culture, 33*, 213–218.

Sachau, E. C. (1879). *The chronology of ancient nations*. London: W. H. Allen.

Sachau, E. C. (1910). *Alberuni's India* (Vols. I and II). London: Kegan Paul, Trench, Trubner and Co.

Sarton, G. (1927). *Introduction to the history of science* (Vol. I, pp. 693–737). Baltimore: Williams and Wilkins.

Sayılı, A. (1979). Al-Bīrūnī and the history of science. In M. M. Said (Ed.), *Al-Bīrūnī commemorative volume* (pp. 706–712). Karachi, Pakistan: Times Press.

Al-Biṭrūjī

Julio Samsó

Al-Biṭrūjī (fl. 1185–1192) was an Andalusian astronomer whose complete name seems to be Abū Isḥāq (ibn?) al-Biṭrūjī, Nūr al-Dīn. Nothing is known about his biography apart from the fact that his name probably derives from the region of Los Pedroches, near Cordoba, and that he was a disciple of the philosopher ▶ Ibn ṭufayl (ca. 1110–1185). The latter was already dead when al-Biṭrūjī wrote his only known work, the *Kitāb fī-l-hayʾa* (Book on Cosmology), which seems to have been read by the anonymous author of a book on tides dated in 1192. On the other hand, al-Biṭrūjī's treatise was translated into Latin by Michael Scott in Toledo in 1217.

Al-Biṭrūjī was a member of the Andalusian school of Aristotelian philosophers composed of Ibn Bājja (1070?–1138), the aforementioned Ibn ṭufayl, Ibn Rushd (Averroes, 1126–1198), and Mūsā ibn Maymūn (Maimonides, 1135–1204). All these authors criticized Ptolemaic astronomy due to its mathematical character which did not agree with Aristotelian physics. Al-Biṭrūjī was, however, the only one who made a serious, although unsuccessful, attempt to create an astronomical system which could have a physical reality. In it he uses homocentric spheres in the Eudoxan tradition which he combines with materials derived from the Toledan astronomer ▶ Ibn al-Zarqāllu (Azarquiel, d. 1100). It is interesting to remark that al-Biṭrūjī's dynamics are not exclusively Aristotelian but also use Neoplatonic concepts such as the impetus theory which he seems to have been the first to introduce into Western Islam. Al-Biṭrūjī's system was soon known in Western Europe and became very popular among Scholastic philosophers of the thirteenth century, who considered it a serious alternative to Ptolemy.

See Also

▶ Ibn Al-Zarqāllu
▶ Hay'a

References

Carmody, F. J. (1952). *Al-Biṭrūjī. De motibus celorum. Critical edition of the Latin translation of Michael Scott*. Berkeley, CA: University of California Press.

Goldstein, B. R. (1971). *Al-Biṭrūjī: On the principles of astronomy* (Vol. 2). New Haven, CT: Yale University Press.

Samsó, J. (1992). *Las Ciencias de los Antiguos en al-Andalus* (pp. 330–356). Madrid, Spain: Mapfre.

Alchemy in China

Fabrizio Pregadio

In China, as elsewhere, alchemy is a science based on cosmological doctrines, aiming to afford (a) an understanding of the principles governing the formation and functioning of the cosmos, and (b) the transcendence of those very principles. These two facets are complementary and ultimately equivalent: the alchemist rises through the hierarchy of the constituents of being by "exhausting" (*jin* or *liao*, two words also denoting "thorough knowledge") the nature and properties of each previous stage. He thus overcomes the limits of individuality, and ascends to higher states of being; he becomes, in Chinese terms, a *zhenren* or Authentic Man.

While historical and literary sources (including poetry) provide many important details, the bulk of the Chinese alchemical sources is found in the *Daozang* (Daoist Canon), the largest collection of Daoist texts. One fifth of its approximately 1,500 texts are closely related to the various alchemical traditions that developed until the fifteenth century, when the extant Canon was compiled and printed. Later texts are included in the *Daozang jiyao* (Essentials of the Daoist Canon) and other minor collections. Modern study of the alchemical literature began in the present century, after the Canon was reprinted and made widely available in 1926. Among the most important contributions in Western languages are those of Needham (1978), Sivin (1968, 1976, 1980, 1990), Ho (1985), Baldrian-Hussein (1984), and Robinet (1989).

Though the underlying doctrines remained unchanged, Chinese alchemy went through a complex and not yet entirely understood development along its 20 centuries of documented history. The two main traditions are conventionally known as *waidan* or "external alchemy" and *neidan* or "internal alchemy." The former, which arose earlier, is based on the preparation of elixirs through the manipulation of natural substances. Its texts consist of recipes, along with descriptions of ingredients, ritual rules, and passages concerned with the cosmological associations of minerals and metals, instruments, and operation. Internal alchemy developed as an independent discipline around the middle or the late Tang period (618–906). It borrows a substantial part of its vocabulary from its earlier counterpart, but aims to produce an elixir – equated with transcendental knowledge – within the alchemist's person.

At the basis of both traditions are traditional doctrines of metaphysics and cosmology. Chinese alchemy has always been closely related to the teachings that find their classical expression in the early "philosophical" texts of Daoism, especially the *Daode jing* and the *Zhuangzi*. The cosmos as we know it is conceived of as the final stage in a series of spontaneous transmutations stemming from original nonbeing. This process entails the apparent separation of primeval Unity into the two complementary principles, yin and *yang*. Once the cosmogonic process is completed, the cosmos is perceived as subject to the laws of cosmology, *wuxing*, the Five Agents or Phases. The alchemist's task is to retrace this process backward. Alchemy, whether "external" or "internal," provides him with a support, leading him to the point when, as some texts put it, "Heaven spontaneously reveals its secrets." Its practice must be performed under the close supervision of a master, who provides the oral instructions (*koujue*) necessary to an understanding of the processes that the adept performs with minerals and metals, or undergoes within himself.

In order to transcend space and time – the two main features of the cosmos as it is ordinarily perceived – the alchemist should take extreme care of their correspondences to the work he performs. Space is delimited and protected by talismans (*fu*), and the laboratory (*danwu* or "chamber of the elixirs"), and instruments are properly oriented. According to some texts, heating must conform to minutely defined time cycles. This system, known as "fire times" (*huohou*) and sometimes described in painstaking detail, allows an adept to perform in a relatively short time the same work that Nature would achieve in thousands of years – in other words, to accelerate the rhythms of Nature. Bringing time to its end, or tracing it back to its beginning, is equivalent: in either case time is transcended, and the alchemist gains access to the eternal, constant present that precedes (or follows, though both terms become inadequate) the time of cosmogony and cosmology. The same is true with space: its center, where the alchemist places himself and his work, is a point devoid of dimension. From this point without space and time he is able to move at will along the axis that connects the higher and lower levels of being ("Heaven," *tian* and the "Abyss," *yuan*).

Among a variety of procedures that the sources describe in an often allusive way, and in a language rich in metaphors and secret names, two stand out for their recurrence and importance. The first is based on lead (*yin*) and mercury (*yang*). In external alchemy the two substances are refined and joined in a compound whose properties are likened to the condition of primal Unity. In internal alchemy, lead becomes a cover name for the knowledge of the Dao (pure yang, *chunyang*) with which each being is fundamentally endowed, but which is obscured (i.e., transmuted into yin) in the conditioned state. Mercury, on the other hand, represents the individual mind. The second most important method, which is proper to external alchemy, is centered on cinnabar (yang). The mercury contained therein (representing as such the Yin principle contained within the yang) is extracted and newly added to sulfur (yang). This process, typically performed nine times, finally yields an elixir embodying the luminous qualities of pure yang. This yang is not the complementary opposite of yin, but, again, represents the one before its apparent separation into the two complementary principles.

The final object of both disciplines is represented as the preparation of an elixir commonly defined as *huandan* (lit., elixir of return). This expression, recurring in the whole literature, originally denotes an elixir obtained by bringing the ingredients back to their original condition through repeated cyclical operations – an operation comparable to the process that the adept performs within himself with the support of the alchemical practice. The word *dan* (elixir) also denotes cinnabar, suggesting that the process begins and ends on two corresponding points along an ascensional spiral. This synonymy also shows the centrality of cinnabar in external alchemy, where this substance plays a role comparable to that of gold in the corresponding Western traditions. This role is taken by lead in internal alchemy. Both lead and gold, in their turn, are denoted by the word *jin*. The value of gold, and the word "gold" itself, is therefore mainly symbolic in China: the elixir, whether external or internal, and whatever its ingredients, is often defined as "gold," and Golden Elixir (*jindan*) is a name of the alchemical arts.

The extant *waidan* sources suggest that the two main methods outlined above acquired progressive importance in the history of the discipline. In the ► Huangdi jiuding shendan jing (Book of the Nine Elixirs) and other texts dating from the first centuries AD, cinnabar is never the main ingredient of an elixir, and the lead-mercury compound – sometimes replaced by refined lead alone – is only used as a layer in the crucible together with other ingredients. In these methods, the substances undergo cycles of refining in a hermetically sealed crucible. This process consists of a backward reenactment of cosmogony that brings the ingredients to a state of *prima materia*. The elixir can be finally transmuted into alchemical gold projecting on it a minute quantity of the native metal. Important details on the early phase of Chinese alchemy are also found in portions of the *Baopu zi neipian*, written around AD 320 by ► Ge Hong. Its descriptions of processes that can be compared with extant sources are, however, often abridged and sometimes inaccurate.

During the Tang dynasty, the *waidan* tradition reached one of its peaks with Chen Shaowei (beginning of the eighth century), whose work describes the preparation of an elixir obtained by the refining of cinnabar. Each cycle yields a "gold" that can be ingested, or used as an ingredient in the next cycle. In the second part of the process, the final product of the first part is used as an ingredient of a *huandan*. Among the representative texts of this period are several collections of recipes, one of the most important of which was compiled by ► Sun Simo. The first half of the Tang dynasty also marked the climax of contacts between China and the Arabic world. These exchanges may be at the origin of the medieval word *alchymia*, one of whose suggested etymologies is from middle Chinese *kiem-yak* (the approximate pronunciation of the modern *jinye* or "Golden Liquor") with the addition of the Arabic prefix *al*-.

While the Tang period is sometimes defined as the golden age of external alchemy, it also marked the stage of transition to internal alchemy. This shift, sometimes taken to be only due to the multiplication of cases of elixir poisoning, or to the influence of Buddhism, requires further study to be properly evaluated. The very incidence and relevance of cases of accidental poisoning (which claimed their toll even among Emperors) suggest that external alchemy had lost, at least to some extent and in some contexts, its soteriological character, and that its practices had become known outside the legitimate transmission. Some masters may, therefore, have transmitted their doctrine modifying the supports used for the practice. In internal alchemy, the adept's person itself performs the role which natural substances and instruments play in external alchemy. In doing so, this discipline avails itself – in ways and degrees that vary, and which require further study to be correctly understood – of traditional Chinese doctrines based on the analogies between macrocosm and microcosm, of earlier native contemplative and meditative disciplines, and of practices of Buddhist origin (apparently of Tantric character, through the possible medium of the Tiantai school).

Among the forerunners of internal alchemy is the Shangqing (Supreme Purity) tradition of Daoism, as practiced for example by ► Tao Hongjing. Based on revelations of the late fourth century, this school attributed particular importance to meditation, but also included the compounding of elixirs among its practices. (Shangqing represents in fact the first example of close relations between alchemy and an established movement of "religious" Daoism.) The relevant sources exhibit the earliest traces of the interiorization of alchemy. Among the texts used in this school is the *Huangting jing* (Book of the Yellow Court), a meditation manual often quoted in *neidan* texts.

In Song and Yuan times, the history of *neidan* identifies itself with that of the lines of transmission known as Southern Lineage (*nanzong*) and Northern Lineage (*beizong*). The respective initiators were Zhang Boduan (eleventh century) and Wang Zhe (1112–1170). Both schools placed emphasis on the cultivation of *xing* and *ming*, which constitute two central notions of internal alchemy. *Xing* refers to one's original nature, whose properties, transcending individuality, are identical to those of pure being and, even beyond, nonbeing. *Ming* denotes the "imprint," as it is, that each individual entity receives upon being generated, and which may or may not be actualized in life (the word also means "destiny" or "life," but neither translation covers all the implications in a *neidan* context). The Northern and Southern lineages, and subtraditions within them, were distinguished by the relative emphasis given to either element. The textual foundation of both lineages was provided by the *Zhouyi cantong qi* of ▶ Wei Boyang, and the *Wuzhen* pian (Awakening to Reality), a work in poetry by Zhang Boduan.

During the Ming and Qing dynasties the *neidan* tradition is known to have divided into several schools, but their history and doctrines are still barely appreciated. One of the last greatest known masters of this discipline was Liu Yiming (eighteenth century), who, in his works, propounded an entirely spiritual interpretation of the scriptural sources of his tradition.

See Also

▶ Five Phases (*Wuxing*)
▶ Ge Hong
▶ *Huangdi jiuding shendan jing*
▶ Sun Simo
▶ Wei Boyang
▶ *Yinyang*

References

Baldrian-Hussein, F. (1984). *Procédés secrets du Joyau Magique. Traité d' Alchimie Taoïste du XIe siècle*. Paris: Les Deux Océans.

Baryosher-Chemouny, M. (1996). *La Quête de l'Immortalité en Chine: Alchimie et Paysage Inté rieur sous les Song*. Paris: Dervy.

Chee, D. S.-H. (2001). *The gold elixir: The circular path of the tao*. Ph.D. Dissertation. Carpinteria, CA: Pacifica Graduate Institute.

Eliade, M. (1978). *The forge and the crucible* (2nd ed.). Chicago: University of Chicago Press.

Ho, P. Y. (1985). *Li, Qi and Shu: An introduction to science and civilization in China*. Hong Kong, China: Hong Kong University Press.

Kohn, L. (2005). *Health and long life: The Chinese way/by Livia Kohn in cooperation with Stephen Jackowicz*. Cambridge, MA: Three Pines Press.

Liu, X. (2001). *Search of immortality: Daoist inner alchemy in early twentieth century China*.

Needham, J. (1978). Alchemy and early chemistry in China. In T. T. Segerstedt (Ed.), *The frontiers of human knowledge* (pp. 171–181). Uppsala, Sweden: Uppsala Universitet.

Needham, J., et al. (1974, 1976, 1980, 1983). *Science and civilisation in China*. Vol. V. Parts 2–5. Cambridge, MA: Cambridge University Press.

Pregadio, F. (1996). Chinese alchemy. An annotated bibliography of works in western languages. *Monumenta Serica, 44*, 439–476.

Robinet, I. (1989). Original contributions of Neidan to Taoism and Chinese thought. In Livia Kohn in Cooperation with Yoshinobu Sakade (Eds.), *Taoist meditation and longevity techniques* (pp. 297–330). Ann Arbor, MI: Center for Chinese Studies, The University of Michigan.

Schipper, K., & Hsiu-huei, W. (1986). Progressive and regressive time cycles in Taoist ritual. In J. T. Fraser, N. Lawrence, & F. C. Haber (Eds.), *Time, science, and society in China and the west (The study of time, V)* (pp. 185–205). Amherst, MA: University of Massachusetts Press.

Sivin, N. (1968). *Chinese alchemy: Preliminary studies*. Cambridge, MA: Harvard University Press.

Sivin, N. (1976). Chinese alchemy and the manipulation of time. *Isis, 67*, 513–527.

Sivin, N. (1980). The theoretical background of elixir alchemy. In J. Needham et al. (Eds.), *Science and civilisation in China. Vol. V. Chemistry and chemical technology. Part 4. Spagyrical discovery and invention: Apparatus, theories and gifts* (pp. 210–305). Cambridge, UK: Cambridge University Press.

Sivin, N. (1990). Research on the history of Chinese alchemy. In Z. R. W. M. von Martels (Ed.), *Alchemy revisited. Proceedings of the international conference on the history of alchemy at the University of Groningen. 17–19 April 1989* (pp. 3–20). Leiden, The Netherlands: E. J. Brill.

Alchemy in Islam

Karin Ryding

Arabic alchemical writing and documentation emerges in approximately the second half of the eighth century (750–800 AD), a period that witnessed substantial growth in intellectual activity and methodological refinement for all the known sciences. With the rapid expansion of the Islamic empire, knowledge from civilizations such as the Greek, Persian and Indian was melded and shared by means of the new lingua franca, Arabic. The unifying force of the Arabic language enabled scholars of diverse ethnic and disciplinary origins to exchange ideas, to transmit those ideas to their students, and to develop conceptual frameworks for exploring and expanding knowledge of the natural world. The Arabic term *al-kīmyāʾ* appears morphologically to be non-Arabic in origin, most likely a borrowing from Syriac *kīmīyā*, which may derive from Greek *khemeia*, or *khymia*, prefixed with the definite article *al-* in Arabic (Ullman, 1965, p. 110; Wild, 1965, p. 4). This word has survived as the term for the entire pre-modern tradition of protochemistry. Nonetheless, this era within the Arabic/Islamic cultural tradition remains little explored and poorly understood within mainstream history of science.

Arabic alchemical writings show influences of Egyptian, Greek, Sabaean, Syriac, Persian, and Indian cultures. Hermetic and gnostic influences are abundant, as many Arabic alchemical texts combine description and analysis of naturally occurring substances and chemical experiments with firm admonitions to adepts on the need for purity of heart, behavior and intent in order for transformation to occur (See Affifi (1949), Plessner (1954), and Corbin (1964, pp. 179–183) on hermeticism in Arabic sciences. For more on the Arabic *corpus hermeticum* see Klein-Franke (1973). On Islamic gnosis see Corbin (1975), and for Egyptian hermeticism in particular, see Fowden (1996)). The texts evidence not only cultural syncretism, but also interweave practices for psycho-spiritual transcendence with procedures to transform natural substances. The distinctive discourse of Arabic alchemical texts is variable in style. Sometimes it is descriptive, didactic, and straightforward, other times complex, highly abstract, mystical, and profoundly arcane.

That alchemy was well established as a branch of scientific study is attested by the fact that two tenth-century Arabic encyclopedia authors, al-Nadīm and ▶ al-Khwārizmī, each have extensive chapters on alchemy. Both chapters are available in English translation (Dodge, 1970; Ryding, 1994). Al-Nadīm focuses on the history, personalities, and scholarly works of the alchemists, whereas al-Khwārizmī concentrates on the instruments, substances and procedures involved in alchemical operations.

The earliest Arab contributor to alchemical science is reputed to have been the Umayyad prince Khālid ibn Yazīd ibn Muʿāwiya ibn Abī Sufyān (ca. 665–704) (Nadīm, 1970, chapter on alchemy). Tradition says that he was instructed in alchemy by a Christian monk named Morienus/Marianus. A Latin manuscript entitled the *Booklet of Morienus Romanus*, *of old the Hermit of Jerusalem*, *on the Transfiguration of the Metals and the Whole of the Ancient Philosophers' Occult Arts*, appeared in Paris in 1559 with the notation that the original translation from the Arabic was dated 1182. Stavenhagen (1974) has details on the manuscript as well as the English translation. Documentation of al-Khālid's alchemical interests is sketchy; no works of his on the topic have been discovered, and some scholars consider al-Khālid's reputation for alchemical scholarship unjustified (e.g., Ruska, 1924).

The central figure in Arabic alchemy is the semilegendary Jābir ibn Hayyān, who is said to have lived in Mesopotamia during the second half of the eighth century and died around 810–815 AD (Holmyard, 1923, p. 47). Nadīm gives Jābir's full name as (Abū Mūsā ʿĀmī) Abū ʿAbdallāh ▶ Jābir ibn ḥayyān ibn ʿAbdallāh al-Kūfī, known as ▶ al-Ṣūfī (Nadīm, 1988, p. 420). Elsewhere his name is given as Abū Mūsā, and he is variously described as Tūsī, Tartūsī or Tarsūsī, Harranian and from Khorasān (Holmyard, 1923, p. 47). Major Arab biographers (including Nadīm, Qifṭī, and al-Kutubī) consider him a genuine historical personage (Qiftī, 1903, p. 160–161; Al-Kutubī, 1973). Sarton considers him "the most famous alchemist of Islam," calling the era 750–800, the Age of Jābir ibn ḥayyān" (Sarton, 1927, p. 521).

There has been debate as to the extent of Jābir's authorship of what is referred to as the Jābirian corpus, with Kraus, Mieli, Ruska, and Plessner asserting that these works are largely attributable to an early Ismaʿīlī sect in the late tenth century (Kraus 1986, also Plessner &

Kraus, 1968; Plessner, 1980), whereas Holmyard, Stapleton, and more recently, Corbin and Lory, give substantially more credence to the authorship of the historical Jābir (See especially Corbin (1986, pp. 68–69), where he discusses the work of Paul Kraus, “notre regretté collègue” who, he states, “fūt entraîné sur sa lancée à un certain extrémisme.” (our sorely-missed colleague, who was drawn by his impulsiveness to a certain degree of extremism.) He goes on to state that “il se trouve que depuis trente ans la théorie traditionnelle a trouvé de vigoureux défenseurs, dont les recherches ont sérieusement ébranlé la thèse extrémiste de Paul Kraus.” (For 30 years the traditional theory has found vigorous defenders whose research has seriously weakened the extremist thesis of Paul Kraus.) See also Holmyard (1923), Corbin (1964: 184ff); Lory’s introduction to Corbin, 20ff; Stapleton (1936), and Sezgin (1971, pp. 132–269). Cf. Hachmi (1961), Macuch (1982), Mahmūd (1975), and Burnett (1992)). The Jābirian manuscript matrix may include later accretions from commentators and imitators, with a core of authentic older writings.

Whether or not the original Jābir is the source of all the manuscripts attributed to him in Arabic, and whether or not any of those writings constitute the source of the contributions of the European Geber has not yet been established, since the extant Arabic manuscripts have not been compared thoroughly or systematically with those in Latin of the European Geber. On this topic, see Holmyard’s introduction to Russell (1678, 1928), esp. pp. xvii–xxi and on the European Geber see Newman’s extensive 1991 analysis.

As Manfred Ullman states (1965, p. 112),

> Arabic alchemy holds a key position in the development of chemical thinking as a whole. However, in glaring contrast to its importance, it has been regrettably neglected by research until now. Most of what historians of science have written on the Arabic alchemists is second-hand, based on obsolescent literature and disfigured by gross errors. A vast and fertile field lies here open to research; access to it, however, is not easy.

Ullman (1965, p. 113) cites three components of the theoretical foundations of Arabic alchemy (1) The quicksilver-sulfur method for synthesizing gold, calculating the true proportions of quicksilver and sulfur in gold and endeavoring to reproduce those proportions; (2) The doctrine of “the relations of quantities” (used especially in the Jābirian texts). This took the form of speculation on the concept of balance, especially the “balance of letters”, a form of phonosymbolism wherein the letters of the Arabic alphabet are attributed certain weights (in dirhams) and qualities (dryness, moisture, heat, cold) that correspond proportionately to the contents of minerals and metals as they occur in the names of those metals (Kraus 1986, vol. 2, pp. 223–236). Thus the name of a particular metal such as lead (*usrub*) reflects exactly the essence of that metal; (3) Formulating the elixir (*al-ʾ iksīr*) that, when added to base metals, has the power to transform them into gold or silver, or to grant everlasting life.

Other major contributors to the vast alchemical literature of Islam include Abū Bakr Muhammad ibn Zakariyā al-Rāzi (Rhazes) (ca. 864–925 or 935), whose work in alchemy “takes a new, more empirical and naturalistic approach than that of the Greeks of Djabir” (Goodman, 2001), Muhammad Ibn Umayl (ca. 900–960), and Aydamīr ibn Alī al-Jildakī (fourteenth century). Translations of all these texts, starting with Jābir, are sorely needed.

References

Affifi, A. E. (1949). The influence of hermetic literature on Muslim thought. *Bulletin of the School of Oriental and African Studies, 13*, 840–855.

Al-Khwārizmī, Abū Abdallah Muhammad ibn Ahmad ibn Yūsuf (fl. ca. 976). (1895). *Mafātīḥ al-ʿulūm*. Ed. G. van Vloten. Leiden, Netherlands: Brill.

Al-Kutubī, Muhammad ibn Shākir. (1973). *Fawāt al-wafayāt*. Ed. Ihsān ʿAbbās. Beirut, Lebanon: Dār al-Thaqāfa.

Avicenna (1927). De congelatione et conglutinatione lapidum: being selections of the kitāb al-shifaaʾ. *Arabic and Latin Texts*. Ed. E. J. Holmyard and D. C. Mandeville. Paris: Geuthner.

Bosworth, C. E. (1963). A pioneer arabic encyclopedia of the sciences: Al-Khwarizmi’s keys of the sciences. *Isis, 54*(1), 97–111.

A

Burnett, C. (1992). The astrologer's assay of the alchemist: Early references to alchemy in arabic and latin texts. *Ambix, 39*(3), 103–109.
Corbin, H. (1964). *Histoire de la philosophie islamique*. Paris: Gallimard.
Corbin, H. (1973/1975). La science de la balance et les correspondances entre les mondes en gnose islamique. *Eranos conference*, Ascona. Leiden, Netherlands: Brill.
Corbin, H. (1986). In P. Lory (Ed.), *Alchemie comme art hieratique*. Paris: l'Herne.
Dubs, H. H. (1961). The origin of alchemy. *Ambix, 9*(1), 23–36.
Fowden, G. (1996). *The Egyptian hermes*. Cambridge: Cambridge University Press.
Goodman, L. E. Al-Rāzi, Abu Bakr Muhammad b. Zakariyyā. (2001). *Encyclopedia of Islam*. Vol. 1.1. Leiden, Netherlands: Koninklijke Brill NV.
Hachmi, M. Y. (1961). The beginning of Arab alchemy. *Ambix, 9*(3), 155–161.
Holmyard, E. J. Jābir ibn Hayyān. (1923). Proceedings of the royal society of medicine. *History of Medicine, 16*, 46–57.
Holmyard, E. J. Jābir ibn Hayyān. (1924). A critical examination of Berthelot's work upon arabic chemistry. *Isis, 6*, 479–499.
Jābir ibn Hayyān (d. ca. 800). (1928). In E. J. Holmyard (Ed.), *The Arabic works of Jabir ibn Hayyan*. Paris: Librairie Orientaliste Paul Geuthner.
Jābir ibn Hayyān (d. ca. 800). (1935). In P. Kraus (Ed.), *Mukhtārāt rasāʾil Jābir ibn Hayyān*. Cairo, Egypt: Maktabat al-Khānjī.
Jābir ibn Hayyān (d. ca. 800). (1983). In P. Lory (Ed. and Trans), *Dix traites d'alchimie*. Paris: Sindbad.
Jābir ibn Hayyān (d. ca. 800). (1988). In P. Lory (Ed.), *Tadbīr al-ʾ iksīr al-ʾaʿ Zam*. Damascus, Syria: Institut Français.
Klein-Franke, F. (1973). The geomancy of Ahmad b. Ali Zunbul: A study of the Arabic Corpus Hermeticum. *Ambix, 20*(1), 26–35.
Kragh, H. (1987). *Introduction to the historiography of science*. Cambridge, MA: Cambridge University Press.
Kraus, P. (1942/1986). *Jabir ibn Hayyan: Contribution à l'histoire des idées scientifiques dans l'Islam*. 2 vols. Paris: Les Belles Lettres.
Lory, P. (1983). *Jābir ibn Hayyān: Dix traités d'alchimie*. Paris: Sindbad.
Macuch, R. (1982). Greek technical terms in Arabic sciences. *Graeco-Arabica, 1*, 11–31.
Mahmūd, Zakī Najīb. *Jābir ibn Hayyān*. Cairo: Al-hayʾa l-miṣriyya l-ʿāmma li-l-kitāb, 1975.
Mieli, A. (1938). *La science arabe et son role dans l'evolution scientifique mondiale*. Leiden, Netherlands: Brill.
Nadīm, Abū l-Faraj ibn Abī Yaʿqūb. (1970). In B. Dodge (Ed. and Trans), *The Fihrist of Al-Nadim: A tenth century survey of Muslim culture*. 2 vols. New York: Columbia University Press.
Nadīm, Abū l-Faraj ibn Abī Yaʿqūb. (1988). *Al-Fihrist*. Ed. Riḍā Tajaddud ibn ʿAlī ibn Zayn al-ʿAbidīn al-ḥāʾirī al-Māzindarānī. Beirut, Lebanon: Dār al-Masīra.
Newman, W. R. (1991). *The summa perfectionis of pseudo-geber: A critical edition, translation and study*. New York: Brill.
Plessner, M. (1954). Hermes trismegistus and Arab science. *Studia Islamica, 2*, 45–60.
Plessner, M. & Kraus, P. (1968). Djabir b. Hayyan. *Encyclopedia of Islam*. New Edition. Vol. 2. Leiden, Netherlands: Brill.
Plessner, M. & Kraus, P. (1980). Jābir Ibn Hayyān. *Dictionary of Scientific Biography*. Vol. 7. New York: Scribner.
Qiftī, Jamāl al-Dīn Abū al-Hasan ʿAlī ibn Yūsuf. (1903). In J. Lippert (Ed), *Ta'rīkh al-hukamāʾ* (p 196-?). Leipzig. Ret Baghdād: Al-Muthannā.
Ruska, J. (1924). *Arabische Alchemisten*. Heidelberg, Germany: C. Winter.
Russell, R. (1928). *The works of Geber*. 1678. Englished by Richard Russell. New edition with introduction by E. J. Holmyard. London: J.M. Dent and Sons, Ltd.
Ryding, K. C. (1994). Islamic alchemy according to Al-Khwarizmi. *Ambix, 41*(3), 121–134.
Ryding, K.C. (1997). The Heritage of Arabic Alchemy: The multicultural matrix. In A. Hasnawi, A. Elamrani-Jamal et M. Aouad (Eds.), *Perspectives arabes et mé diévales sur la tradition scientifique et philosophique grecque*. Leuven-Paris: Peeters; Paris: Institut du Monde Arabe.
Sarton, G. (1927). *Introduction to the history of science* (Vol. 1). Baltimore: Williams and Wilkins.
Sezgin, F. (1967). *Geschichte des Arabischen Schrifttums* (Vol. 4). Leiden, Netherlands: Brill.
Stapleton, H. E. (1936). Further notes on the Arabic alchemical manuscripts in the libraries of India. *Isis, 26*(1), 127–131.
Stapleton, H. E., Azo, R. F., & Hidayat Husain, M. (1927). Chemistry in Iraq and Persia in the Tenth Century, A.D. *Memoirs of the Asiatic Society of Bengal, 8*(6), 317–412.
Stapleton, H. E., Lewis, G. L., & Sherwood Taylor, F. (1949). The sayings of Hermes quoted in the *mā' al-waraqī* of Ibn Umail. *Ambix, 3*(3 and 4), 69–90.
Stapleton, H. E., Lewis, G. L., & Sherwood Taylor, F. (1953). The antiquity of alchemy. *Ambix, 5*(1 and 2), 1–43.
Stavenhagen, Lee (Ed and Trans). (1974). *A Testament of Alchemy, being the revelations of Morienus, ancient adept and hermit of Jerusalem to Khalid ibn Yazid ibn Mu'awiyya, King of the Arabs of the divine secrets of the magisterium and accomplishment of the alchemical art*. Hanover, NH: for Brandeis University Press by the University Press of New England.
Ullman, M. (1965). Kīmyāʾ. *Encyclopedia of Islam*. New edition. Vol. 5. Leiden, Netherlands: Brill.
Wild, S. (1965). *Das Kitab Al-Ayn und die Arabische Lexikographie*. Wiesbaden, Germany: Harrassowitz.

Alcohol Fermentation in Australian Aboriginals

Maggie Brady
Canberra, ACT, Australia

Australia, it has been said, was the world's only "dry" continent, and its Indigenous peoples were one of the few societies in the world that had no traditional alcoholic beverages (Cleland, 1957, p. 159; Dingle, 1980, p. 228; Spencer, 1988). Australians commonly believe that prior to contact with outsiders in the eighteenth century, neither Aboriginal people nor Torres Strait Islanders (the two Indigenous peoples of the country) knew of the process of fermentation and thus how to make drinks containing alcohol. This is taken by some commentators to be the explanation for widespread alcohol abuse in later years. If people had no alcoholic drinks, it is argued, they lacked the traditions and rituals associated with alcohol consumption and had no need to develop the internal social controls that would contain any unwanted effects of intoxication.

These interpretations are only partly true for there are documented accounts suggesting that Aboriginal people in some regions did, in fact, know about fermentation and produced mild, low-alcohol drinks from the natural flora. The Torres Strait Islands (between Australia and Papua New Guinea) are a little different, with the residents of some islands learning how to ferment and distill an intoxicating drink (*tuba*), as a result of contact with outsiders from the East Indies or the Philippines. In this case, as a result of cultural diffusion, Islanders adopted and *made indigenous* a drink that originated from elsewhere.

Before European settlement, Aboriginal hunters and gatherers also harvested, prepared, and used a number of plant-based narcotics and stimulants. These were primarily chewed, nicotine-containing drugs, including the highly prized narcotic *pituri* (from the plant *Duboisia hopwoodii*), and numerous wild tobaccos of the genus *Nicotiana*. All these plants required detailed knowledge of the landscape (the strongest *pituri* grew in a particular region of southwest Queensland and was traded from there), preparation techniques (drying and fragmenting the leaves), and methods of enhancing the drugs' effects by the addition of alkaline wood ash from particular trees. This increased the absorption of nicotine through the skin once the mixed quid was chewed or stored behind the ear (Clarke, 2007, pp. 105–109; Watson, 1983). Smoking was not practiced prior to contact with outsiders.

Way-a-linah: A Drink from the Tasmanian Cider Gum

In numerous regions of Australia, Aboriginal people made sweet, watery drinks by steeping nectar-bearing blossoms in water; these nonalcoholic drinks were consumed immediately rather than being left for natural fermentation to occur (Moore, 1978, p. 213; Petrie, 1904). But the sap of the Tasmanian "cider gum" is a well-documented example of a locally made drink that was allowed to ferment. In 2005, Tasmanian Aboriginal artist Mick Quilliam painted a canvas depicting this tree, around the base of which were grooves made by innumerable pairs of feet (Fig. 1). His painting commemorates the tree and its value to Aboriginal Tasmanians. The symbolic footprints were those of the many Aboriginal people who came from all directions to harvest *way-a-linah*, the Aboriginal name for a fermented drink made from the copious sweet sap of this high-altitude gum tree, *Eucalyptus gunnii* (Maiden, 1924, p. 119).

An early account of its use by Aboriginal people comes from George Augustus Robinson, a free settler in Tasmania who made several expeditions into the interior and who became known as the man who tried unsuccessfully to help the Tasmanians to survive the disastrous impact of European settlement that had commenced in 1803. His was the only detailed post-settlement record of Aboriginal life and languages there. In 1831 Robinson was traveling in the high country of Tasmania's north with several

Alcohol Fermentation in Australian Aboriginals, Fig. 1 Tasmanian artist Mick Quilliam's painting of the cider gum (2005) depicts the tree as a meeting place, with a trench worn around its base by the feet of the many Aboriginal people who came to harvest its sap (Natural ochers and pigment on canvas, reproduced with permission of the artist)

Aborigines, looking for any remaining Mairremmener people. His journal entry for 28 November 1831 shows that he was in the Lake Echo region when he first saw the cider tree:

> The natives caught seven kangaroo this evening, but what interested me most were the numerous cider trees which skirted this extensive plain and which were the first I had seen. Most of those trees had been tapped by the natives. This they had effected by perforating a hole in the tree a short distance above the ground by means of sharp stones and then making a hole at the bottom of the tree into which the liquid is conveyed and from which they extract it, sometimes if the hole is small by sucking it through a reed or twisted bark. In some of these holes I observed upwards of a quart [one litre] of this juice and which my people greedily partook of. It is exceeding sweet and well flavoured and in this respect resembles the flavour of cider. Some that had been dried by the sun had an apple taste. . . .The natives are very fond of the juice and I am told it frequently makes them drunk. (Plomley, 1966, p. 534)

According to historian N. J. B. Plomley who edited Robinson's journals, Robinson made a point of recording plants used as foods by the Aborigines and provided useful information about the distribution of plant communities. Robinson was clearly intrigued by what he called the "melliferous" cider gum, noting abundant stands of the tree whenever he encountered them and observing that the syrupy sap was attractive to ants, cockatoos, and animals as well as to the "natives." Some trees were huge, 12 ft in circumference, and produced what he described as "tolerable quantities" of the oozing liquid, which he thought was triggered by the warmth of the sun. A tree can yield half a liter of sap daily during the summer months. As it happened, Robinson's journey on this occasion in 1831 coincided with the time of year when the *Eucalyptus gunnii* sap flows most prolifically. Extracting the sap required local knowledge; the trees were and are found only in a limited area of the high country. At the proper season, during December and January (the quantity of sap lessens in February), Aboriginal people bored or cut into the trunk to release the sap which collected in a larger hole, a kind of holding tank made at the foot of the tree. Robinson witnessed Aborigines dipping their tin pannikins [cups] into these tanks at the base of the trees. Robinson (Plomley, 1966, p. 557) wrote,

> Holes at the bottom of those trees had been made to receive the juice and which answered the purpose of a tank. Some of the liquor had dried and was white and resembled in appearance and taste a

> bruised apple; some was brown. It was amusing to see the natives run from tree to tree to suck this juice, of which they are very fond.

Another nineteenth-century description from the naturalist Daniel Bunce provides further detail. He states that the Aborigines covered these collecting holes with a flat stone in order to stop birds and animals from drinking, which implies that the liquid rested there for some time. "When allowed to remain any length of time," Bunce wrote, "it ferments and settles into a coarse sort of wine or cider, rather intoxicating if drank to excess" (Bunce, 1857, p. 47; Clarke, 2007, p. 105). Little is known about exactly how strong *way-a-linah* might have been: J. H. Maiden (the Government Botanist who wrote an 8-volume revision of the genus Eucalyptus) tested the fluid from a sample of sap and found that it contained sugar, acetic acid, water, and alcohol. Some non-Aboriginal people likened the juice to black beer or treacle, and Aboriginal people themselves used language terms which distinguished the unfermented "honey" (which was known as *wen.ner*) from the fermented "cider" (*way-a-linah*) (Plomley, 1976, p. 183). Early accounts by R. C. Gunn (after whom the eucalyptus species was named) mention that (European) shepherds and stockmen also cut the trees and harvested and consumed the sap. There were unsourced reports that at Christmastime 1826, the Aborigines of Lake Arthur indulged in a great eucalyptus cider orgy (MacPherson, 1921).

Sadly, in recent years large numbers of old *Eucalyptus gunnii* have been dying as a result of drought, and the trees are under threat from clearing, grazing, burning, and seed collection. The feet grooves can still be seen around the trunks of a few particular trees, along with old scars from the tapping process. Many present-day Aboriginal people have made and tasted the drink. Mick Quilliam, the painter, describes it as being sweet and tangy and about as alcoholic as a light beer.

Mangaitch: A Fermented Drink from Western Australia

In 1992 an Aboriginal alcohol service in Perth, Western Australia, produced a series of radio programs about alcohol and substance abuse. Aboriginal author Doris Pilkington was the narrator. The program began by questioning the argument that because alcohol was a recent introduction to Western Australia, Aboriginal people had not learned how to cope with it or develop tolerance. "Our people knew about fermentation and used alcohol on special occasions," said the narrator,

> We made it by soaking blossom of banksias and eucalyptus, and by dissolving the nectar and allowing it to stand. But the alcoholic content was slight and the use of these drinks was limited to special occasions and certain times of the year. In other words we exercised our own restraints. (Noongar Alcohol and Substance Abuse Service [NASAS], 1992)

Doris Pilkington was referring to a drink known to Aboriginal people in Western Australia as *mangaitch*. It was made from the flower-bearing cones of a species of banksia which produced a substance so sweet that it was known by Europeans as the honeysuckle tree (Moore, 1978, p. 136). The first detailed description of the drink was made by the physician and anthropologist W. E. Roth who described two species of banksia growing in the southwest of Western Australia. The banksia bore cones with pitcher-shaped flowers full of honey "especially visited by the black cockatoos." Aboriginal people collected large numbers of cones and carried them alongside "swamps" where they dug troughs, lining them with boat-shaped containers or vats made of sheets of tea-tree bark.

> The vat was next filled with these cones and water, in which they were left to soak. The cones were subsequently removed and replaced with others until such time as the liquid was strongly impregnated with honey, when it was allowed to ferment for several days. The effect of drinking this "mead" in quantity, was exhilarating, producing excessive volubility. The aboriginals called the cones and the fermented liquour produced therefrom both by the same name – the *mangaitch*. (Roth, 1904, p. 49)

Daisy Bates, an eccentric amateur anthropologist who worked in Western Australia, wrote that in the early 1900s there were annual feasts of *mangaitch*, with visitors from elsewhere hosted by the Aboriginal people of the South

Perth district. She also described how the “mungaitch honey-groves” were being razed to make way for flocks of sheep and herds of cattle (Bates, 1985, p. 241).

Kambuda: A Drink Made from the Spiral Pandanus

Another Indigenous fermented drink has been documented from the Borroloola region, near the Gulf of Carpentaria in the Northern Territory. It was made from the nuts of the spiral pandanus – a common pandanus in the Northern Territory from which Aboriginal people also harvest its leaves, which are stripped and rolled to make fiber for baskets. When ripe and red or orange in color, the nuts were roasted on the fire, then crushed. The crushed pulp was soaked in water for 2 days in a bark dish, making a mixture known as *wuthuwuthu* (in the Yanyuwa language). This made a fermented drink known as *kambuda*. It was said by Herbert Basedow that on ceremonial occasions the Aborigines drank more than usual and that the drink produced “merriment” (Basedow, 1918). One anthropologist recalled older Yanyuwa-speaking women were still making this drink in the 1980s (Brady, 2008).

All three drinks described here were undoubtedly low-alcohol drinks; however they did have mood-altering effects, and their existence indicates that Aboriginal people in these three widely separated regions of Australia knew of fermentation and how to achieve it. It was not until outsiders came to Australian shores that the Indigenous peoples tasted stronger alcohols for the first time: spirits such as rum and arrack and sweet and fortified wines. The English colonization of Australia began in 1788 in Sydney, New South Wales, but from the 1600s foreign ships had been making landfall on Australian coasts – either deliberately or unintentionally. The west coast of Australia in particular was peppered with shipwrecks, mostly of Dutch ships heading from the Cape of Good Hope to Batavia (now Jakarta, Indonesia); because of difficulties with the accurate measurement of longitude, they failed to turn north in time. All ships carried wines and spirits and some shipwrecks left hundreds of men stranded in remote regions; it is possible that Aboriginal people tasted alcoholic beverages on these occasions. Dutch sailors visiting the west coast of the Cape York Peninsula in 1756 gave arrack (a strong distilled spirit made in Southeast Asia) to some Aborigines in an attempt to kidnap them (Heeres, 1899). The same drink was carried to northern Australia by fishermen from Makassar in Sulawesi from around 1700, giving Aboriginal people along the coast of what is now Arnhem Land in the Northern Territory their first taste of a distilled spirit (Fig. 2). The Makassan fleets sailed annually to collect the delicacy *bêche-de-mer* from shallow coastal waters, and their praus brought many desirable goods to share with the Aboriginal owners of the land, including rice, cloth, dugout canoes, iron knives, tobacco, and arrack (Clark & May, 2013; Macknight, 1976). Aboriginal people borrowed and incorporated the language terms for many of these items from the Makassar language, and these loan words are now part of the Yolngu and other languages of northern Australia (Evans, 1992).

The Makassans were, by all accounts, enthusiastic consumers of arrack, which was produced locally around the town of Makassar as well as being imported from Batavia in Java. Arrack can be made by distilling “toddy” (eighteenth-century Europeans often referred to this as “palm wine”), the fermented sweet juices exuding from the flowering buds of a number of palm trees, such as nipa, fan, areca, and coconut palm (Burkill, 1966; Clarke, 2007; Wallace, 1989). There is some evidence that visiting Makassans deliberately planted both areca and coconut palms on Australian soil in an effort to produce toddy and arrack during their regular months-long visits (cf. Clarke, 2007, p. 129; Ganter, 2006, p. 46); whether they succeeded, however, is unknown.

Making *Tuba*

It was in the islands of the Torres Strait (TSI), following contact with outsiders, that local people learned and adopted the techniques of both

Alcohol Fermentation in Australian Aboriginals, Fig. 2 Map to show the routes taken by Makassan *bêche-de-mer* fishermen to northern Australia c. 1700–1907

fermentation and distillation in order to produce what was, in effect, an "indigenous" alcoholic beverage known as *tuba* (Brady & McGrath, 2010). It was indigenous to the extent that the ingredients for making it were sourced and harvested locally from palm trees, its manufacture was incorporated into local knowledge systems, and its consumption became embedded in local Indigenous economic and social practice. It is difficult to say exactly when and by what means the technical knowledge of palm toddy fermentation and distillation arrived in the Torres Strait which, by the nineteenth century, was a busy international maritime hub, part of the "polyethnic north" attracting pearl and trochus divers and lugger crews and laborers (Ganter, 2006, p. 198). Knowledge of *tuba* making could have arrived from several directions: from the Malay Archipelago to the west (including the Makassan and Bugis traders from Sulawesi), from the islands in the Pacific to the east, or from Singapore or the Philippines to the north-west. Peoples from all these regions at various times manufactured these drinks, but oral

Alcohol Fermentation in Australian Aboriginals, Fig. 3 Extraction of toddy ("palm wine") on the Indian subcontinent (Lithograph, Louis van Houtte 1868–1888)

histories collected from Torres Strait Islanders, together with a Filipino origin for the term *tuba*, point to the Philippines and the "Manila men" (as they are known locally) as being the most likely source for this diffusion of technical knowledge.

Tuba is a Tagalog term from the Philippines, meaning "fermented coconut milk" (Schnukal, 2004), and in the Torres Strait, it describes the pale juice that seeps from a cut to the unopened fructifying bud of a coconut palm. Both written records and oral histories describe the production techniques for the drink – a process that remained remarkably unchanged over centuries. The toddy collector climbed the tree and hung a container under the cut bud to catch the juice: "You cut the point off and tie a rope down and bend it and chop it off, until the juice run out. We used a Sunshine milk tin," a man from Murray Island said in 2004 (Fig. 3). This procedure was repeated every day, as Joseph Banks had pointed out in his journal of the *Endeavour* voyage of 1770, while visiting the island of Savu (now in Indonesia), "people . . . climb the trees for that purpose every morning and evening" (Beaglehole, 1963, p. 162). *Tuba* was made on the islands of the central and eastern groups in the Strait that could support coconut palms – indeed some residents planted large groves of trees for this purpose.

The juice could be drunk straight from the tree but the Islanders learned to leave their tuba to ferment in large bottles or clay-stoppered pots. In this form the drink was said to taste like vinegar or beer with an alcohol content around 4 %; some Islanders used this fermented mix as a raising agent for bread: "I got taste for that bread! I prefer my mother's tuba bread to any in a bakery! The yeast is homemade" (Brady & McGrath, 2010, p. 318). The remaining tuba was distilled, using bamboo tubes and a metal drum to boil and steam the mixture, hence the local name "steamed tuba" for the resultant distilled drink. "He makes a big bamboo, at the end there's a long thing for the drips and a big drum and he boils it up. Another bamboo goes up and steam goes through the bamboo and catches it. It's very clear, like gin" (Brady & McGrath, p. 318; Fig. 4).

The distilled version was a strong "rough and ready job" as one Islander described it and virtually identical to the arrack that had been introduced to mainland Aboriginal groups by the Makassan *bêche-de-mer* fishers. Perhaps because it was so strong, it seems to have been drunk sparingly. With the advent of easily available commercial alcohols, licensed outlets and the end of race-based prohibitions on alcohol in the mid-twentieth century, *tuba* is now no longer consumed on the TSI, but in earlier years it had many uses. *Tuba* was explicitly made and consumed during the years of prohibition in the nineteenth and early twentieth centuries (supplies of liquor were banned to Aboriginal "natives and half-castes," Aboriginal natives of the Pacific Islands or Polynesians born in Queensland), and thus it played a role in deliberately undermining the authority of the superintendent teachers who were responsible for local governance on the Islands. Offering *tuba* was a means for Islander

Alcohol Fermentation in Australian Aboriginals, Fig. 4 Distillery for *tuba* (Guam, Mariana Is.). The stills on the Torres Strait Islands were similar to this (Lithograph, A. Pellion 1819)

families to show hospitality to their guests. It was sold to other Islanders for cash, and during World War II (when thousands of US and allied air force men passed through a northerly air base on Horn Island), several Island families "made a quid" by selling steamed tuba to the "Yanks." It seems that relatively few health or social problems were associated with drinking *tuba* or steamed *tuba*, and in general Torres Strait Islanders have positive memories of the drink. This introduced but indigenized alcohol was harvested, manufactured, and distributed as part of an informal local economy and became embedded in the social and cultural life of the people of the islands on which it was made.

References

Basedow, H. (1918). Narrative of an expedition of exploration in North-western Australia. *Proceedings of the Royal Geographical Society of Australasia, South Australian Branch, 18* (1916–1917).

Bates, D. M. (1985). *The native tribes of Western Australia* (White, I., Ed.). Canberra, ACT: National Library of Australia.

Beaglehole, J. C. (1963). *The endeavour journal of Joseph Banks 1768–1771* (Vol. 2). Sydney: Trustees of the Public Library of New South Wales.

Brady, M. (2008). *First taste. How indigenous people learned about grog*. Canberra, ACT: Foundation for Alcohol Research and Education.

Brady, M., & McGrath, V. (2010). Making tuba in the Torres Strait Islands: The cultural diffusion and geographic mobility of an alcoholic drink. *Journal of Pacific History, 45*(3), 315–330.

Bunce, D. (1857). *Australasiatic reminiscences*. Melbourne: J.T. Hendy.

Burkill, I. H. (1966). *A dictionary of the economic products of the Malay Peninsula*. Kuala Lumpur: Ministry of Agriculture and Co-operatives.

Clark, M., & May, S. K. (2013). *Macassan history and heritage. Journeys, encounters and influences*. Canberra, ACT: ANU e-press. http://epress.anu.edu.au

Clarke, P. A. (2007). *Aboriginal people and their plants*. Dural, NSW: Rosenberg Publishing.

Cleland, J. B. (1957). Australia: Ethno-ecology. Our natives and the vegetation of Southern Australia. *Mankind, 5*(4), 149–162.

Dingle, A. E. (1980). "The Truly Magnificent Thirst": An historical survey of Australian drinking habits. *Historical Studies, 19*(75), 227–249.

Evans, N. (1992). Macassan loanwords in top end languages. *Australian Journal of Linguistics, 12*, 45–91.

Ganter, R. (2006). *Mixed relations: Asian-aboriginal contact in North Australia*. Perth, WA: University of Western Australia Press.

Heeres, J. E. (1899). *The part borne by the Dutch in the discovery of Australia 1606–1765*. London: Luzac & Co.

Macknight, C. C. (1976). *The voyage to Marege'. Macassan trepangers in northern Australia*. Melbourne, VIC: Melbourne University Press.

MacPherson, J. (1921). The use of narcotics and intoxicants by the native tribes of Australia, New Guinea, and the Pacific. *Sydney University Medical Journal*, 108–122.

Maiden, J. H. (1924). *Forest flora of New South Wales* (Vol. 7, 1903–1924). Sydney: Government Printer.

Moore, G. F. (1978). *Diary of ten years eventful life of an early settler in Western Australia and also a descriptive vocabulary of the language of the Aborigines* (Facsimile ed.). Perth, WA: University of Western Australia Press. (Original work published 1886)
Noongar Alcohol and Substance Abuse Service (NASAS). (1992). *"Grog. . .it bites like a serpent". Twelve radio programs on 2 cassettes about alcohol and substance abuse*. East Perth, WA: N.A.S.A.S. & Wordstars.
Petrie, T. (1904). *Tom Petrie's reminiscences of early Queensland (dating from 1837) recorded by his daughter*. Brisbane, QLD: Watson Ferguson.
Plomley, N. J. B. (Ed.). (1966). *Friendly mission. The Tasmanian journals and papers of George Augustus Robinson 1829–1834*. Hobart, TAS: Tasmanian Historical Research Association.
Plomley, N. J. B. (1976). *A word list of the Tasmanian Aboriginal languages*. Launceston: Foot and Playstead Pty.
Roth, W. E. (1904). Notes of savage life in the early days of west Australian settlement. *Proceedings of the Royal Society of Queensland, 17*, 45–69.
Schnukal, A. (2004). *Dictionary of Torres Strait Creole*. Kuranda, QLD: Rams Skull Press.
Spencer, D. J. (1988). Transitional alcoholism – The Australian Aboriginal model. In *Drug issues affecting aboriginal Australians* (Technical Information Bulletin No. 79, pp. 15–21). Canberra, ACT: Australian Government Publishing Service.
Wallace, A. R. (1989). *The Malay archipelago*. Oxford: Oxford University Press. (Original work published 1869)
Watson, P. (1983). *This precious foliage. A study of the Aboriginal psycho-active drug Pituri* (Oceania Monograph 26). Sydney: University of Sydney.

Alcoholic Rice Beverages

Uma Ahuja[1] and Subhash Chander Ahuja[2]
[1]College of Agriculture, CCS Haryana Agricultural University, Kaithal, Haryana, India
[2]Rice Research Station, CCS Haryana Agricultural University, Kaithal, Haryana, India

There are many "*aqua vitae*" – beverages made from millets, grapes, dates, palm, sugarcane, potato, and cereals including rice. Traditional foods provide a basic diet while alcoholic beverages supplement enhanced nutrition and palatability. People also drink alcoholic beverages to forget the aches of their daily toils. An abundant supply of rice in South East Asia has produced a variety of spirits, wine, and beers. *Wong-tsiu* and *chaoxing* of China, *saman* of Malaysia, *chhang* of Tibet, and *sake* of Japan are some of the favorites.

In some religions, alcohol is a taboo. However, rice alcoholic beverages (RAB), like rice itself, have attained the status of sacred items in many Asian countries including the tribes of the central, East, Himalayan belt, and North Eastern states of India. RAB constitute an integral part of dietary culture due to the climatic conditions and have strong ritual importance among the ethnic people. In contrast to tribal people, peasant Hindus do not employ rice beer (or fermented grains in general) in rituals. This perhaps reflects an aesthetic aversion to the rotting and decay connotations of fermentation (Hancett, 1988).

RAB are home products in the tribal belt of India and are offered as a welcome drink in all households. Nagas do not know any other drink except rice beer; milk is used only in urban areas. Young and old, rich and poor, and men, women, and children relish it equally (Singh, 1995). In Europe Austrian beer and *tapuy* in the Philippines are products of rice brewing (Anonymous 1993). During pre-partition days, half of Indian rice exported was brewed into alcoholic drinks in Europe and the USA (Watt, 1901). At present about 7 % of rice production in the USA is used along with barley to make beer lighter and tastier for Americans (White, 1994). In the world of trade, broken rice used for brewing is called "brewers' rice." According to British records, the Ho tribe of Bihar were so fond of rice beer that they spent most of the year's rice storage preparing rice beer (Ahuja, Thakrar, Ahuja et al., 2001).

We have no written records of the initiation of the rice beverage drinking tradition, but there is no doubt among the people about its divine origin (Das, 1972). The Bodos of Assam credit Lord Mahadeva, the Karbi/Mikir to Chang Charpau (god of creation), the Mundas of Orissa to Singbonga, and the supreme God and the Konds of Orissa to Nirantalli – Supreme Mother Earth – for teaching the art of brewing. Most tribes consider the rice beer of divine origin; the

Bhuiyan of Orissa credit their hero Boram Burha (Ahuja et al., 2001).

Like the rice beer, the starter tablet is also considered as divine. The Kabris believe that God told Kabri women in her dream to make starter tablet using fecal matter of the Vokongching bird. The Adi and Mising people (Assam) consider that the starter tablet was created by the spilled milk of the fairy Miti Omum and was made into cakes by Engo Takar using plants grown on spilled milk and named it E'pop (Pegu et al., 2013).

In India fermenting drinks from rice is an age-old art. As early as 2000 BC, the Indus Valley civilization seems to have practiced alcoholic fermentation and distillation. In the later Vedic period, grain-derived products were *masara*, *kilala*, *kashaya*, *prasanna*, and *svetasura*. *Masara* may have been a pre-Aryan drink made from barley and later rice. *Prasanna* was fermented rice flour flavored with spices, bark, and fruits. In *svetasura* clarity was achieved by adding sugar to *prasanna*. Drinking was frowned upon in *Ṛgveda* and in the *Sūtras*. Kshatriyas were not permitted with grain-based liquors. The classic Indian medical authorities took a balanced view of drinking. Moderation was counseled as alcohol increases the mental principle *pitta* while decreasing both the physical and vitality principles *kapha* and *vata* (Achaya, 1998). Āyurvedic texts describe preparation of *sura* from fermenting rice flour which was hard to digest and caused constipation, increased fat, urine, and *kapha* and was used to treat gaseous abdominal swelling, dropsy, and reduced strength. *Varuni sura* was made by *punarava* and rice was easily digestible and cured flatulence (Sekar, 2007). *Bhagwat Puran* refers to distillation of liquor from wild rice. Aryans made sura from wild rice, flowers, and barley (Kumar, 1988).

Megasthenes, accompanying Alexander on his crusade to India, wrote in his memoirs (ca. 50 AD) that Indians avoided intoxicating drinks. However, for religious ceremonies, drinking of rice beer was permitted. The favorite drink Madhuka referred to in Kautilya's *Arthaśāstra* was made of ten ingredients with fermented rice (Ahuja et al., 2001).

Ingredients

Rice in different forms is used as basic material for preparing beverages (beer, wine, or liquor) as paddy, boiled, raw, or germinated rice. Chinese and Japanese prepare drinks from ground rice powder; Filipinos prefer fried rice, while at other places boiled rice is used as the basic ingredient. Kodavas of Coorg in Karnataka use germinated rice for the preparation of a strong whisky called *Kachana Kallu* which is consumed lavishly during *Huttari*, the rice harvesting festival (Pai, 1994; Ponnappa, 1988). Tribal people in Silvassa, Maharashtra, prepare rice wine by using pounded paddy and potatoes. The paddy is pounded with the husk, placed in an earthen pot with a small quality of yeast, and allowed to ferment for 6 days. It is then distilled over a slow fire into a crystal clear, potent drink.

Various tribes prepare rice beer at home by fermenting boiled rice soaked in water using a starter tablet (Jeyaram et al., 2008; Tamang et al., 2007) known by different names in various Indian states (Table 1). Regional specialization and the uniqueness of the process have been developed to such a fine level to give taste and color specific to each tribe (Deori et al. 2007; Saikia et al. 2007). The main point of modification is the herbs used in the starter tablets serving as a microbial culture for fermentation. The starter tablet is prepared by mixing rice flour with roots, leaves, bark, or seeds of the selected plants. The quality of the starter culture is said to be dependent on the variety of plant parts used and also on the maintenance of proper sanitary conditions. Every tribe has its distinct herbs used in their starter tablet (Table 1). The Deori tribe of Assam formerly used about 100 plants which have been reduced to 30–40. In Manipur there are two kinds of starter tablets. Normally a *chuwan* (starter) is a circular shape with an umbilical type of dimple in the center, but in male chuwan, there are three umbilical dimples instead of one.

The preference for rice variety used for fermentation differs from community to community. The Khasis of Meghalaya generally use

Alcoholic Rice Beverages, Table 1 Plants used in starter tablets of Alcoholic rice Bevarages by Tribes of India

Tribe/state	Rice beer/distillate	Starter tablet	Tablet constituents
Oraons	*Jhara*	*Ranu dabai*	*Elephantopus scaber* roots, *Argyreia bella* stem, *Casearia graveolens* bark, *Symplocos racemosa*
Orissa			
Santhals	*Harhia*	*Ranu dabai*	*Coccinia grandis*, *Clerodendrum viscosum*, *Vernonia cinerea*, *Plumbago zeylanica*, *Wattakaka volubilis*
Bihar, Bengal			
Gonds, central India	*Handia*	*Ranu dabai*	*Argyreia bella*, *Buchanania lanzan*, *Casearia graveolens*, *Cassine glauca* (Kumar & Rao, 2007)
		25 plants	
Dimasa Naga,	Judima	Umhu	*Glycyrrhiza glabra*, *Acacia pennata*
Jeme Naga	Dekuijao, nduijao	Nduhi	*Glycyrrhiza glabra*
Angami	Zutho		
Derois	Sujen	Perok kushi	*Jasminum sambac*, *Zanthoxylum hamiltonianum*, *Lygodium flexuosum*, *Acanthus*
			leucostachys, *Cyclosorus exlensa*, *Alstonia scholaris*, *Alpinia malaccensis*, *Costus speciosus*
Adi Arunachal	Opo, ennog	Sityeh	*Clerodendrum viscosum*, *Veronica* sp.
Galo Arunachal	Poka	Apong kusure	*Clerodendrum viscosum*, *Debregeasia longifolia*, *Diplazium esculentum*, *Pilea* sp., *Urtica hirata*, *Solanum kurzii* (Bora et al., 2013)
Miris	*Apong*	*Apop pitha*	*Scoparia dulcis*, *Cyclosorus*, *Costus speciosus*, *Adhatoda zeylanica*, *Zanthoxylum hamiltonianum*, *Naravelia zeylanica*, *Melothrea heterophyla*
Assam			
Maities	*Atingba*, *yu*	*Hamei*	*Albizia myriophylla*, *Tectona grandis* L.f., *Ficus hispida*, *Alocasia indica*
Manipur			
Tripura	ChuwkBwtwk/chuwarak	Chuwan	Jack fruit leaves, Thakotor, Tokhiseleng
Tripura			Pineapple leaves, red chili
Bodos	*Jou bishi*	*Angkur*	*Xanthium strumarium*, *Scoparia dulcis*, *Clerodendrum viscosum*
Assam			
Rabha	Choko/fortica	Bakhor, phap	*Ananas comosus*, *Artocarpus heterophyllus*, *Calotropis gigantea*, *Capsicum frutescens*
Assam			
Ao, Nagaland	Zutho	Piazu	Germinated rice powder
Kabri(Assam)	HorAlang/hor arak	Thap	*Croton joufra*, *Artocarpus heterophyllus*, *Phlogacanthus thyrsiflorus*, *Solanum viarum*, *Acacia pennata*

(*continued*)

Alcoholic Rice Beverages, Table 1 (continued)

Tribe/state	Rice beer/distillate	Starter tablet	Tablet constituents
Ahoms	*Koloh pani*	*Vekur pitha*	*Oldenlandia corymbosa*, *Lygodium* sp.
Assam			*Hydrocotyle sibthorpioides*, *Centella asiatica*, *Cissampelos pareira*, *Piper nigrum*
Jaintias	*Sadhiar*, *kiad*	*Thiat*	*Khaw-iang/hawiang-iang leaves*
(*Meghalaya*)			
Tribals Lahaul- Spiti HP	*Chang/sra*	*Phab*	*Saccharomyces fermentati*

a red variety *kho-so* (Samati and Begum 2007), the Nagas use maize, Mundas of Chhattisgarh and Bihar use *karaini* or gora rice, Dimasis use *biron*, and the Rabhas of Assam prefer *sali aus* and boro rice. When boro rice is used, the beer obtained is reddish brown in color and has a shelf life of 6–12 months (Deka & Sarma, 2010).

The Adi and Nishis of Arunachal Pradesh prepare white *apong* and blackish *ennog*, respectively, from white and black rice (added with rice husks), and after fermentation, it is stored in bamboo vessels lined with *ekkam* (*Phryium capitulum* L) and *oko* (*Zingiberaceae* family) leaves, respectively (Tiwari & Mahanda, 2007). In Lahaul and Spiti, Himachal Pradesh *lugari* and *chhang* are prepared, respectively, from uncooked and cooked rice. Lugari is consumed only as a fermented product while chhang is used both as fermented and distilled (Kanwar et al., 2011).

Glutinous rice is preferred to non-glutinous rice, owing to the taste and alcohol content of the product. The Miris of Assam prepare whitish *noggin apong* from boiled and *poro apon* from glutinous rice to which ash of partially burned paddy husk and straw is added (Gogoi et al., 2013). The Bodos also prepare two types of beer called *maibra jou* from glutinous *bishi* and *matha jou bishi* from non-glutinous rice (Das et al., 2012).

In addition to the type and form of rice used, the Mundas *of* Orissa and central India add some plants to increase intoxication or to decrease the period of fermentation while preparing *handia* (Kumar & Rao, 2007). They use *Elephantopus scaber* L. roots, *Argyreia bella* stems, and the bark of *Casearia graveolens* and *Symplocos racemosa*. The Kols of Madhya Pradesh use *Madhuca longifolia* flowers, rhizomes of *Imperata cylindrica*, and *Cissampelos pareira* with fruits of *Syzygium cumini* in fermenting rice beer (Mittre, 1991). The Apatani tribe of Arunachal Pradesh add ash extract of *Eleusino coracana* and *Saurauia roxburghii* to broth, the Ahoms of Assam add seeds of Datura, and the Adivasi of Assam add leaves of *Nicotiana tabacum* and *Polygonum hydropiper*. The Kabris and Deoris of Assam and Meities of Manipur add different types of fern leaves to give a strong aroma to rice beer. Half-burnt rice husk ash is added by the Adi, Kabris, and Miris (Chakrabarty et al., 2009; Gogoi et al., 2013; Tanti et al., 2010).

Some tribes distill the fermented product to obtain a strongly alcoholic distillate which has more shelf life (Table 1). The fermented and distilled products are of different ceremonial significance. The Kabris of Assam use the fermented *hor alank* in worship and marriages, while they use the distilled one during social occasions and death ceremony (Teron, 2006). The Rabhas of Assam believe that *fortica* has a curative effect on psychiatric patients (Deka & Sarma, 2010).

Among the various drinks from rice like beer, wine, and whisky, it is rice beer that is more popular among tribal people. In fact rice beer is called the “national” intoxicating drink of the tribes. Rice beverages are used in various ceremonies in various Asian countries. Rice beer is widely used in rites of passage and agricultural festivals. In all events in life from births to funerals, sowing to harvesting crops, friendship to revenge, argument to settlement, abduction, and murder, and happiness to sorrow, rice beer is indispensable (Saikia et al. 2007). In the East and Northeast, rice beer is part of every household and is offered and served to guests like tea (Das, 1972; Pegu et al., 2013). The Kabris of Assam, during the marriage ceremony, fill a gourd shell with *hor lank* and give it to the bride’s father (Teron, 2006). Rice beer is used as money when it is paid as a court fee and bride price by a Lakher of Nagaland and as compensation for adultery in Orissa. In marriages, the number of *handia* to be given to the bride’s side is decided well in advance. They offer rice beer to all spirits.

The social, religious, cultural, and personal life of the Mising people of Assam offers a panoramic view of the use of rice beer, *apong*. In social life, it is consumed as refreshing drink by both men and women after a day’s hard work. It is served as a welcome drink to guests. It is customary to use *apong* during marriage, birth, and death events, rituals, festivals, and on the assembly of village chiefs. In the Miris of Assam, discussions on marriage proposals are initiated by offering *noggin apong* from the boy’s to the girl’s father and it is served only on the agreement of the proposal. No ritual is considered complete without offering *apong* to the concerned deity. The *po:ro apong* is indispensable during traditional harvesting festivals and in funeral ceremonies (Pegu et al., 2013). The ritual use of *apong* has its origin with the legend of the origin of *E’pob* (starter cakes). *Po:ro apong* is indispensable during traditional harvesting festivals *Ali-a:ye Li’gang* and *Po:rag* and in funeral ceremonies and also in *Urom apin*, *Dodgang*, and *Dobur ui* rituals. Both *noggin* and *Po:ro Apong* are used during *Tani siko* (ritual for deceased persons; Pegu et al., 2013).

Rice beer is relished equally by men, women, and children during social and agricultural ceremonies and festivals, and its use is a must in social ceremonies and rites (Ahuja et al., 2001). The Oraons and Mundas of Orissa make rice beer after sowing and at transplanting in hopes of a bumper harvest (Crooke, 1896; Kumar, 1988). They thresh the crop after Khariharn Puja with sacrifice of fowl and oblations of rice beer (Roy, 1928). The Deuris of Assam use *sujhen*, rice beer, in their household pujas and in elaborate rituals at the riverside to please the water deity, Jalki Dangoriya (Das, 1972). In Silvassa (Maharashtra), tribal people use rice wine in Vasant Utsav. The belief is that unless one is knocked out and fully drunk, he or she would not get the blessing of the Goddess Mahavidya (Pai, 1994). Rice wine is considered to be a favorite drink of deities such as Kameshwari in Assam, Kamakhya in South, and Durga in Bengal. Offerings of animal sacrifice and rice wine are a must (Bhattacharyya, 1978; Das, 1972; Das & Mahapatra, 1979).

Chhang is offered to deities and also exchanged as an important gift during weddings and other auspicious ceremonies by tribes of the Himalayan region. *Chhang* is an indispensable hospitality beverage among tribal people of Lahaul valley and is considered to provide protection against cold during winter months (Savitri & Bhalla, 2007).

RAB have their medicinal value too. The Bodos and the Rabhas use it for stomachache, urinary problems, insomnia, body ache, inflammation, diarrhea, expelling worms, and cholera (Deka & Sarma, 2010). The Maria tribes of Bastar take *handia* as a light tranquilizer. It is also given to treat fever, dysentery, diarrhea, and gynecological complaints (Kumar & Rao, 2007). The Gond tribe of Surguja district use *ranu* tablets in treating cholera (Ahuja et al., 2001). The people of Manipur use *yu* as a medicine, relaxant, and in the poor health condition of women due to irregular menstrual flow, infertility factors, obesity, loss of appetite, and low nourishment of foods (Singh & Singh, 2006). *Yu* is also used for treating fever, body ache, and common cold and is smeared over the face and body parts as a beauty care product.

The residue after extraction of *yu* is given for fast and healthy growth of pigs. The Kabris use *horalank* to add aroma and flavor and to increase the shelf life of dried fish. Highly concentrated *hor acho* is used in dysentery and pharyngitis. The Mising believe that having two or three glasses (about 500 ml) of *po*:*ro apong* a day can prevent formation of kidney stones (Pegu et al., 2013). The Rabhas give rice beer to bulls to promote body strength and to cure swelling legs (Deka & Sarma, 2010).

Taboos and Safety Rite

The Santhals always keep one or a few dry chillies and a piece of charcoal, while the Rabhas place charcoal and *Ricinus communis* leaves on the raw materials and on products at different steps in order to keep all the evil forces away which may deteriorate the quality *of rice beer* (Deka & Sarma, 2010). The Miris and Deuris keep citrus fruits away from the vicinity during preparation of *E*'*pob* and *apong*, because they are said to make *apong* acidic or sour (Pegu et al., 2013). The Kabris believe consumption of *hor* before offering to God is a taboo. Preparation of *thap* (fermenter tablet) by women of the clan Bey and clan Hanjang is considered taboo by Kabris (Teron, 2006). Normally Miri women prepare apong, but during the ritual *dobur puja*, *men extract apong* because participation of women is a social taboo. In Manipur it is believed that a drop of sweat fallen into the production of beer will spoil the whole mass (Singh & Singh, 2006). During funeral ceremonies, the *handia* is not made in the deceased's house and relatives bring it. In Tripura women should not menstruate at time of preparation of chuwan. She is also barred during a postnatal period of one month.

Originally rice beer was used as an antidote to fatigue and also as a prophylactic against sun stroke, snake bite, and other problems which tribal people usually faced during their work in the fields. Since it was produced at home, it was not eligible for excise duty, so the British discouraged home-brewed drinks which led to a higher consumption of distilled liquors, disturbing the social order (Ray, 1993). The medicinal herbal mix which imparts such prophylactic properties to rice beer is not widely known now, and with the migration of young people to cities the knowledge is confined to a few elders.

References

Achaya, K. T. (1998). *A historical dictionary of Indian food* (p. 345). Delhi: Oxford University Press.

Ahuja, U., Thakrar, R., Ahuja, S. C., et al. (2001). Alcoholic rice beverages. *Asian Agri-History, 5*(4), 309–319.

Anonymous, (1993). Beverages from rice. *Philippine Rice Newsletter*, *6*(4), 4.

Bhattacharyya, A. (1978). *Folklore of Bengal* (p. 187). New Delhi, India: National Book Trust.

Bora, S. S., Lahan, P. L., Madumita, B., et al. (2013). Natural resource management by Galo tribe of Arunachal Pradesh. *Asian Agri -History, 17*, 335–344.

Chakrabarty, J., Sharma, G. D., Tamang, J. P., et al. (2009). Substrate utilisation in traditional fermentation technology practiced by tribes of North Cachar Hills district of Assam. *Assam University Journal of Science & Technology: Biological Sciences, 4* (I), 66–72.

Crooke, W. (1896). *Religion and Folklore of Northern India* (p. 435). New Delhi: S. Chand & Co (Rev. ed.).

Das, J. (1972). *Folklore of Assam* (p. 142). New Delhi, India: National Book Trust.

Das, A. J., Deka, S. C., Miyaji, T., et al. (2012). Methodology of rice beer preparation and various plant materials used in starter culture preparation by some tribal communities of North-East India: A survey. *International Food Research Journal, 19*(1), 101–107.

Das, K. B., & Mahapatra, L. M. (1979). *Folklore of Orissa* (p. 160). New Delhi, India: National Book Trust.

Deka, D., & Sarma, G. C. (2010). Traditionally used herbs in the preparation of rice-beer by the Rabha tribe of Goalpara district, Assam. *Indian Journal of Traditional Knowledge, 9*(3), 459–462.

Deori, C., Bengum, S. S., Mao, A. A., et al. (2007). Ethno botany of *Sujen*, a local rice beer of Deori tribe of Assam. *Indian Journal of Traditional Knowledge, 6*(1), 121–125.

Gogoi, B., Dutta, M., Mondal, P., et al. (2013). Various ethno medicinal plants used in the preparation of *Apong*, a traditional beverage use by mising tribe of upper Assam. *Journal of Applied Pharmaceutical Science, 3*(4 Suppl 1), S86–S89.

Hancett, S. (1988). *Colored rice*. Delhi: Hindustan Publishing Corporation.

Jeyaram, K., Singh, W. M., Capece, A., Romano, P., et al. (2008). Molecular identification of yeast species associated with ‘Hamei’- A traditional starter used for rice wine production in Manipur, India. *International Journal of Food Microbiology, 124*, 115–125.

Kanwar, S. S., Gupta, M. K., Katoch, C., Kanwar, P., et al. (2011). Cereal based traditional alcoholic beverages of Lahaul and Spiti area of Himachal Pradesh. *Indian Journal of Traditional Knowledge, 10*(2), 251–257.

Kumar, T. T. (1988). *History of rice in India* (p. 242). Delhi, India: Gyan Publishing House.

Kumar, V., & Rao, R. R. (2007). Some interesting indigenous beverages among the tribals of Central India. *Indian Journal of Traditional Knowledge, 6*, 141–143.

Mittre, V. (1991). Wild plants in Indian folk life – A historical prospective. In S. K. Jain (Ed.), *Contributions to Indian ethno botany* (pp. 39–59). Jodhpur, India: Scientific Publishers.

Pai, P. (1994). Celebrating spring in Silvassa. *The Tribune, 199*.

Pegu, R., Gogoi, J., Tamuli, A. K., Teron, R., et al. (2013). *Apong*, an alcoholic beverage of cultural significance of the Mising community of northeast India. *G.J.I.S.S, 2*(6), 12–17.

Ponnappa, K. (1988). Coorg fare. *India Magazine, 8*(6), 60–65.

Ray, A. (1993). *Mizoram* (p. 284). New Delhi, India: National Book Trust.

Roy, S. C. (1928). *Oraons religion and customs*. KM Banejee, Sham Bazar, Calcutta, India.

Saikia, B., Tag, H., Das, A. K., et al. (2007). Ethno botany of foods and beverages among the rural farmers of Tai Ahom of North Lakhimpur District, Assam. *Indian Journal of Traditional Knowledge, 6*(1), 126–132.

Samati, H., & Begum, S. S. (2007). Kiad, a popular local liquor of Pnar tribe of Jaintia hills district, Meghalaya. *Indian Journal of Traditional Knowledge, 6*(1), 133–135.

Savitri, & Bhalla, T. C. (2007). Traditional foods and beverages of Himachal Pradesh. *Indian Journal of Traditional Knowledge, 6*(1), 17–24.

Sekar, S. (2007). Traditional alcoholic beverages from ayurveda and their role on human health. *Indian Journal of Traditional Knowledge, 6*(1), 144–149.

Singh, P. (1995). *Nagaland* (p. 210). New Delhi, India: National Book Trust.

Singh, P. K., & Singh, K. I. (2006). Traditional alcoholic beverage, Yu of Meitei communities of Manipur. *Indian Journal of Traditional Knowledge, 5*(2), 184–190.

Tamang, J. P., Dewan, S., Tamang, B., Rai, A., Schillinger, U., Holzapfel, W. H., et al. (2007). Lactic acid bacteria in Hamei and Marcha of North East India. *Indian Journal of Microbiology, 47*, 119–125.

Tanti, B., Gurung, L., Sarma, H. K., Buragohain, A. K., et al. (2010). Ethano botany of starter culture used in alcohol fermentation by a few ethnic tribes of Northeast India. *Indian Journal of Traditional Knowledge, 9*(3), 463–466.

Teron, R. (2006). *Hor*, the traditional alcoholic beverage of the Karbi tribe of Assam. *Natural Product Radiance, 5*(5), 377–381.

Tiwari, S. C., & Mahanda, D. (2007). Ethnological observations fermented food products of certain tribes of Arunachal Pradesh. *Indian Journal of Traditional Knowledge, 6*(1), 106–110.

Watt, G. (1901). *A dictionary of economic products of india* (Vol. I-VIA). Delhi, India: Cosmo Publications. (Reprint.)

White, P. T. (1994). Rice, the essential harvest. *National Geographic, 185*(5), 48–79.

Al-Damīrī

Emilia Calvo

Al-Damīrī Muḥammad ibn Mūsa ibn ʿĪsā was born in Cairo, Egypt in AD 1341. Although he began work as a tailor, he soon decided to study with the leading teachers of the time such as Bahāʾ al-Dīn al-Subkī, Jamāl al-Dīn al-Asnāwī, Ibn ʿAqīl, and others. He became a professional theologian and taught in different centers such as al-Azhar University, achieving a great recognition for his preaching and his ascetic life. A very religious man, he made the pilgrimage to Mecca six times between AD 1361 and 1367 and died in Cairo in AD 1405.

The majority of al-Damīrī’s works are conventional commentaries and epitomes of earlier works such as the one on al-Nawawī’s *Minhāj* (a manual of Islamic law). He also wrote sermons and treatises on canon law. Most of these works seem to be lost. His most famous work is *Hayāt al-ḥayawān* (Life of the Animals), a zoological dictionary which contains information on the animals mentioned in the *Quʾrān* and in the Arabic literature. It includes not only the zoological aspects, but also everything related to the animals mentioned.

The work contains 1,069 articles describing a lesser number of animals because the same animal is occasionally described twice using two different names. The animals are described in alphabetical order and usually contain seven sections (1) grammatical and lexicographical peculiarities of the name, (2) a description of the animal according to the leading authorities, (3) Muslim traditions in which the animal is mentioned, (4) juridico-theological considerations regarding the animal, (5) proverbs about the animal, (6) the medicinal properties of the products derived from the animal, and (7) rules for the interpretation of dreams in which the animal appears.

There are three versions of this work: the large (*al-kubrā*), the medium (*al-wusṭā*), and the small (*al-ṣugrā*) and it has been republished several times and translated into Persian and Turkish.

References

Kopf, L. (1965). al-Damīrī. *Encyclopédie de l'Islam* (2nd ed. Vol. 2, pp. 109–110). Leiden/Paris: E. J. Brill/G. P. Maisonneuve.

Sarton, G. (1948). *Introduction to the history of science* (pp. 1214, 1326, 1639–1641). Baltimore, MD: Williams & Wilkins.

Vernet, J. (1971). Al-Damīrī. *Dictionary of scientific biography* (Vol. 3, pp. 548–549). New York: Charles Scribner's Sons.

Al-Farghānī

Ahmed Bouzid

Al-Farghānī, Abu-l-ʿAbbas Aḥmad ibn Muḥammad ibn Kathīr was born in Farghana, Transoxania and died in Egypt, ca. 850. He was a famous astronomer during the time of the ʿAbbasid caliph ▶ al-Maʾmūn and a contemporary of ▶ al-Khwārizmī, al-Marwarudhī, ▶ al-Jawharī, and Yaḥya ibn Abi-Manṣūr. He was well known in the Latin Middle Ages under the name of Alfraganus, thanks principally to his widely read book, *Compilatio astronomica* (also called *Liber 30 differentiarum*, Book of the 30 Chapters), which is a summary of Ptolemy's *Almagest*. The work still survives in Arabic under the following titles: *Jawāmiʿ ʿilm al-nujūm wa'l-ḥarakāt al-samāwiyya*, *Uṣūl ʿilm al-nujūm*, *ʿllal al-aflāk*, and *Kitāb al-fuṣūl al-thalāthīn*. The *Jawāmiʿ* (sometimes translated as *Elements*) provided the medieval reader with a rather comprehensive account of Ptolemy's astronomy through a well-organized, accessible, and nonmathematical presentation. The work was translated into Latin at least twice in the twelfth century: by John of Spain (John of Seville) in 1135, and by Gerard of Cremona before 1175. The *Jawāmiʿ* was also translated into Hebrew during the thirteenth century by Jacob Anatoli. Copies of this translation exist today in Berlin, Munich, Vienna, and Oxford, among other places. In 1590, drawing from Anatoli's translation, Jacob Christmann published the third Latin version of the book in Frankfurt-am-Main. A later Latin translation of the text, along with al-Farghānī's original Arabic, was published in 1669 by Jacob Golius. Widely circulated in the West during the Middle Ages, the *Jawāmiʿ* was frequently referenced by medieval writers, and it is generally accredited today for having contributed considerably to the propagation of knowledge on the Ptolemaic system. In addition to the *Jawāmiʿ*, al-Farghānī wrote on the astrolabe. A number of his manuscripts on the subject survive under the following titles: *Fīṣanʿ at al-asṭurlāb*, *al-Kāmil fi'l-asṭurlāb*, and *Kitāb ʿamal al-asṭurlāb*.

See Also

▶ *Almagest*: Its Reception and Transmission in the Islamic World
▶ Astrolabe

References

Carmody, F. J. (1956). *Arabic astronomical and astrological sciences in latin translation*. Berkeley, CA: University of California Press.

Duhem, P. (1959). *Le système du monde: histoire des doctrines cosmologiques de Platon á Copernic* (Vol. 2, pp. 204–214). Paris: A. Hermann.

Sabra, A. I. (1981). Al-Farghānī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 4, pp. 541–545). New York: Charles Scribner's Sons.
Saliba, G. (1994). *A history of arabic astronomy: Planetary theories during the golden age of Islam*. New York: New York University Press.

Al-Fazārī

Boris A. Rosenfeld
PA, USA

Abū Isḥāq Ibrāhīm ibn ḥabīb ibn Sulaymān ibn Samura ibn Jundab al-Fazārī (d. ca. 777) was a Muslim astronomer and the first Muslim constructor of astrolabes. He was the author of many scientific works whose manuscripts are not extant, but the Arabic historians Abū'l-Faraj Muḥammad ibn Nadīm al-Warrāq al-Baghdādī (d. 993) in his *Kitāb al-fihrist al-ʿulūm* (Bibliography of Sciences) and Jamāl al-Dīn ʿAlī ibn al-Qifṭī (1173–1248) in his *Taʾrīkh al-ḥukamā* (History of Sages) mention one mathematical and five astronomical works by al-Fazārī:

1. *Kitāb fī tasṭīh al-kura* (Book on the Projection of a Sphere onto a Plane)
2. *al-Zīj ʿalā sinī al-ʿarab* (Astronomical Tables According to Arabic Years)
3. *Kitāb al-ʿamal bi'l-asṭurlāb al-musaṭṭaḥ* (Book on the Use of the Plane Astrolabe)
4. *Kitāb al-ʿamal bi'l-as ṭurlābāt dhawāt al-ḥalaq* (Book on the Use of Astrolabes with Rings)
5. *Kitāb al-miqyās li'l-zawāl* (Book on the Gnomon for the Noon)
6. *Qaṣīda fī ʿilm al-nujūm* (Poem on the Science of Stars)

His son Muḥammad translated an astronomical work *Brāhma-sphuṭasiddhānta* by the sixth-century Indian astronomer and mathematician Brahmagupta from Sanskrit into Arabic. The Arabic name of this work, *Sindhind*, came from the word *siddhānta*, astronomical texts, and the Arabic name for India, *Hind*. The extant fragments of *Sindhind* have been translated into English by David Pingree.

Boris A. Rosenfeld: deceased

See Also

- ► Astrolabe
- ► Brahmagupta

References

Matvievskaya, G. P., & Rosenfeld, B. A. (1983). *Mathematicians and astronomers of medieval Islam and their works (8-17th c.)* (Vol. 2, p. 29). Moscow: Nauka (in Russian).
Pingree, D. (1970). The fragments of the works of al-Fazārī. *Journal of Near Eastern Studies, 27*(2), 103–123.
Plofker, K. (2014). Fazārī: Muḥammad ibn Ibrāhīm al-Fazārī. In *Biographical encyclopedia of astronomers* (pp. 706–707).
Sarton, G. (1927). *Introduction to the history of science* (Vol. 1, p. 530). Baltimore: Williams & Wilkins.
Suter, H. (1900). *Mathematiker ind Astronomen der Araber und ihre Werke* (pp. 3–5). Leipzig: Teubner.

Alfonso X

Julio Samsó

Alfonso X, King of Castile (1252–1284) and a patron of literature and learning, made an important effort to recover Arabic and, very especially, Andalusian astronomical materials by translating them first into Spanish and later into Latin. His collaborators were one Muslim convert into Christianity, eight Christians (of whom four were Spaniards and another four Italians) and a very important group of five Jews. Alfonso failed in his attempt to integrate in his team a Muslim scientist of the importance of Muḥammad al-Riqūṭī but his interest for us here lies in the fact that his translations preserve Andalusian astronomical works which would have been lost otherwise. This is the case, for example, of the *Libro de las Cruzes* (Book of Crosses), a late Latin astrological handbook translated into Arabic in the early ninth century and revised, in the eleventh century, by a certain ʿUbayd Allāh. Other works which are only known through his translations are the *Lapidario* (a book on the magical applications of stones) written by the otherwise unknown Abolays, the two books on the construction of equatoria written by Ibn al-Samḥ (d. 1035) and ► Ibn al-Zarqāllu (d 1100), ʿĀlīibn Khalaf's book on the use of the plate for all latitudes (*Lámina Universal*, Toledo, eleventh century) and Ibn al-Zarqāllu's treatise on the construction of the armillary sphere. Other works which are, apparently, originals contributed to the European diffusion of Arabic astronomical ideas: the famous *Alfonsine Tables*, extremely popular between the fourteenth and the sixteenth centuries, were strongly influenced by the *Tables* of ► al-Battānī and marked a turning point in the development of late Medieval European astronomy.

See Also

► Ibn al-Zarqāllu

References

Comes, M. (1991). *Ecuatorios andalusies. Ibn al-Samḥal-Zarqāllu y Abū-lṣalt*. Barcelona, Spain: Instituto de Cooperación con el Mundo Arabe and Universidad de Barcelona.

Comes, M., Roser, P., & Julio, S. (Eds.). (1987). *De Astronomia Alphonsi Regis. Proceedings of a Symposium on Alfonsine Astronomy held at Berkeley (August. 1985) and other paper on the same subject*. Barcelona, Spain: Instituto "Millas Vallicrosa" de Historia de la Ciencia Arabe.

García Avilés, A. (1996). Two astromagical manuscripts of Alfonso X. *Journal of the Warburg and Courtauld Institutes, 59*, 14–23.

García Avilés, A. (1999). Alfonso X y la Tradición de la Magia Astral. In *Scriptorium Alfonsi: de los Libros de Astrologia a las Cantigas de Santa Maria* (pp. 83–103). Madrid, Spain: Editorial Complutense.

Procter, E. S. (1951). *Alfonso X of castile patron of literature and learning*. Oxford, UK: Clarendon Press.

Algebra in China

Lam Lay Yong

Arithmetic and geometry are the two oldest branches of mathematics. Algebra has its beginnings from both of them when attempts were made to generalize operations and relationships. Initially, such ideas were expressed in words; in the course of time, they were represented by some form of notation. The symbols facilitated the methods which in turn generated new concepts and methods. For instance, we are now able to solve with ease any arithmetical problem involving what we call a pair of linear equations in two unknowns through the use of the notational equations $ax + by = c$ and $dx + ey = f$. Around AD 825, Muḥammad ibn Mūsā ► al-Khwārizmī wrote a book expressing equations in words. In order to arrive at a solution, the two sides of an equation were manipulated through two main operations which he called *al-jabr* and *al-muqābala* – the name "algebra" was derived from the first word.

In ancient China, arithmetic developed through the use of the rod numeral system. Arithmetic was fully developed – not only were the methods of addition, subtraction, multiplication, and division known, but also the manipulations of the common fraction and the decimal fraction were commonplace, and methods such as those involving proportion and the Rule of Three were widely used. This article will describe very briefly how the mathematicians were able to generalize arithmetical operations and relationships which resulted in general methods of solution. The period covered will be from antiquity to the beginning of the fourteenth century. Traditional ► mathematics in China was at its height during the thirteenth and early fourteenth centuries; this was a time in Western Europe when the importance of the new arithmetic that evolved from the Hindu-Arabic numeral system was just beginning to be realized.

It might seem strange and improbable that the ancient Chinese were able to find general methods of solving equations since they did not compute through a written system but through the use of rods. However, the rod numeral system was extremely sophisticated and flexible, and the positions where the numerals were placed usually represented certain mathematical concepts. For example, let us consider a set of linear equations in three unknowns which we now write in the following manner:

$$a_1x + b_1y + c_1z = d_1,$$
$$a_2x + b_2y + c_2z = d_2,$$
$$a_3x + b_3y + c_3z = d_3.$$

The ancient Chinese would notate such a mathematical concept by placing the numerical values of the as, bs, cs, and ds in rod numerals in the following matrix form:

$$\begin{matrix} a_3 & a_2 & a_1 \\ b_3 & b_2 & b_1 \\ c_3 & c_2 & c_1 \\ d_3 & d_2 & d_1 \end{matrix}$$

The positions occupied by the rod numerals were important – the positions in the first row represented the first unknown, and those in the second and third rows represented the second and third unknowns, respectively.

The aim of the method was to obtain a group of zeros forming a triangle in the top left diagonal half of the matrix through a process of elimination with two columns at a time. Thus the elimination process would result in zeros for the positions which were occupied by a_3, a_2, and b_3 of the above matrix. After this was attained, the third unknown was derived from the third column from the right. This result would be able to derive the second unknown from the second column, and the solutions would in turn derive the first unknown from the remaining column.

The method is called *fang cheng* and can be found in the eighth chapter of *Jiu zhang suan shu* (Nine Chapters on the Mathematical Art). The whole chapter is devoted to the solutions of such equations which include a problem involving five equations in five unknowns and another involving five equations in six unknowns.

The matrix notation was derived through an evolution of a fundamental tradition that used positions occupied by rod numerals to represent concepts or things. Besides the placement of numerals involving the common fraction, problems related to proportion were solved by similar operations. The ancient Chinese were familiar with what is now called the Rule of False Position which, for them, originated from the solution of the concept of a pair of linear equations in two unknowns. The method is called *ying bu zu* and is the precursor of the *fang cheng* method.

The procedure for finding the square root of a number was derived from the geometrical division of a square into smaller areas. This was then arithmetized through the placement of rod numerals to become a general method. The offshoot of this method was the solution of what we call a quadratic equation of the form $x^2 + bx = c$, where b and c are positive. The ninth chapter of *Jiu zhang suan shu* has a problem involving an equation of this form. Besides the method of finding the square root, the book also gives the method of finding the cube root of a number. Knowledge of this method led to the solution of a cubic equation of the form $x^3 + ax^2 + bx = c$, where a, b, and c are positive. The seventh-century work *Jigu suanjing* (Continuation of Ancient Mathematics) by ▶ Wang Xiaotong has problems involving such equations.

The struggle to solve other types of quadratic equations besides the one mentioned above was depicted by the thirteenth-century mathematician ▶ Yang Hui, who quoted from the works of Liu Yi of the eleventh century – Liu Yi's works are now no longer extant. Though the concepts of the different types of quadratic equations were initially derived from a variety of geometrical considerations, the arithmetization of their operations through rod numerals revealed certain patterns and similarities which enabled the emergence of a general method of solution.

In his explanation of the development of the polynomial equation and its solution, Yang Hui quoted another eleventh-century mathematician, ▶ Jia Xian. He pointed out that Jia Xian was familiar with the triangular array of numbers now known as the Pascal triangle and was the first to realize its close relationship with the procedure of root extraction. From here, Jia Xian laid the foundation for a ladder or algorithmic method of finding the root of a number of any degree. This eventually provided the breakthrough to finding a solution of any numerical polynomial equation.

It was Qin Jiushao's detailed and systematic methods of explaining the problems in his book, ▶ Shushu jiuzhang (Mathematical Treatise in Nine Sections), that established beyond doubt the competence of the Chinese mathematicians to solve numerical equations of higher degree. Among the problems in the book, there are three that are involved with equations of the fourth degree and one of the tenth degree. These equations are of the following form:

$$\begin{aligned}
&-x^4+763200x^2-40642560000=0,\\
&-x^4+15245x^2-6262506.25=0,\\
&-x^4+1534464x^2-526727577600=0,\\
&x^{10}+15x^8+72x^6-864x^4-11664x^2-34992=0.
\end{aligned}$$

Yang Hui, Li Ye, and Zhu Shijie were the other thirteenth-century mathematicians who were also familiar with the algorithm method of solving a polynomial equation of any degree. This method is now generally accepted as similar to that put forward by Horner in 1819.

The Chinese were able to express the complex concept of a polynomial equation through the placement of rod numerals on the counting board. This notational representation was called *tian yuan shu* (Technique of the Celestial Element) in which an equation was formulated in terms of the unknown called *yuan*. An equation of the form

$$a_0x^n+a_1x^{n-1}+\cdots+a_{n-1}x+a_n=0$$

was represented in rod numerals in a vertical line as follows:

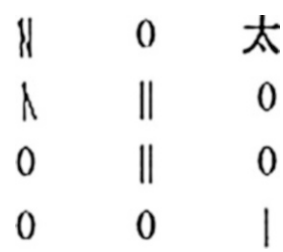
$$\begin{array}{c} a_n\\ a_{n-1}\\ \vdots\\ a_1\\ a_0 \end{array}$$

The positions occupied by the rod numerals had meanings – the first row signified that the rod numeral was a constant and the other rows in the downward direction signified that the numerals were the coefficients of the unknown in increasing power.

From here, Zhu Shijie in his *Siyuan yujian* (Precious Mirror of the Four Elements), written in 1303, proceeded to express polynomial equations in two, three, and four unknowns with rod numerals. For instance, the equation in two unknowns

$$(-x-2)y^2+\left(2x^2+2x\right)y+x^3=0$$

is expressed as follows:



The slanting rod indicates that the numeral is negative. In the first column from the right, the character *tai* indicates the constant of the equation, which in the above case is zero. This column, which is similar to the notation of a polynomial in one unknown, represents $0+0x+0x^2+x^3$. The second column represents $0y+2xy+2x^2y+0x^3y$, and the last column represents $-2y^2-xy^2+0x^2y^2+0x^3y^2$.

Zhu Shijie gave examples to show how a set of simultaneous polynomial equations of varying degrees up to four unknowns could be reduced to an equation in one unknown, and thereby finding the solution. For example, he illustrated how the set of equations of the form

$$\begin{aligned}
&-2y+x+z=0,\\
&-xy^2+4y-x^2+2x+xz+4z=0,\\
&y^2+x^2-z^2=0,\\
&2y+2x-u=0
\end{aligned}$$

was reduced to the following single equation in one unknown:

$$4u^2-7u-686=0.$$

In *Siyuan yujian*, Zhu Shijie excelled in another area in algebra: he gave correct formulae for the sums of higher order equal difference series. They are of two types which may be described in the following manner.

First type:

$$1+2+3+4+\cdots+n=\frac{1}{2!}n(n+1),$$

$$1+3+6+10+\cdots+\frac{1}{2!}n(n+1)$$
$$=\frac{1}{3!}n(n+1)(n+2),$$

$$1+4+10+20+\cdots+=\frac{1}{3!}n(n+1)(n+2)$$
$$=\frac{1}{4!}n(n+1)(n+2)(n+3),$$

$$1+5+15+35+\cdots+=\frac{1}{4!}n(n+1)(n+2)(n+3)$$
$$=\frac{1}{5!}n(n+1)(n+2)(n+3)(n+4),$$

$$1+6+21+56+\cdots+\frac{1}{5!}n(n+1)(n+2)(n+3)(n+4)$$
$$=\frac{1}{6!}n(n+1)(n+2)(n+3)(n+4)(n+5).$$

Second type:

$$1\cdot1+2\cdot2+3\cdot3+\cdots+n\cdot n=\frac{1}{3!}n(n+1)(2n+1),$$

$$1\cdot1+2\cdot3+3\cdot6+\cdots+n\cdot\frac{1}{2!}n(n+1)$$
$$=\frac{1}{4!}n(n+1)(n+2)(3n+1),$$

$$1\cdot1+2\cdot4+3\cdot10+\cdots+n\cdot\frac{1}{3!}n(n+1)(n+2)$$
$$=\frac{1}{5!}n(n+1)(n+2)(n+3)(4n+1).$$

It was ▶ Shen Guo (1032–1095) who initiated the study of this type of series and he was followed by ▶ Yang Hui and Zhu Shijie – their basic technique was related to the piling of stacks.

The foundation of algebra, as we know it today, and its impetus for growth arose from the successful development of arithmetic based on the Hindu-Arabic numeral system. In the earlier civilizations, there were various beginnings of algebra which also depicted the struggle to find expressions for arithmetical operations and geometrical relationships. The development of algebra in China has proved to be unique and significant with its growth being maintained continuously until the Ming dynasty (1368–1644).

The essential ingredient that fostered the growth of algebra in traditional China was the rod numeral system. What was extraordinary about it was its notation: the position of each digit of a numeral represented the place value of that digit, such as units, tens, hundreds, and so forth. This notation of a number freed the mind of unnecessary work and enabled arithmetic to be developed to the fullest. The same kind of thinking in the use of the positions of rod numerals to represent concepts or things made possible the subsequent evolution of algebra.

Though the Chinese used rods to develop algebra, the results obtained manifested numerous similarities with our early algebra. In the solution of a set of simultaneous linear equations, the ancient Chinese invented the matrix notation and the *fang cheng* method of elimination. About 1,500 years later, ▶ Seki Kowa and Leibniz initiated the study of determinants – Seki Kowa knew of the *fang cheng* method.

In searching for a general solution of a polynomial equation, ▶ Jia Xian drew attention to a triangular array of numbers which we now call Pascal's triangle. The method that the Chinese used to solve the polynomial equation was rediscovered by Horner half a century later. The concise notation of expressing the concept of a polynomial equation led Zhu Shijie to invent a notation to express a set of polynomial equations up to four unknowns. He gave examples to show how to solve them. In eighteenth-century Europe, it was Étienne Bezout who initiated the study of solving a pair of polynomial equations in two unknowns. Zhu Shijie's formulae for the series of higher order equal difference series also showed that he was a few centuries ahead of his counterparts in Europe.

It is ironical that the use of rods, which enabled the expansion and sustenance of algebra in China for over one and a half millennia, was also the reason for its decline. The rods were used not only for the development of mathematics but also for computation. By the Song dynasty (960–1279), a faster-paced society could not tolerate the time required for manipulating the rods. The demand for quicker computation led to the invention of the ▶ abacus. However, the abacus was only suitable for swift calculations and had neither the potential to foster the growth of mathematics nor the capacity to allow for the conceptual retention of what had already been developed in mathematics. The replacement of the rods by the abacus signaled the demise of traditional mathematics.

Since ancient times, the Chinese mathematicians had been using a base ten place value numeral concept in the rod numerals, and so it would not have been difficult for them to adopt this concept in a written form. If they had made such an adoption during the switch to calculation with the abacus, there would have been a smooth transference of mathematical concepts from the rod medium to the written medium. However, such an adoption was only made when western mathematics entered China beginning with the arrival of Matteo Ricci in 1582. The consolation from this erroneous turn of events was that during the sixteenth and seventh centuries many Chinese were still knowledgeable in traditional mathematics, and they helped greatly to lighten what would have been a tremendous upheaval in the change to the new mathematics.

See Also

- ▶ Abacus
- ▶ al-Khwārizmī
- ▶ Computation: Chinese Counting Rods
- ▶ Jia Xian
- ▶ Jiuzhang Suanshu
- ▶ Li Zhi (Li Ye)
- ▶ Qin Jiushao
- ▶ Seki Kowa
- ▶ Wang Xiaotong
- ▶ Yang Hui
- ▶ Zhu Shijie 朱世傑

References

Hoe, J. (1977). *Les systèmes d'équations polynômes dans le Siyuan yujian (1303)*. Paris: Collège de France, Institut des Hautes Études Chinoises.

Lam Lay Yong. (1977). *A critical study of the Yang Hui Suan Fa. A thirteenth-century Chinese mathematical treatise*. Singapore, Singapore: Singapore University Press.

Lam Lay Yong. (1980). The Chinese connection between the Pascal triangle and the solution of numerical equations of any degree. *Historia Mathematica, 7*, 407–424.

Lam Lay Yong. (1982). Chinese polynomial equations in the thirteenth century. In L. Guohao et al. (Eds.), *Explorations in the history of science and technology in China* (pp. 231–272). Shanghai, China: Shanghai Chinese Classics Publishing House.

Lam Lay Yong. (1994). Jiu Zhang Suanshu (nine chapters on the mathematical art: An overview). *Archive for History of Exact Sciences, 47*(1), 1–51.

Lam Lay Yong, & Ang Tian Se. (1992). *Fleeting footsteps. Tracing the conception of arithmetic and algebra in ancient China*. Singapore, Singapore: World Scientific.

Libbrecht, U. (1973). *Chinese mathematics in the thirteenth century. The Shu-shu chiu-chang of Ch'in Chiu-shao*. Cambridge, MA: MIT Press.

Martzloff, J. C. (1988). *Histoire des Mathématiques Chinoises*. Paris: Masson.

Needham, J. (1959). *Science and civilisation in China* (Mathematics and the Sciences of the Heavens and the Earth, Vol. 3). Cambridge: Cambridge University Press.

Yan, & Shiran, L. D. (1987). *Chinese mathematics. A concise history* (J. N. Crossley & A. W. C. Lun, Trans.). Oxford, UK: Clarendon Press.

Algebra in India: *Bījagaṇita*

Takao Hayashi
Doshisha University, Kyoto City, Japan

Bījagaṇita, which literally means "mathematics (*gaṇita*) by means of seeds (*bīja*)," is the name of one of the two main fields of medieval Indian mathematics, the other being *pāṭīgaṇita* or "mathematics by means of algorithms." *Bījagaṇita* is so called because it employs algebraic equations (*samīkaraṇa*) which are compared to seeds (*bīja*) of plants since they have the potentiality to generate solutions to mathematical problems. *Bījagaṇita* deals with unknown numbers expressed by symbols. It is therefore also called *avyaktagaṇita* or "mathematics of invisible (or unknown) [numbers]." Algebraic analyses are also employed for generating algorithms for many types of mathematical problems, and the algorithms obtained are included in a book of *pāṭī*. *Bījagaṇita* therefore also means "mathematics as a seed [that generates *pāṭī* (algorithms)]."

Extant works in *bījagaṇita* include Chapter 18 (*kuṭṭaka* only) of Āryabhaṭa's *Mahāsiddhānta* (ca. AD 950 or 1500), Chapter 14 (*avyaktagaṇita*) of Śrīpati's *Siddhāntaśekhara* (ca. AD 1050), Bhāskara's *Bījagaṇita* (AD 1150), Nārāyaṇa's *Bījagaṇitāvataṃsa* (before AD 1356, incomplete), and Jñānarāja's *Bījādhyāya* (ca. AD 1500). Śrīdhara's work (ca. AD 750), from which Bhāskara quotes a verse for the solution of quadratic equations, is lost. Chapter 18 (*kuṭṭaka*) of Brahmagupta's *Brāhmasphuṭasiddhānta* (AD 628) has many topics in common with later works of *bījagaṇita*, but the arrangement of its contents is not so systematic as that of the later works, and an unusual stress is placed on *kuṭṭaka* as the title of the chapter suggests. *Kuṭṭaka* (lit. pulverizer) is a solution to the linear indeterminate equation: $y = (ax + c)/b$.

The symbols used for unknown numbers in *bījagaṇita* are the initial letters (syllables) of the word *yāvattāvat* (as much as) and of the color names such as *kālaka* (black), *nīlaka* (blue), *pīta* (yellow), etc. The use of the color names may be related to Āryabhaṭa's *gulikā* (see below). Powers of an unknown number are expressed by combination of the initials of the words *varga* (square), *ghana* (cube), and *ghāta* (product). A coefficient is placed next (right) to the symbol(s) to be affected by it, and the two sides of an equation are placed one below the other. A dot (or a small circle) is placed above negative numbers. Thus, for example, our equation, $5x^5 - 4x^4 + 3x^3 - 2x^2 + x = x^2 + 1$, would be expressed as:

yāvaghaghā 5 *yāvava* $\dot{4}$ *yāgha* 3 *yāva* $\dot{2}$ *yā* 1 *rū*0,

yāvaghaghā 0 *yāvava* 0 *yāgha* 0 *yāva* 1 *yā* 0 *rū*1,

where *rū* is an abbreviation of *rūpa* meaning an integer or an absolute term. The product of two (or more) different unknowns is indicated by the initial letter of the word *bhāvita* (produced): e.g., *yākābhā* 3 for $3xy$.

These tools for algebra had been fully developed by the twelfth century, when Bhāskara wrote a book entitled *Bījagaṇita* (AD 1150), the main topics of which are "four seeds" (*bījacatuṣṭaya*), namely, (1) *ekavarṇa-samīkaraṇa* or equations with one color (i.e., in one unknown), (2) *madhyamāharaṇa* or elimination of the middle term (solution of quadratic equations), (3) *anekavarṇasamīkaraṇa* or equations with more than one color, and (4) *bhāvitaka-samīkaraṇa* or equations with "the product" (i.e., of the type $ax + by + c = dxy$).

At least part of this algebraic notation was known to Brahmagupta. He uses the words *avyakta* (invisible) and *varṇa* (color) for denoting unknown numbers, when he gives his rules concerning the same four seeds as Bhāskara's, in Chapter 18 (*kuṭṭaka*) of his *Brāhmasphuṭasiddhānta*. The details of Brahmagupta's algebraic notation are, however, not known to us.

Bhāskara, a contemporary of Brahmagupta, did know the word *yāvattāva*, meaning an unknown number, but it is not certain if he used it in equations, because he expresses the equation, $7x + 7 = 2x + 12$, without the symbol *yā* as:

7	7
2	12

in his commentary (AD 629) on the *Āryabhaṭīiya*. In the same work, he refers to four seeds which are said to generate "mathematics of practical problems" (*vyavahāragaṇita*) having eightfold of names beginning with "mixture," but the kinds of seeds he mentioned by the names *yāvattāvat*, *vargāvarga* (square), *ghanāghana* (cube), and *viṣama* (odd) are not exactly known. Similar terms (*yāvattāvat*, *varga*, *ghana*, and *vargavarga*) occur in a list of ten mathematical topics given in a Jaina canon, *Sthānāṅga* (Sūtra 747), which is ascribed to the third century BCE.

Āryabhaṭa used the term *gulikā* (a bead) for an unknown number when he gave his rule for linear equations of the type $ax + b = cx + d$

in his *Āryabhaṭīya* (AD 499). All the equations to which he gave solutions (including *kuṭṭaka*) are linear, although his rules for the interest and for the period of an arithmetical progression presuppose the solution of quadratic equations.

Brahmagupta gave many theorems for *vargaprakṛti* (lit. square nature), i.e., the indeterminate equation of the second degree: $Px^2 + t = y^2$, but it was Jayadeva (the eleventh century or before) who gave a complete solution for the case $t = 1$ (the so-called Pell's equation).

Bījagaṇita reached its culmination in the twelfth century, when Bhāskara gave solutions to various types of equations of quadratic and higher degrees by means of *kuṭṭaka* and *vargaprakṛti*. They include: $(ax + b)^2 = cy^2 + d$; $(ax + b)^2 = cy^2 + dy + e$; $(ax + b)^2 = cy^4 + dy^2$; $(ax + b)^2 = cy^6 + dy^4$; $(ax + b)^2 = cy^2 + dz^2 + e$; $(ax + b)^2 = cy^2 + dyz + ez^2$; $x + y + a = r^2, x - y + a = u^2, x^2 + y^2 + b = v^2, x^2 - y^2 + c = w^2$ ($r, u, v,$ and w are not required); $ax + b = y^2$; $ax + b = y^3$; $(ax^n + c)/b = y$ ($n = 2$ or 3; x and y are integers). Bhāskara pointed out the infinity and invariability of the quantity called *kha-hara* ("zero-divisor"), that is, $a/0$ (a is an integer), and compared them to those of the god Viṣṇu. This assertion of the invariability was later criticized by Jñānarāja (ca. AD 1500), who claimed that the invariability of *kha-hara* does not hold true for the addition of fractions.

Kṛṣṇa (fl. ca. 1600) in his commentary on the *Bījagaṇita* gave detailed rationales (*upapatti*/*yukti*) of Bhāskara's rules. Kṛṣṇa also showed that the apparent change of *kha-hara* pointed out by Jñānarāja does not affect its infinity.

See Also

- Arithmetic in India: *Pāṭīgaṇita*
- Āryabhaṭa
- Bhāskara I
- Brahmagupta
- Jayadeva
- Nārāyaṇa Paṇḍita
- Śrīdhara
- Śrīpati

References

Bag, A. K. (1979). *Mathematics in ancient and medieval India*. Varanasi: Chaukhambha Orientalia.

Colebrooke, H. T. (1817). *Algebra with arithmetic and mensuration from the Sanscrit of Brahmegupta and Bháscara*. London: Murray. (Reprinted in Wiesbaden: Dr Martin Söndig oHG, 1973. Reprinted with a foreword by S. R. Sarma, Delhi: Sharada Publishing House, 2005).

Datta, B., & Singh, A. N. (1935/1938). *History of Hindu mathematics* (2 Vols.). Lahore: Motilal. (Reprinted in 1 Vol. Bombay: Asia Publishing House, 1962. Reprinted in 2 Vols. Delhi: Bharatiya Kala Prakashan, 2001).

Dutta, A. K. K. (2010). Bhāvanā and cakravāla. In C. S. Seshadri (Ed.), *Studies in the history of Indian mathematics* (pp. 145–199). New Delhi: Hindustan Book Agency.

Ganguli, S. (1931/1932). Indian contribution to the theory of indeterminate equations of the first degree. *Journal of the Indian Mathematical Society. Notes and Questions*, **19**, 110–120, 129–142, 153–168.

Hayashi, T., & Kusuba, T. (1998). Twenty-one algebraic normal forms of Citrabhānu. *Historia Mathematica, 25*, 1–21.

Hayashi, T. (2004). Two Benares manuscripts of Nārāyaṇa Paṇḍita's *Bījagaṇitāvataṃsa*. In C. Burnett et al. (Eds.), *Studies in the history of the exact sciences in honour of David Pingree* (pp. 386–496). Leiden: Brill.

Hayashi, T. (2009). Bījagaṇita of Bhāskara. *SCIAMVS, 10*, 3–301.

Hayashi, T. (2012). A Hitherto unknown commentary on the Bījagaṇitādhyāya of Jñānarāja. *Souvenir of the International Seminar on History of Mathematics at Ramjas College, University of Delhi, November 19–20, 2012*, pp. 51–53.

Hayashi, T. (Ed. & Trans.) (2012). *Kuṭṭākāraśiromaṇi of Devarāja*. New Delhi: Indian National Science Academy.

Jain, P. K. (Ed. & Trans.) (2001). *The Sūryaprakāśa of Sūryadāsa*. Vadodara: Oriental Institute.

Joseph, G. G. (2011). *The crest of the peacock: Non-European roots of mathematics* (3rd ed.). Princeton/Oxford: Princeton University Press, esp. Chapters 8–10.

Keller, A. (2006). *Expounding the mathematical seed: A translation of Bhāskara I on the mathematical chapter of the Āryabhaṭīya* (2 Vols.). Basel: Birkhäuser.

Lal, R. (1993). Integral solutions of the equation, $Nx^2 + 1 = y^2$ in ancient Indian mathematics (*Cakravāla* or the cyclic method). *Gaṇita Bhāratī, 15*, 41–54.

Patte, F. (2010). The resolution of Diophantine equations according to Bhāskara and a justification of the Cakravāla by Kṛṣṇadaivajña. *Gaṇita Bhāratī, 32*, 73–105.

Patte, F. (Ed. & Trans.) (2004). *Le Siddhāntaśiromaṇi* (2 Vols.). Genève: Droz.

Plofker, K. (2009). *Mathematics in India*. Princeton/Oxford: Princeton University Press.
Ramasubramanian, K., & Srinivas, M. D. (2010). Development of calculus in India. In C. S. Seshadri (Ed.), *Studies in the history of Indian mathematics* (pp. 201–286). New Delhi: Hindustan Book Agency.
Selenius, C.-O. (1975). Rationale of the Cakravāla process of Jayadeva and Bhāskara II. *Historia Mathematica, 2*, 167–184.
Sen, S. N. (1971). Mathematics. In D. M. Bose et al. (Eds.), *A concise history of science in India* (pp. 136–212). New Delhi: Indian National Science Academy.
Shukla, K. S., & Sarma, K. V. (Ed. & Trans.) (1976). *Āryabhaṭīya of Āryabhaṭa*. New Delhi: Indian National Science Academy.
Sinha, K. N. (1986). Algebra of Śrīpati: An eleventh century Indian mathematician. *Gaṇita Bhāratī, 8*, 27–34.
Srinivasiengar, C. N. (1967). *The history of ancient Indian mathematics*. Calcutta: The World Press.
Sundar Ram, S. (2012). *Bījapallava of Kṛṣṇadaivajña: Algebra in sixteenth century India – A critical study*. Chennai: The Kuppuswami Sastri Research Institute.
Varadarajan, V. S. (1998). *Algebra in ancient and modern times*. Providence, RI: American Mathematical Society.

Algebra in Islamic Mathematics

(*with the collaboration of* Osman Bakar and Kamel Arifin Mohd Atan)

Mat Rofa Bin Ismail

The word *algebra* is derived from the Arabic *al-jabr*, a term used by its founder, Muḥammad ibn Mūsā ▶ al-Khwārizmī, in the title of his book written in the ninth century, *al-Jabr wa'l-muqābalah* (The Science of Equations and Balancing). Algebra is also known as "the science of solving the unknowns in equations."

The simplest equation with one unknown is of the form $ax = b$, with a and b as constants x here is called *al-jadhr* of the equation. Al-Khwārizmī enumerated six standard second-degree equations in his *al-Jabr wa'l-muqābalah*:

$$ax^2 = bx, \qquad ax^2 = b, \qquad ax = b,$$
$$ax^2 + bx = c, \quad ax^2 + c = bx, \quad ax = bx + c.$$

Also, he provided solutions to these equations using algebraic and geometrical justifications.

The main aim of al-Khwārizmī's algebra was to provide the Muslim community with the necessary arithmetical knowledge essential in their daily calculation needs, such as in matters pertaining to heritage and legacy, transaction, sharing and partnership, loss and profit, irrigation and land-acreage, and geometrical problems. Al-Khwārizmī devoted about half of his *al-Jabr wa 'l-muqābalah* to such problems.

▶ Abū Kāmil Shujāʿ ibn Aslam of Egypt (AD 850–930) gave his treatise on algebra the name *al-Jabr wa 'l-muqābalah*, the same title as al-Khwārizmī's. This treatise gives commentaries on al-Khwārizmī's six standard quadratic equations using Euclid's lemmas in geometry to justify the existence of two roots for a general quadratic equation. In the twelfth century, Abū'l-Fath ʿUmar bin al-Khayyām listed 39 standard cubic equations in his *Risāla fi'l-barāhīn ʿalā masā'il al-jabr wa 'l muqābalah*, and solved them by intersecting suitable conic-sections (circle or semicircle, parabola, hyperbola, and ellipse) using Apollonius's theory of ▶ conics. The solutions to the equations were represented by intersections of the curves, but he failed to identify the exact numerical solutions. Many attempts had been made toward finding the geometrical solutions of cubic equations before ʿUmar al-Khayyām mentioned them in his book, such as those by ▶ al-Māhāni and Abu'l-Jūd.

Also in the twelfth century, Sharaf-al-Dīn al-Ṭūsī examined the cubic equation species classified by ʿUmar al-Khayyām and provided their solutions through a systematic study of the minimum and maximum values of their associated functions. He gave the number of real solutions of a cubic equation in terms of its coefficients.

In the third portion of his *Kitāb fi 'l-al-jabr wa'l-muqābalah*, Abū Kāmil discussed indeterminate problems (*mu ʿādalah siālah*) of the second degree. Some of these were of Greek origin and could be found in the *ṣinā ʿah al-jabr* by Diophantus, the translation of *Arithmetica* by ▶ Qusṭā ibn Lūqā. The problems were then cited by Leonardo Fibonacci in his book *Liber* *abaci*. Abū Kāmil concentrated on enumerating the possible solutions of simultaneous equations in his *ṭarā'if al-ḥisāb*. They were based on the problem of determining the number of birds that could be purchased with 100 dirhams. Somebody is to buy 100 fowls, given that, for example, a rooster costs five units, a hen 3, and chicks are sold three for one unit. Problems of this type gave rise to a system of equations of the form:

$$x + y + z + u + v = 100 \\ = ax + bx + cz + du + ev.$$

In the case of $a = 2$, $b = 1/2$, $c = 1/3$, $d = 1/4$, $e = 1$ Abū Kāmil gave 2,696 possible integer solutions. The analysis marks the birth of a field in algebra which is known today as linear algebra.

Extraction of square and cubic roots became an important subject of discussion in arithmetic and algebra books, or *ḥisāb al-Hindī* based on Indian Mathematics during the heyday of the Muslim mathematicians. The rule for the extraction of roots was then based on binomial expansion of the form $(a + b)^n$. Al-Ṭūsī listed the coefficients in the expansion of $(a + l)^n - a^n$ for some n, in his *Jawāmiʿ* and arranged them in a triangular form which he called *manāzil al-ʿadad*. This triangular arrangement came to be known in the West as Pascal's triangle, after Blaise Pascal, the famous French mathematician who published his *Traité du triangle arithmé tique* in 1665. Such an arrangement was also drawn up by ▶ al-Karajī in one of his books. This was further mentioned by Samuʿīl (or Samauʿal) ibn ʿAbbas, also called al-Maghribī (eleventh century), in his *al-Bāhir fī 'l-jabr*. ʿUmar al-Khayyām did write a book on the extraction of cubic and fourth roots, but the book is assumed to be lost. The extraction of the fifth root was carried out by al-Kāshī in the fifteenth century in his *Miftāḥ al-ḥisāb*. He gave a numerical example of extracting the fifth root of 44,240,899.506,197 (order of trillions).

In the expansion of an algebraic term raised to a certain power, the concept of the negative number is extremely important. Muslim mathematicians made a substantial contribution to the development of this concept. Abū'l-Wafā al-Būzjānī in his *Ma Yaḥtaj ilayh al-kuttāb wa 'l-ʿummāl min ʿilm al-ḥisāb* considered debts as negative numbers. For example, the calculation for $35 + (-20) = 15$ was written as 35 + *dain* 20 = 15 − (*dain* = debt). ▶ Abū Kāmil, as a commentator on the *al-Jabr wa 'l-muqabalah* of ▶ al-Khwārizmī, explained the application of positive and negative signs for the purpose of expanding the multiplication $(a \pm b)(c \pm d)$. This resulted in his rules:

$$(+)(+) = + = (-)(-), (+)(-) = (-)(+) = -.$$

These rules are embodied in his famous work *Kitāb al-jabr wa 'l-muqābalah*. Al-Karajī showed clearer examples illustrating operations with negative quantities in his al-Fakhrī. These rules are implicitly used throughout the book:

$$a - (-b) = a + b, \qquad (-a) + b = -(a - b), \\ (-a) - (-b) = -(a - b), (-a) - b = -(a + b).$$

Samuīl and Ibn al-Bannāʾ al-Marrākushi then made some finer rules about calculations involving negative numbers in their works, *al-Bāhir fī 'l-jabr* and *Kitāb al-jabr wa 'l-muqābalah*, respectively.

The art of proving became an important part of mathematical science. The direct and proof by contradiction methods are two important tools in proving mathematical statements. In some cases, however, they fail to work, especially in proving formulae containing integral terms. In this case, the method of *istiqrāʾ*, or proof by induction, is an appropriate one to use. Al-Karajī wrote an article by that name to explain this method. Samuīl and Ibn al-Haytham used it to prove some formulae on infinite series. A good example of the employment of proof by contradiction was given by ▶ Abū Jaʿfar al-Khāzin to establish some properties of right-angled triangles. These can be found in the treatise *Risālah fī 'l-muthallathāt al-qāʿimat al-zawāyā* or in the *Tadhkirat al-aḥbāb fī bayān al-tuḥābb* of Kamāl al-Dīn al-Fārisī. The contradiction method based on the logical property "if (statement a is true) then it implies (statement b is true)" is equivalent to "if (statement b is not true) then (statement a is not true).” The converse, however, is not always true. This type of reasoning is characteristic of discussions in *manṭiq* or logic.

To explain the method of *istiqrāʾ*, Samuʿīl proved the case $n = k$ through the assumption that the case $n = k - 1$ is true. For example, to prove $a^3\, b^3 = (ab)^3$, Samuʿīl started with the assumption of $a^2\, b^2 = (ab)^2$ (which had been proved before), then multiplied both sides by (ab) to obtain $(ab)(a^2\, b^2) = (ab)(ab)^2 = (ab)^3$. Using the proposition mentioned earlier, i.e., $(ab)(cd) = (ac)(bd)$, he obtained $(ab)(a^2\, b^2) = a^3\, b^3$. Although in this demonstration, Samuʿīl used particular numbers instead of a general k, he successfully showed the method of *istiqrāʾ* correctly as we understand it today. Some writers, however, continue to attribute the method to Pascal or Bernoulli in the seventeenth century (Yadegari, 1978).

The inherent idea in the use of logarithm is to expedite the multiplication process by converting it into an addition one. This is done by employing the rules of exponent. Abū’l-ḥasan al-Nasawī wrote a book on the idea in Persian which was later translated into Arabic with the title *al-Muqniʿ fī ʻl-ḥisāb al-Hindi*. Ibn Yūnus (eleventh century), a well-known Egyptian astronomer, discovered the role of the trigonometric relation

$$\cos(a)\cos(b) = \frac{1}{2}[\cos(a+b) + \cos(a-b)]$$

in transforming the process of multiplication into addition. For example, suppose one wishes to obtain the product of 35.84 and 54.46. Since cos (69°) = 0.3584 and cos(57°) = 0.5446, then (35.84)(54.46) = 1951.5 by using this identity. This formula had been proven earlier by Abū’l-Wafā al-Būzjānī (d. 998) in his commentary on the *al-Majesṭi* (*Almagest*) of Ptolemy.

The expression of a fraction in the decimal form, based on an extant manuscript, goes back to *Kitāb al-fuṣūl fī al-ḥisāb al-Hindī* of Abu’l-ḥasan Aḥmad ▶ al-Uqlīdisī. It was written in the year 341H (AD 952). Uqlīdisī operated on the number 19 by consecutive halvings. First, he obtained (using his symbol) 9′5 then 4′75, 2′375, 1′11875, and finally 0′59375 (some commas indicating separations of hierarchy were dropped in the manuscript). Subsequently, Samuʿīl al-Maghribī gave a clearer idea of the notion of decimal fractions in his *al-Qiwāmi fi ʻl-ḥisāb al-Hindī*. This book was written in the year AD 1172. The quotient of 210 by 13 was expressed as follows:

The square root of 10 is expressed as 3.16227, a clear definition of a decimal fraction, as the number 16,227 is considered part of 1,000,000, with 3 as a whole number. More precisely, 3.16227 means:

Integer	Parts of 10	Parts of 100	Parts of 1,000	Parts of 10,000	Parts of 100,000
16	1	5	3	8	4

$$3 + \frac{1}{10} + \frac{6}{100} + \frac{2}{1,000} + \frac{7}{100,000}.$$

Jamshīd al-Kāshī (fourteenth century) expressed the decimal fraction in both al-Khwārizmī’s and the astronomers’ system in the article “*al-Risāla al-muḥīṭīyyah*.” He gave the value of 2π as 6.2831853071795865 (in al-Khwārizmī’s decimal system) or as 6-6, 16, 59, 28, 1, 34, 51, 46, 15, 50 (in the astronomers’ sexagesimal system).

The method of writing numbers as decimal fractions later appeared in the West in Stevin’s *de Theinde* or its French version, *La Disma*, in 1585. To indicate the integral and fractional portions of the number, Stevin employed a stroke to separate the two. He is considered the founder of the decimal fraction by some writers in the West.

Nicomachus in his *al-Madkhal ilā ʿilm al-ʿadad* (an Arabic translation of *Introduction*) gave the four first perfect numbers: 6, 28, 469, and 8,128. Ismail al-Māridīnī (twelfth century) added some others to the list of perfect numbers: 6, 28, 496, 8128, 1130816, (2096128), 33550336, 8589869056, 137438691328, (35184367894528). Actually, the two numbers in brackets are not perfect. This mistake is due to the difficulty in determining the primality of a number.

One can observe from al-Māridīnī’s list that it is hard to find an odd perfect number.

The numbers seem to be even, and the first digit (remember that Arabs write from the right) of a perfect number obtained by the formula is always 6 or 8. Indeed, the perfect numbers described by the formula $(2^{n-1} - 1)2^n$ are always even, since they are the product of even and odd numbers. However, many think that odd perfect numbers do exist. Euler, centuries later (1849), in his paper in *Tractus de numererum doctrina*, described a necessary condition for the existence of an odd perfect number, but it was not a sufficient condition.

Other types of numbers that became the subject of scrutiny of Muslim mathematicians are the deficient and abundant numbers. The mathematicians supplied some criteria to identify these numbers:

- Every odd number less that 945 is deficient.
- Every even-times-even number has factors less than itself.
- The first abundant number is 12, and the first odd one in this class is 945.
- If $2^n\ S$ is a perfect number, then $2^{n+1}\ S$ is an abundant number, and $2^{n-1}\ S$ is a deficient number.

Kamāl al-Dīn al-Fārisī (d. 1320) in his treatise, *Tadhkirah al-aḥbāb fi bayān al-tuḥābb* supplied the rule to find pairs of amicable numbers (*al-a'dād al-mutaḥābbah*) in a systematic way. Thābit ibn Qurra (836–901) developed the theory of amicable numbers and provided a technique to find such pairs in his *Risālah fi'l-a'dād al-mutaḥābah*. Al-Fārisī reached the same conclusions through somewhat different paths. He based his new technique on the systematic knowledge of the divisors of a composite number and their sum. A pair of amicable numbers is defined as a pair of numbers (a, b) with the properties that the sum of all possible proper divisors of a is equal to b and the sum of all possible proper divisors of b is equal to a.

Ibn ṭāhir al-Baghdādī defined a new variety of numbers known as equivalent numbers or numbers of equal weight (*muta'adilan*) in his *al-Takmila fi'l-ḥisāb*. According to him:

> If we have a given number and wish to find two numbers, the parts of which make up this number, we reduce it by one and split the result into two prime numbers, then two others, and so on, as many times as we can. The product of each pair is a number equivalent to the given number. Thus if we are given 57, we split 56 into (3.53), (13,43), etc. The products of 53 by 3 and 4 by 13 are numbers such that the sum of the parts of each is 57. (Saidan, 1977)

Equivalent numbers had not been studied by al-Baghdādī's contemporaries, nor by mathematicians for a few generations after him, until the time of Muḥammad Bāqir al-Yazdī (seventeenth century). Al-Yazdī, in his *ʿUyūn al-ḥisāb*, considered such numbers and chose evenly even numbers to be decomposed as al-Baghdādī had done. In this way it was convenient for him to establish some properties of equivalent numbers, such as: if p and q are prime numbers, then p and q are of equal weight. It was felt that numbers of this kind needed more attention and to be examined further as they exhibited interesting unique behaviors.

The problem of finding the sides (x, y, z) of a right-angle triangle was studied and addressed by many Muslim mathematicians, including Samuʾīl (twelfth century) and ▶ Abū Jaʿfar al-Khāzin (tenth century). ▶ Al-Khwārizmī considered some basic problems related to a right-angled triangle. These problems became the source of his algebraic problems in his *Kitāb a-jabr wa 'l-muqābala*. Samuʾīl in his *al-Bāhir fi 'l-ḥisāb* showed that any triple of the form

$$\left(a, \frac{(a^2 - b^2)}{2b}, \frac{(a^2 + b^2)}{2b}\right)$$

with a, b, c being appropriate positive integers, would describe right-angled triangles. Earlier, al-Khāzin had considered such problems in his *Risālah fī al-muthallathāt alqā 'imat al-zawāyā al-munṭaqat al-aḍlāʿ*. He showed that it was not possible that any triple (x, y, z), with x and y being odd (or evenly even) could be the sides of a right-angled triangle with z as an integer. Al-Khāzin then used the results to study the problems of the form $x^m + y^n = z^p$ with m, n, and p some small positive integers. He left out some cases, however, such as $m = n = p$ 3 or 4, for such problems have no solutions. Problems of these types were examined centuries later by de Fermat (1736).

The problem of splitting a cube into three other cubes, i.e., to find the solution of the equation with three unknowns, $x^3 + y^3 + z^3 = n^3$, was discussed by Ibn ṭāhir al-Baghdādī (tenth century) in *Takmila fi ʻl-ḥisāb*. He gave the answer as

$$(x, y, z) = \left(\frac{n}{2}, \frac{2n}{3}, \frac{5n}{6}\right).$$

This problem then reappeared in the works of Barbareta (1910).

See Also

- ▶ Abū Kāmil
- ▶ Abū'l-Wafāʾ
- ▶ al-Karajī
- ▶ Al-Kāshī
- ▶ al-Khwārizmī
- ▶ al-Uqlīdisī
- ▶ Ibn al-Bannāʾ
- ▶ Ibn Yūnus
- ▶ Qusṭā ibn Lūqā
- ▶ Samūʿīl ibn ʿAbbās (Al-Maghribī)
- ▶ Sharaf al-Dīn al-Ṭūsī
- ▶ Thābit ibn Qurra
- ▶ Umar al-Khayyām

References

ʿAbd al-Raḥman, ḥikmat Najīb. (1977). *Dirāsāt fī tārīkh al-ʿulūm ʿinda al-ʿArab. al-Mawṣil*: Wizārat al-Taʿlīm al-ʿĀlī wa-al Baḥth al ʿIlmī, Jāmiʿat al-Mawṣil, 140.

Al-Daffa, A. A., & Stroyls, J. (1984a). *Studies in the exact sciences in medieval Islam*. New York: Wiley.

Al-Daffa, A. A. & Stroyls J. (1984b). Some myths about logarithms in near eastern mathematics. In *Studies in the exact sciences in medieval Islam* (p. 27). New York: Wiley.

Anbouba, A. (1978). L'Algébra arabe aux IX et X siècles, Aperçu general. *Journal of History of Arabic Science, 2*, 66–100.

Berggren, J. L. (1986). *Episodes in the mathematics of medieval Islam*. New York: Springer.

Fraenkel, A. A. (1943). Problems and methods in modern mathematics. *Scripta Mathematica, 9*, 162–168.

Hughes, B. (1996). Arabic algebra: Victim of religious and intellectual animus. In M. Folkerts (Ed.), *Mathematische Probleme im Mittelalter: Der lateinische und arabische Sprachbereich* (pp. 197–220). Wiesbaden, Germany: Harrassowitz.

Kasir, D. S. (1931). *The algebra of ʿUmar al-Khayyām*. Ph.D. Thesis, Columbia University.

McCarthy, P. (1957). Odd perfect numbers. *Historia Mathematica, 23*, 43–47.

Naini, A. D. (1983). A new type of numbers in a 17th century manuscript: Al-Yazdi on numbers of equal weight. *Journal of History of Arabic Science, 7*, 125–139.

Nasr, S. H. (1968). *Science and civilization in Islam*. Cambridge, MA: Harvard University Press.

Picutti, E. (1989). Pour l'histoire des sept premiers nombres parfaits. *Historia Mathematica, 16*, 123–136.

Rashed, R. (1977). Tārīkh al-jabr wa ikhtirāʾal-kusūr al-ʿusyuriyyah (The history of algebra and the discovery of decimal fractions). In *Proceedings of the first international symposium for the history of Arabic science* (pp. 169–86). Aleppo, Syria: Institute for the History of Arabic Science.

Rashed, R. (1985). *Oeuvres mathématiques*. Paris: Les belles lettres.

Saidan, A. S. (1973–1984). *Tārikh ʿilm al-ḥisāb al-ʿArabi*. Amman, Jordan: al-Lajnah al-Urdunīyah lil-Taʿrīb wa-al Nashr wa-al Tarjamah.

Saidan, A. S. (1977). Number theory and series summation in two Arabic texts. In *Proceedings of the first symposium for the history of Arabic science* (p. 152, Vol. 2). Aleppo, Syria: University of Aleppo.

Shawki, J. & al-Daffa, A. A. (1985–1986). *Al-ʿUlūm al-riādiyyāt fi'l-ḥaḍārah al-Islāmiyyah*. New York: Wiley.

Yadegari, M. (1978). The use of mathematical induction by Abū Kāmil Shujāʿ ibn Aslam (850–930). *Isis, 69*, 259–262.

Youschkevitch, A. A. P. (1964). *Geschichte der mathematik im mittelalter*. Leipzig, Germany: Teubner.

Algebra in the Malay World: A Case Study of Islamic Mathematics

Mat Rofa Bin Ismail and Kamel Ariffin Mohd Atan

The Malay World comprises countries which are now known as Malaysia, Indonesia, Brunei, Singapore, Thailand, Philippines, and Kampuchea.

This part of the world is also known as *Nusantara* or *Pascabima*. Ptolemy, the Egyptian geographer, visited the Malay world in the second century AD and called it "Golden Chersonese" (*Semenanjung Emas* in Malay – a beautiful golden peninsula) for its beauty and greenness. Indian travelers once referred to it as *Sunarvabumi*, which can be translated in the same way. The significance of this area in ancient history as a meeting place for sea travelers between ► east and west is due to its strategic location between India and China.

The region went through its own history under many religious influences such as Hinduism, Buddhism, and Islam. It is recorded that Islam came to this region in the very early period of the Umayyad caliphate when a Srivijayan king embraced Islam during the reign of Caliph Umar ibn al-Aziz (AD 717–720). Since then, Islam gradually became an important religion in the region. Religious matters, such as compulsory charity (*zakat*), inheritance problems (*farāʼiḍ*), and crescent sighting to mark a new month in the lunar calendar needed knowledge of systematic mathematical calculation. For these purposes, the works of ► al-Khwārizmī, Ibn al-Bannāʼ, al-Turtūsī, Ibn al-Hāʼim, Ulugh Beg and ► Ibn al-Yāsamīn in algebra, mathematics and astronomy were frequently cited by the Malay scholars.

Text books in algebra and arithmetic, such as *Khulasah al-ḥisab* (A Concise Treatise on Mathematics) by al-ʻAmili, *Talqīḥ al-afkār* (Combining Ideas) and *al-Urjūyah al-Yāsaminiyyah* (The Poem of al-Yasamin) by Ibn al-Yāsamin, *Tuḥfah al-aʼdād li dhawī al-rushd wa al-rashād* (A Special Arithmetic for the Wise and the Rightly Guided) by Ibn Hamzah al-Maghribi, *Kashf al-asrār* (Unveiling of Secrets) by al-Qalsaldi, *Talkhīṣ al-ḥisab* (Purification of Mathematics/Understanding Mathematics?) by Ibn al-Bannāʼ al-Marrakushi, and *Murshid al-ṭālib ila asna al-mutalib* (Student's Guide to Excellence in the Pursuit of Knowledge) by Ibn al-Haʼim, were among frequent quoted references by Malay writers (see Zain, 2001).

The beginning of the history of Islamic mathematics can be traced to the late eighth century. Among the earliest Muslim mathematicians was al-Khwārizmī (780–850 AD) who introduced a new system of numbering which greatly simplified the Roman one which had been widely used previously. The decimal system (*aʼshariyyah*) provided simplification in carrying out basic arithmetical operations. In the Islamic tradition of knowledge, religious scholars who were experts in the field of theology were also conversant with and masters of other areas of knowledge. These included astronomy, medicine, the arts, logic, and rhetoric. Among those who fall into this category are ► al-Kindī (born 796 AD), ► al-Battānī (858–929), Ibn al-Haytham (965–1038), ► al-Bīrūnī (973–1048), and Ibn Sīnā (eleventh century). By the fourteenth century Islamic civilization was already very rich in its mathematical knowledge. Scholars moved to other fields besides basic mathematics.

The treatise by Ibn al Bannāʼ, entitled *Rafʻu al-ḥijāb ʻan Aʼmāl al-ḥisāb* (Unveil the Cover in the Arts of Mathematics) or *Khulasah al-ḥisab* by al-ʻĀmili, discussed the subject of basic arithmetic and algebra. For example, the discussion of permutations and combinations in the book of Ibn al-Bannāʼ (fourteenth century) marks the first advance made by Islamic mathematics since the time of al-Khwārizmī. Islamic scholars continued to be active and productive in the field of mathematics until the seventeenth century, when their involvement waned due to backlash in the political arena during that period and subsequent to it. Until that time many outstanding treatises were produced and became references not only by contemporaneous scholars, but also by mathematicians in the subsequent centuries. They played an outstanding role in shaping and providing directions for the future development of mathematics in the world. Muslim works were brought into Europe by early scholars by translating Arabic treatises into Latin. Leonardo Fibonacci was among the pioneers in this pursuit. Centers of learning set up in places such as Cordova, Toledo, and other places in Spain became the focal point of convergence for western scholars to study Islamic mathematics.

Islamic mathematics came into the Malay world through the efforts of Malay religious scholars who had gone to the Middle East to study Islamic theology. They mastered the mathematics of the day in its original form and in an integrated manner with branches of theology. Whatever was learnt in the Middle East was brought back and disseminated to students in traditional schools. Among the works collected and brought back were books on a variety of branches of mathematics which had been their references during their study, especially in Mecca, Medina, and the University of Al-Azhar. Some of the scholars became writers and produced mathematical works based on their learning experience. Many of the written works were in the form of leaflets, short notes, and letters, written in Malay using the Arabic script. These works came down to us through the descendants of these scholars. Though only a few manuscripts survived, they give us a glimpse of the serious efforts and quality of work of the early Malay scholars in mathematics.

The documentation of Islamic mathematics in the Malay World has to date not been completed. The earliest known record of a treatise in logic by a Malay writer, entitled *'Ilm al-Manṭiq* (The Art of Logic), is dated 1593. However our search for such treatises in mathematics written in the region mainly concentrated on surviving documents that are dated later than the eighteenth century.

The records tell us about the existence of a number of Malay mathematicians for the period between the nineteenth and mid-twentieth century. They were mathematicians who were also scholars in religious studies. Our early survey (Ismail, 1995) showed that they originated mainly from Fatani/Patani (in southern Thailand), Sumatera Indonesia, and Kelantan Malaysia. Some were also of Riau and Kampuchean origin. They were highly respected by the Malay community then and now because of their knowledge in religion as well as in other scholarly areas. Syeikh Daud al-Fatani (b. 1720 AD), for example, was regarded as one of the great Malay scholars during that period. So were Syeikh Abdul Kadir al-Fatani (b. 1817 AD), Syeikh Muhammad Nur al-Fatani (b. 1873), Faqih Wan Musa al-Fatani (second half of nineteenth century), and Syeikh Wan Ahmad Mohamad Zain al-Fatani (1856–1908). Another Malay scholar was Ahmad bin Abdul Latif al-Khatib al-Minangkabawi from Sumatra, Indonesia. He is regarded as the greatest Malay mathematician of the nineteenth century. Syeikh Tahir Jalaluddin (1867–1957), also of Sumatran origin, who later settled down in peninsular Malaysia, was regarded as a fine Malay astronomer towards the end of the nineteenth century. So was 'Umar Nuruddin al-Kelantani.

Mathematical works by Ahmad bin Abdul Latif al-Khatib al-Minangkabawi entitled *'Alam al-ḥussāb* (The Banner for Mathematicians) (1892) and *Rauḍat al-ḥussāb* (The Garden for Mathematicians) (1890) became the models for others to follow in the Malay world then. *'Alam al-ḥussāb* was a Malay version of the Arabic *Rauḍat al-ḥussāb*. Al-Khatib was the first Malay *imam* (prayer leader), *khatib* (Friday prayer's speaker) and religious teacher in Masjid al-Haram Mecca, appointed by The Holy Land's authority. Many of his students came from the Malay region. In these two books were mathematical topics of the period found in the Muslim world, which included number theory, algebra, geometry, trigonometry, approximation theory, and discussions on daily problems especially those arising from Islamic practices (*fiqh*) and the like. The contents of these works reflected the discussions and debates that took place in the period that began in ninth century and ended in the seventeenth, especially on the works of Muhammad bin Musa ► al-Khwārizmī produced during the late eighth and early ninth centuries. Also included were those by Abu Kamil Shuja' al-Aslam (tenth century), Abu Bakar al-Karaji (eleventh century), Ibn Yasamin (twelfth century), Ibn al-Bannā' (fourteenth century), Ibn Hamzah al-Maghribi (sixteenth century), and Baha'uddin al-'Amili (seventeenth century).

Umar Nurudin's work on the distribution of properties left behind by deceased members of the family was entitled *Pelajaran Membahagi Pesaka* (Lessons in Distribution of Inheritance) (early nineteenth century). His other works include *Syams al-Fathiyyah fi A'amāl al Juyūb* (The Guiding Light to Success in the Art of

Trigonometry) or *al-Jaibiyyah* (The Art of the (Trigonometrical) Sine) (1925), *Rubu' al-Mujayyab* (The Quadrant of the (Astronomical) Sine) (date unknown), and *Miftāḥ al-Ta'alīm* (The Key to Teaching and Learning) (1924). In the early twentieth century a scholar by the name of Muhamad Nur al-Ibrahimi, from Sumatra Indonesia, wrote a treatise on logic called *'Ilm Mantiq* (The Art of Logic) (1931). Sheikh Muhammad Nur Ibrahim of Kelantan wrote a book *Bantuan Ketika Bagi Orang yang Membahagi Pusaka* (A People's Guide to Inheritance Problems) (1936). Earlier, in 1932 he published a book entitled *Pilihan Mastika pada Menerangkan Qiblat dan Ketika* (Selected Gems in the Calculation of the Qibla Direction and (Prayer) Times), on the exact Qibla location in Mecca. Syeikh Tahir Jalaluddin, of Sumatran origin, wrote a book on the mathematical method of determining Muslim prayer times, entitled *Pati Kiraan pada Menentukan Waktu yang Lima dengan Logaritma* (The Essence of Calculations Related to the Five Prayer Times Using Logarithms) in 1938. He also authored two other books on astronomy and wealth distribution. His book on astronomy, *Risā'il fi'l-Falak* (Treatises on Astronomy), contained an article by Abdul Rahman Kelantan bin Muhamad al-Battul which was dated 1826. In our view, this may be the oldest extant treatise on astronomy ever found in the Malay language.

An arithmetic text written by Abd Qadir ibn 'Ali al-Sakhawi, known as *Matn al-Sakhawiyyah* (The Shortened Version of Sakhawi), was rewritten by Sheikh Wan Ahmad bin Muhammad Zain of Patani with some significant commentaries and footnotes towards the end of the nineteenth century. This book was a standard text in arithmetic and algebra among new students in Islamic schools. The commentator mentioned the book by Ibn al-Ha'im as one of the references in his commentary.

The philosophy of learning mathematics in the Malay Islamic world is closely linked to the concept of the relationship between Allah, The Supreme Being and man, his servant. A Muslim is always conscious of this relationship and of the fact that whatever he has at his disposal must be directed to the expression of his enslavement to Allah. Hence in the pursuit of knowledge he is always aware of his role and the roles of knowledge in glorifying the Supreme Being and the confines of his activities in this pursuit. Islam places high priority on the importance of learning. It is a religion whose understanding relies greatly on the grasp and the depth of one's knowledge of the physical and nonphysical world. Hence the learning of mathematics became necessary in a Muslim's life, as this subject is a tool in enhancing one's understanding of the world. If one is aware that the world is a creation of Allah, one's understanding of the greatness and infinite wisdom of Allah will be further heightened by grasping the mathematics principles that describe Allah's creations. Also the knowledge he has mastered will make him better able to contribute to the development of his society, which is also consonant with the teachings of the religion. Hence the positions of scholars and intellectuals rank high in an Islamic environment.

Among the daily activities in a Muslim society is the conducting of business transactions. Bartering, weighing, and using other means were characteristic activities in Muslim markets. All of these are closely connected to the ability to compute based on agreed principles. In his book *'Alam al-ḥussāb*, al-Khatib gave examples of the units of measures which were in use during that time. These include *sen*, *ringgit*, and *rupiah* as currency units, *pikul*, *kati*, *saga*, *kundi*, and *bungkal* as weights measures, *hasta* and *depa* for length units and *cupak*, and *gantang* for volume. Further discussions on the topic of measures according to al-Khatib can be found in his book in Arabic entitled *Sulh al-Jama'atain* (Conciliation of the Two Parties). Quizzes were also included in al-Khatib's books. They ranged from topics on multiplication and division to determinations of square roots based on real life problems. Among the topics covered in this book are *permulaan ḥisāb* (elementary arithmetic), *haqiqah bilangan* (on counting principles), *hitungan sahih* (on the integers), *kumpulan* (addition), *kurangan* (subtraction), *pukulan* (multiplication), *jenis-jenis pukulan* (types of multiplication), *bahagian* (division), *nisbah a-*

muttaṣilah ḥisābiyah (arithmetic progression), *al-muttaṣilah handasiyah* (geometric progression), *kaifiat mengetahui yang majhul* (systems of equations), *tabādul* (permutations), *kaifiat bilangan kali-kali mungkin* (combinations), *amal dua yang tersalah* (approximations method; golden rule), *al-jabr wa al-muqabbalah* or *amal dengan bertemper dan berkebetulan* (the term in Malay for the *algebra* of ▶ al-Khwārizmī and solutions to quadratic equations), *misāḥah* (plane geometry), and *al-mizan* (modular congruence). Most of the topics covered by this book are taught in modern day Malaysia. An interesting feature of this book, which was also admitted by the author, was the striking similarity between its content and that of the book *Khulāṣah al-ḥisāb* written by al-ʻAmili (seventeenth century) which was one of the many links in the chain of Islamic mathematical tradition which had begun from the time of al-Khwārizmī. Al-Khatib's approach in the teaching of mathematics was almost exclusively influenced by the traditional methods of teaching from the scholars of the early Muslim period which clung to the descriptive way of solving problems. Although symbolism was already introduced in the Islamic world as early as at the time of al-Khwārizmī and further popularized by Abu Kamil, al-Maghribi and later by al-Qalsaldi in Spain (fifteenth century) Malay Muslim mathematicians were not responsive to the idea of adopting the symbolism approach (Ismail, 2004). Descriptive representation of mathematical problems is the special feature of the curriculum in mathematics education outlined above, as demonstrated by the content of the book *ʻAlam al-ḥussāb fi ʻIlm al-nisāb* by al-Khatib, a representative of works written in the Malay language in the nineteenth century.

The motivating factors in the teaching of mathematics in the Islamic system of education in the Malay archipelago are tied to the need to comprehend the basic teachings of the religion and efficient implementation of the administrative procedures as outlined by regulations stipulated by Islamic jurisprudence (*fiqh*) that governs everyday activities in the life of a Muslim. This was the dominant factor in the determination of mathematics education in the Islamic school curriculum prior to the introduction of the secular school system brought by the British in the late nineteenth century.

References

Al-ʻAmili, Bahauddin. (1890) *Khulāṣah al-ḥisāb*. Kaherah, Egypt: Bāb al-Halabi.

Al-Khatib, Ahmad bin Abdul Latif. (1890). *Rauḍah al-ḥussāb*. Kaherah, Egypt: Bab al-Halabi.

Al-Khatib, Ahmad bin Abdul Latif. (1892). *Alam al-ḥussāb*. Maimuniyyah Mecca.

Ismail, M. R. (1995). *Aritmetik dan aljabar Islam*. Serdang, Malaysia: Universiti Pertanian Malaysia Press.

Ismail, M. R. (2004). *Matematik merentasi tamadun*. Kuala Lumpur, Malaysia: Dewan Bahasa Pustaka, Kuala Lumpur.

Zain, S. M. (2001). *Matemadesa*. Bangi, Malaysia: Malaysian mathematical sciences society.

Zain, Sheikh Ahmad Muhamad. *Hashiah ala Matn al-Shawawiyyah*. Private Manuscript.

Algebra, Surveyors'

Jens Høyrup

Around 1930, a mathematical technique very close to later second-degree algebra was discovered in Babylonian cuneiform tablets, most of them dating from the early second and a few from the late first millennium B.C.E. (the "Old Babylonian" and "Seleucid" periods, respectively). Although the texts did not say so in any way, it was supposed that the technique was purely arithmetical, and that its "lengths," "widths," and "areas" were metaphors designating numerical unknowns and their products. The geometry of Euclid's *Elements* II was then believed to represent a Greek geometrical reinterpretation of the arithmetical results of the Babylonians, necessitated by the discovery of irrationality.

A more sophisticated analysis of the Old Babylonian texts shows that the arithmetical interpretation does not hold water. For instance, the texts distinguish sharply between two different concepts that had been understood as one and the same "addition"; two different "subtractions"; two different "halves"; and no less than four different "multiplications." Instead, a nonmetaphorical interpretation as "naïve cut-and-paste geometry" imposes itself. A problem where the sum of the area and the side of a square is said to be 3/4 is solved as in the illustration given later: The square itself represents the area. From one of its sides a "projection" 1 is drawn, which together with the unknown side contains a rectangle with an area equal to the side – the total area of the square itself and this rectangle is thus 3/4. This projection is bisected, and the outer half is moved so that the two halves together contain a square of area equal to

$$\frac{1}{2}, \frac{1}{2} = \frac{1}{4}.$$

This small square completes the gnomon into which the original area 3/4 is transformed as a larger square of area

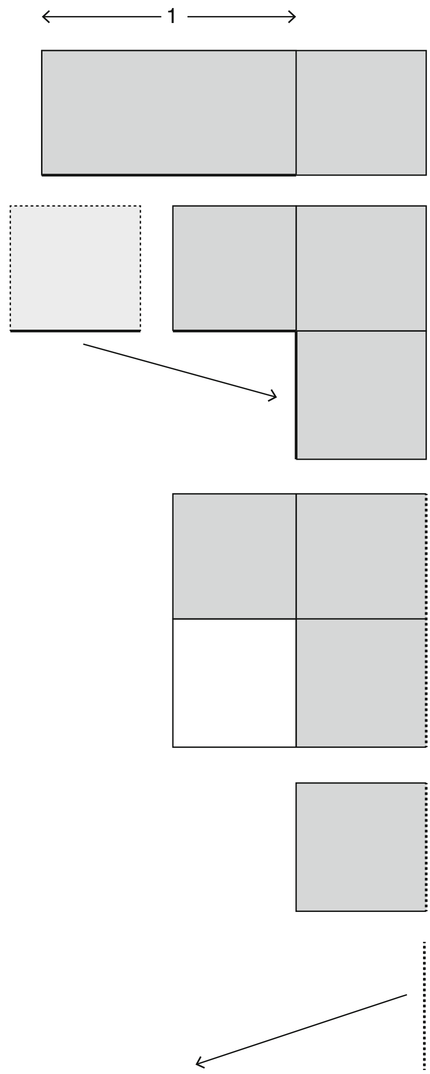
$$\frac{3}{4} + \frac{1}{4} = 1.$$

The side of this completed square will then be $\sqrt{1} = 1$ "Tearing out" that rectangular length 1/2, which was moved around leaves

$$1 - \frac{1}{2} = \frac{1}{2}$$

for the side.

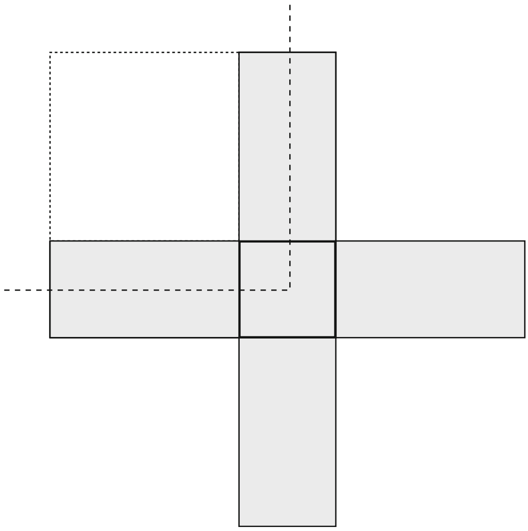
With this technique, the Babylonian scribe school teachers solved problems of much higher complexity than the present one – in non-normalized problems (e.g., if 2/3 of the area plus 1/3 of the side equals 1/3) a change of scale is introduced, but apart from that everything goes by cutting and pasting – the approach is always "naïve" (as opposed to "critical") in the sense that everything can be *seen* immediately to be true. No explicit argument proves that, for example, the two halves of the bisected rectangle really contain a square when arranged as in Fig. 1.



Algebra, Surveyors', Fig. 1 The sum of the area and the side of a square equals 3/4

A few texts, apart from using the terms for "lengths," "widths," and "areas" of fields, hint in other ways at surveying practice. An important example is this problem: "Concerning a field: I have added the four fronts (sides) and the field (the area)." The formulation is unique in mentioning the sides before the area, and so is the solution, which refers to a configuration where a rectangle with length 1 is glued to each side of the field (Fig. 2).

Certain treatises from the Islamic Middle Ages reveal a close connection to this



Algebra, Surveyors', Fig. 2 The four fronts and the area. The *dotted lines* show the solution: one-fourth of the total area is taken and completed as a *square*

cut-and-paste tradition. The best known is al-Khwārizmī's *Algebra* (*Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa'l muqābalah* – The Book of Summary Concerning Calculating, restoration, and Equation) from the early ninth century A.D. The algebraic technique itself is arithmetical and at most obliquely if at all connected to the Babylonian tradition. However, in order to prove the correctness of his algorithms – first the one for "square and ten roots equal 39" – ► al-Khwārizmī makes use precisely of the diagrams of the figures shown, the second with completion in all four corners instead of quadrisection.

Less widely discussed is a *Book on* Mensuration, written by an otherwise unidentified Abū Bakr. The text is known from a meticulous Latin translation made in the twelfth century by Gerard of Cremona, and contains in its first half a large number of problems similar to those known from the Babylonian texts, both in mathematical substance and method and in the very characteristic grammatical format. However, the differences that are also present and systematic reveal that the Babylonian scribe school "algebra" is not the source. Instead, both the scribe school and Abū Bakr appear to have drawn on a surveyors' tradition, which had been present at least in Central Iraq, and probably in a wider region, from the early second millennium B.C.E. onward.

This tradition nurtured and transmitted a stock of recreational problems with appurtenant techniques for their solution. Those that can be determined with some certainty were of the same quasialgebraic nature as the Babylonian problems cited earlier.

If we designate by Q a square area and by s its side, by A a rectangular area and by l, w, and d its sides and the diagonal, we may be fairly sure (from what is common to the scribe school and Abū Bakr together with other medieval sources) that the following problems were present (Greek letters stand for given numbers, which cannot be safely determined because the Babylonian and the Medieval tradition give different values – question marks indicate doubtful presence):

$$s+Q=110;\quad Q-s=90,$$
$$4s-Q=\alpha(??);\quad A+(l\pm w)=\alpha,\quad l\pm w=\beta,$$
$$4s+Q=140;\quad Q-4s=60(?),$$
$$A=\alpha, l\pm w=\beta;\quad A=\alpha, d=\beta.$$

For two squares Q_1 and Q_2, one of which was probably thought of as located concentrically within the other, the four problems $Q_1+Q_2=\alpha, s_1\pm s_2=\beta$ and $Q_1-Q_2=\alpha, s_1\pm s_2=\beta$ were dealt with. All problems are of the second degree (although $Q_1-Q_2=\alpha, s_1\pm s_2=\beta$ reduce trivially to the first degree, since Q_1-Q_2 is easily seen in a diagram to equal $[s_1+s_2]\times[s_1-s_2]$).

Since Abū Bakr's treatise contains the problem $d-s=4$, we may guess that the subscientific tradition solved this problem by equating the diagonal of the 10×10 square with 14. Abū Bakr gives the exact solution $s=4+\sqrt{32}$ whereas the Babylonians (who always worked backward from known solutions in their "algebra") eliminated this "unscientific" problem in the same process as they transformed the restricted stock of surveyors' riddles into a genuine, systematic discipline and into something that can legitimately be regarded as an *algebra*.

The Seleucid cuneiform "algebra" texts have traditionally been understood as faithful continuations of the Old Babylonian tradition. Close scrutiny of the texts shows even this to be a half truth. Indeed, the Old Babylonian mathematical tradition lost its higher, algebraic level when the scribe school system collapsed around 1600 B. C.E., and only the directly applicable level survived in an environment whose professional pride was based on other aspects of its practice. The surveyors' tradition, however, survived, and appears to have supplied the material for an algebraic revival in the later first millennium at the level of scholar scribes. In the meantime, the surveyors had developed more sophisticated methods – e.g., calculating the heights of triangles and using this for area determination instead of restricting themselves to practically right triangles laid out in the terrain. The most important Seleucid algebraic text also reads as a catalog of new problems and methods for the treatment of rectangles, some of them quite refined (e.g., determining the sides from $l + d$ and $w + d$ or from A and $l + w + d$).

The surveyors' tradition influenced not only Late Babylonian scribal mathematics and Medieval Islamic mensuration but also ancient Greek geometry and arithmetic. What is reflected in *Elements* II is, indeed, not Babylonian "algebra" in general but very precisely *that part of Old Babylonian algebra which it shared with the surveyors' tradition* – whence one may conclude that the real inspiration was *not* Old Babylonian scribal mathematics – long since forgotten – but the still living stock of surveyors' riddles. Proposition l, it turns out, justifies the geometrical addition of rectangles which have one side in common, whereas propositions 2 and 3 concern the special cases where sides are subtracted from or added to square areas. Propositions 4 and 7 are used, e.g., in two different but equivalent solutions to the problem of finding the sides of a rectangle from the area and the diagonal. Proposition 6 explains the solution of all problems $Q \pm \alpha s = \beta$ (including "the four sides and the area") and $A = \alpha, l - w = \beta$, while proposition 5 has a similar relation to rectangular problems $A = \alpha, l + w = \beta$ and to $\alpha s - Q = \beta$. Proposition 8, which is used nowhere else in the *Elements*, is associated with the concentric inscription of one square into another, and propositions 9 and 10 are connected to the solution of the problems $Q_1 + Q_2 = \alpha, s_1 \pm s_2 = \beta$.

What the Greek text does is not merely repeat the traditional solutions – in fact, it presents us with theorems, not with problems to be solved. But the theorems are *critiques* of the traditional "naïve" procedures, showing that what is immediately "seen" is indeed correct and can be proved within the axiomatic framework. The proofs fall into two parts, the first of which establishes the equality of areas and that the quadrangles which are believed to be squares are indeed so. Then on firm ground, the second part goes through the traditional cut-and-paste procedure.

Propositions 11–13 are connected to matters found in Abū Bakr's treatise, and the textual evidence suggests that at least propositions 12 and 13 (the generalized Pythagorean theorem) were originally developed independently of the Greek theoreticians, as part of the "new" stage of the surveyors' geometry. Propositions 1–10, on the other hand, are completely untouched by the innovations. This critique thus seems to go back to a moment when the "new" development had not yet taken place, or not yet reached the ears of Greek geometers (we may point to the late fifth century B.C.E., the epoch of Hippocrates of Chios and of Theodoros).

Book I of Diophantos' *Arithmetic*, which also contains undressed versions of favorite arithmetical recreational problems, embraces a few problems of the second degree – as it turns out, arithmeticized versions of $A = \alpha, l \pm w = \beta$ and $Q_1 + Q_2 = \alpha s_1 \pm s_2 = \beta$ (all four belonging to the original surveyors' stock). As can be seen from certain passages in Plato, Diophantos' work builds at least in its terminology upon a tradition reaching back to Greek calculators of the fifth century B.C.E. or earlier. The present simple problems can be assumed to belong to the early ingredients of this tradition, which then agrees with the chronological conclusions that could be drawn from *Elements* II.

A single Greco-Egyptian papyrus (probably second century A.D.) shows that the "new" diagonal-centered group of surveyors' problems circulated among the mathematical practitioners of the Greco-Roman orbit at this later moment, without being adopted into the corpus of scientific mathematics. In China, on the other hand, they appear to turn up in the Jiuzhang suanshu (Nine Chapters on Arithmetic) (one of them in a dress which with high probability points back to Babylonia and thus shows the Chinese problems to be borrowed). In the later Chinese tradition, however, this interest disappears again.

"Naïve" geometry is also to be found in the Indian *Śulbasūtra* geometry (mid-first millennium B.C.E.), and a few commentaries to later Indian algebraic works might suggest a fundament in something similar to our surveyors' tradition. The evidence, however, is too shaky to allow any conclusion, except in the case of the ninth century Jaina mathematician ▶ Mahāvīra, whose *Gaṇita-sāra-saṅgraha* contains indubitable borrowings from it, and even treats material stemming from the Bronce Age phase, the preseleucid Late Babylonian phase and the Seleucid phase in separate sections of its geometry chapter. Apart from that and from its role for the emergence of Babylonian "algebra" and for that of Greek metric geometry as found in *Elements* II, the only literate mathematical culture where the anonymous surveyors gained real influence is thus that of medieval Islam. Its reflection in al-Khwārizmī was already mentioned, to which it may be added that al- Khwārizmī's borrowed geometric proofs were taken over by numerous algebraic authors until the mid-sixteenth century – one step in Cardano's solution of the third-degree equation makes use of a three-dimensional generalization of this diagram, another of the solution of the rectangle problem $A = \alpha, l + w = \beta$. Within the mensuration tradition, the twelfth-century ▶ Abraham bar ḥiyya (Savasorda) betrays familiarity with the surveyors' quasialgebraic riddles, in a version which shows him to be independent of Abū Bakr); so does Jean de Murs' fourteenth century *De arte mensurandi*.

As the technique was taken over by scientific mathematicians, the reason to uphold a distinct naïve-geometric tradition disappeared. Abū Bakr had already solved many of the problems in two ways, first by naïve geometry and then by *al-jabr* – the originally subscientific discipline committed to writing and made famous by al-Khwārizmī. Abraham bar ḥiyya, for his part, refers to *Elements* II in his solutions. Nonetheless, the riddles themselves continued to be attractive. They are important in Leonardo Fibonacci's *Pratica geometrie* (1220), which draws on Abraham bar ḥiyya, on Gerard of Cremona's translation of Abū Bakr, and on at least one other work belonging to the tradition. And they turn up again in Luca Pacioli's *Summa de arithmetica geometria Proportioni: et proportionalita* (1494), which still asks for the side when "the four sides and the area" equals 140, with the same anomalous order of the members as in the Bronze Age. The last shimmering of the tradition is in Pedro Nunez' *Libro de Algebra en Arithmetica y Geometria* (1567), after which every trace disappears, together with the knowledge that such a tradition had ever existed.

From the beginning some 4,000 years ago, the surveyors' riddles were algebraic in the sense that the solutions follow steps that correspond to those of a modern solution by means of symbolic algebra. They were also algebraic in the sense that their method was *analytic*: the unknown side of the square is treated as if it were known, and submitted to such operations that at the end it is isolated and thus known – precisely as a modern x.

However, the surveyors' technique lacked two essential characteristics of modern equation-algebra (characteristics which, by the way, modern equation-algebra shares with the Old Babylonian scribe school "algebra"). First, it was no general method for finding unknown quantities; the measurable lines and areas which it manipulated were never used as representatives of something else. It was, and remained until it was taken over and reshaped by the written traditions, a collection of sophisticated riddles with no practical purpose beyond itself. Second, it always dealt with the entities which are naturally present in the geometrical configurations of which it spoke: *the* area, *the* side or *the four* sides, etc. It is never, as we may find it even in those of the Old Babylonian scribal texts which otherwise come closest to the background tradition, "one half of the length and one third of the width" of a rectangle. This is also the reason that its problems are – with one very late and thus dubious exception – always normalized, and a supplementary reason that it did not develop into an all-purpose algebra. We may therefore, legitimately, speak of a surveyors' "algebra" – but not of a surveyors' algebra without quotes.

See Also

▶ Abraham Bar Ḥiyya (Savasorda)
▶ Al-Khwārizmī
▶ Mathematics
▶ Mathematics Practical and Recreational
▶ Surveying

References

The influence of the Near Eastern tradition on Mahāvīra's *Gaṇita-sāra-saṅgraha* is the theme of Høyrup, Jens, Mahāvīra's geometrical problems: Traces of unknown links between Jaina and Mediterranean Mathematics in the classical ages. (2004). In I. Grattan-Guinness, & B. S. Yadav (Eds.), *History of the mathematical sciences* (pp. 83–95). New Delhi, India: Hindustan Book Agency.

The innovations of the Seleucid are treated at depth in: Høyrup, Jens, Seleucid Innovations in the Babylonian "Algebraic" tradition and their Kin abroad. (2002). In Y. Dold-Samplonius et al. (Ed.), *From China to Paris: 2000 years transmission of mathematical ideas* (Boethius, 46) (9–29). Stuttgart, Germany: Steiner.

The most thorough argument for the naive-geometric character of Old Babylonian "algebra" is: Høyrup, Jens, 2002. (2002). In *Lengths, widths, surfaces: A portrait of Old Babylonian Algebra and its Kin* (Studies and Sources in the History of Mathematics and Physical Sciences). New York: Springer.

The surveyors' tradition and its relations to the written mathematical traditions is treated in: Høyrup, Jens, on a collection of geometrical riddles and their role in the shaping of four to six "Algebras. (2001). " *Science in Context 14* 85–131.

Al-Ḥajjāj

Gregg De Young
The American University in Cairo, Cairo, Egypt

Al-Ḥajjāj ibn Yūsuf ibn Maṭar was one of the earliest translators of Greek mathematical and astronomical texts into Arabic. Few details of his life are known. According to a report of the biobibliographer Ibn al-Nadīm, he prepared an Arabic version of Euclid's *Elements* under the sponsorship of the 'Abbāsid caliph, Hārūn al-Rashīd (170–193 AH/AD 786–809). Later, under caliph al-Ma'mūn (198–218 AH/AD 813–833), he prepared a second (and improved) version version (Brentjes, 1994). There are some hints that the mathematician Thābit ibn Qurra (died 288 AH/AD 901) may have helped to revise the latter version.

Neither version is extant (De Young, 1991, 2002–2003, 2005; Lévy, 2005). Quotations from what purports to be the second version serve as the basis for a commentary by al-Nayrīzī (d. early fifth century AH/AD tenth century). These quotations seem, however, to have been edited by the commentator on the basis of the later translation of Isḥāq ibn Ḥunayn (215–298 AH/AD 830–910). There appear to be other traces of the transmission of al-Ḥajjāj in commentaries by Aḥmed al-Karābīsī and in the epitome of the Euclidean *Elements* in Ibn Sīnā's *Kitāb al-Shifā'* (The Cure [of Ignorance]). Probably this transmission tradition also served as the basis for the Latin translation of Adelard of Bath and the nearly contemporaneous Latin version of Hermann of Carinthia (Brentjes, 2000).

Al-Ḥajjāj is also credited with production of an Arabic version of Ptolemy's *Almagest*, perhaps by way of a Syriac intermediary. The relation of this transmission to that of Isḥāq ibn Ḥunayn has not yet been fully established (Kunizsch, 1974). In this case, both traditions are extant, allowing a more careful scrutiny of philological characteristics and translation techniques. Attempts to apply what we learn from a study of the *Almagest* transmissions to Euclid remain incomplete.

See Also

- ▶ *Almagest*: Its Reception and Transmission in the Islamic World
- ▶ Al-Maʾmūn
- ▶ Al-Nayrīzī
- ▶ Thābit Ibn Qurra

References

Brentjes, S. (1993). Varianten einer Ḥağğāğ-version von Buch II der *Elemente*. In M. Folkerts & J. P. Hogendijk (Eds.), *Vestigia mathematica: Studies in medieval and early modern mathematics in honor of H. L. L. Busard* (pp. 47–67). Amsterdam: Editions Rodopi.

Brentjes, S. (1994). Textzeugen und Hypothesen zum arabischen Euklid in der Überlieferung von al-Ḥağğāğ b. Yūsuf b. Maṭar (zwischen 786 und 833). *Archive for History of Exact Sciences*, *47*, 53–92.

Brentjes, S. (2000). Aḥmad al-Karābīsī's commentary on Euclid's Elements. In M. Folkerts & R. Lorch (Eds.). *Sic Itur ad Astra: Studien zur Geschichte der Mathematik und Naturwissenschaften* (pp. 31–75). Wiesbaden: Harrassowitz.

Brentjes, S. (2001). Observations on Hermann of Carinthia's version of the Elements and its relation to the Arabic transmission. *Science in Context*, *14*, 39–84.

Brentjes, S. (2006). An exciting new Arabic version of Euclid's Elements: Ms Mumbai, Mullā Fīrūz R.1.6. *Revue d'histoire des mathématiques 12*, 169–197.

De Young, G. (1991). New traces of the lost Arabic translations of Euclid's Elements. *Physis, 28*, 647–666.

De Young, G. (2002–2003). The Arabic version of Euclid's Elements by al-Ḥajjāj ibn Yūsuf ibn Maṭar. *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften*, *15*, 125–164.

De Young, G. (2005). Diagrams in the Arabic Euclidean tradition: A preliminary assessment. *Historia Mathematica, 32*, 129–179.

Kunitzsch, P. (1974). *Die syntaxis mathematica des Claudius Ptolemaios in arabisch-lateinisch Überlieferung*. Harrassowitz: Wiesbaden.

Kunitzsch, P. (1985). Findings in some texts of Euclid's Elements (Medieval transmission, Arabo-Latin). In M. Folkerts & U. Lindgren. (Eds.), *Mathemata: Festschrift für Helmuth Gericke*. Stuttgart: Franz Steiner, pp. 115–128.

Lévy, T. (2005). Le manuscrit hébreu Munich 36 et ses *marginalia*: un témoin de l'histoire textuelle des *Éléments* de Éuclide au Moyen Âge. In D. Jacquart & C. Burnett (Eds.), *Scientia in margine: Études sur les marginalia dans les manuscrits scientifiques du Moyen Âge à la Renaissance* (pp. 103–116). Paris: Droz.

Al-Hamdānī

Christopher Toll

Abū Muḥammad al-ḥasan ibn Aḥmad ibn Yaʿqūb al-Hamdānī, with the honorific name Lisān al-Yaman ("The Tongue, i.e., the Mouthpiece of the Yaman"), was born into a turbulent time in a turbulent world and was not called to make his time and world less turbulent. He did create not only turbulence, but also a scholarly monument which has remained the pride of his Yamanite compatriots and an enduring contribution to the culture of mankind.

Background and Life

When al-Hamdānī was born, in Ṣanʿāʾ, perhaps on ṣafar 19th, 280 AH (May 10th, 893 AD), the Muslim expansion had created a wide common market and an equally wide uncommonly cultured world, both without frontiers. The common market and the peace of the caliphate had given rise to huge fortunes which had financed numerous cultural and scholarly activities inspired by the new religion Islam, carried by its versatile language, Arabic, on a foundation laid by Hellenistic culture. Members of different religions, Muslims, Christians, and Jews, with different languages, Arabic, Greek, Aramaic and Persian, had collaborated in transforming the Hellenistic heritage into the Islamic culture of Arabic language. It was possible to travel in search of profit, *faḍl* Allāh, or of knowledge, from the River Indus in the East to Spain in the West without being hindered by frontiers, customs, wars, language difficulties, or different currencies.

Knowledge and profit supported each other. New technology, new industries, new goods and new money were spread; palaces, universities and schools were built. Gardens were made for the study of plants; books were written and manuscripts were collected, copied and translated and libraries founded. Scholars and artists met in the houses of patrons, and in spite of intense discussions there reigned a liberal atmosphere. Never in the Middle Ages had there been such a width and liberty in research and teaching.

Nevertheless, there were sectarian conflicts, e.g. with the Khārijites and Shīʿites, which had dynastic and political aspects, and there were nationalistic conflicts, e.g. with the Shuʿūbīya, a movement of mainly Persians who opposed Arab supremacy. There were nationalistic conflicts also among the Arabs themselves when South and North Arabians brought their rivalry as far as Spain. And there were local conflicts where the control of the central power was weak, as in the Yaman, so that local chiefs were able to oust the representative of the caliph. Al-Hamdānī was one of the most energetic champions of South Arabian nationalism, and yet his nationalism prompted him to scholarly and literary works of high value while it also rendered him open to persecution and maybe, as has been said, brought him a premature death in prison.

As his name shows, al-Hamdānī was a descendant of the powerful tribe Hamdān which had already played an important role in the Yaman to the north of Ṣanʿāʾ in pre-Islamic time. He was born in Ṣanʿāʾ, in the neighbourhood in which his family had lived for four generations. He was surnamed Ibn al-ḥāʾik, after an ancestor who was a famous poet, and al-Hamdānī was to take up this family tradition.

A few decades before al-Hamdānī's birth the head of a local dynasty from Shibām, Yuʿfir b. ʿAbdarraḥmān al-ḥiwālī, defeated the governor of the ʿAbbāsid caliphate and later transferred his power to his son Muḥammad who in his turn relinquished it to his son Ibrāhīm. When al-Hamdānī was born, Yuʿfir had recently ordered his grandson Ibrāhīm to murder his father which led to a revolution and the destruction of the silver mine in al-Jawf. In this revolution Ibrāhīm's house was plundered and he himself murdered, and the ʿAbbāsid governor reinstated the power of the caliph. But when al-Hamdānī was a small child the governor was called back to Baghdad and his Turkish soldiers were left to ravage Ṣanʿāʾ. The first Zaydī *imām*, al-Hādī ilā l-ḥaqq, was called in to restore order. The following years witnessed repeated battles between al-Hādī and the Yuʾfirids. When a Fāṭimid *dāʿī* entered the scene, however, the Yuʿfirids under Asʿad b. Ibrāhīm and al-Hādī became allied.

These events did not leave al-Hamdānī unaffected: his own tribe Bakīl of Hamdān won a victory over the Fāṭimid army, and he was imprisoned by Asʿad's nephew, because he was opposed to the foreign element among the followers of the Yuʿfirid's ally. Al-Hamdānī's satirical verses gave rise to a revolt against al-Hādī's son an-Nāṣir, which culminated in the battle of Katafā and the death of an-Nāṣir and his brother ḥasan. Al-Hamdānī escaped from prison to Hamdān's *sayyid* in Rayda and praised the leaders of the revolt in poems. It is thus doubtful that he died in prison in Ṣanʿāʾ in 334/946 as had been said by ṣāʿid b. ṣāʿid al-Andalusī on the authority of the Andalusian caliph al-Mustanṣir; others maintain that he did not die until about 350.

The Geographer

As a scholar, al-Hamdānī had an excellent education and did much travelling. One result of his travels is his geography of Arabia, particularly South Arabia, *Ṣifat jazīrat al-ʿarab*, the only systematic monograph of the Arabian Peninsula from the Middle Ages, which has been preserved in its entirety.

The first part of the work is a general geographical-astronomical introduction which follows Ptolemy. In this introduction al-Hamdānī showed his knowledge of Greek learning (he also quoted Hermes Trismegistos and Dioscorides). He was also familiar with the Indian astronomical work *Sindhind* and its Arabian translator al-Fazārī, as well as Ṣanʿāʾ's own astronomers.

The next part is a work on the physical, political and economical geography of the Arabian Peninsula. Starting with the Yaman, al-Hamdānī describes the different parts of Arabia with their mountains, valleys and wādīs, their vegetation and animal life, their tribes, habitations, villages, towns and castles, the number of inhabitants, the ownership and cultivation and irrigation of land, the pilgrim's roads and the dominions of sultans and governors. One of the themes is meteorology, as has repeatedly been observed, a theme that recurs in al-Hamdānī's medical work *Kitāb al-Quwā* (see below), as he mentions himself in his *Kitāb al-Jawharatayn* (see below).

The geographical description is interspersed with historical, genealogical, ethnographical and psychological notes, and he quotes Islamic and pre-Islamic poetry. In one of the concluding chapters, Hamdānī deals with weather conditions, food, prices, domestic animals and deposits of precious stones.

The Poet

Also as a poet and a collector of poetry al-Hamdānī shows his national and political fervour. His *Qaṣīda aḍ-ḍāmigha fī faḍl al-Qahṭān* is an answer to Kumayt b. Zayd al-Asadī's satirical attack on the South Arabian tribes 200 years earlier. To this poem – of its 590 verses rhyming *in -i/una* 476 are preserved – al-Hamdānī is said to have written a detailed commentary in a big volume. Another poem, *Qaṣīdat al-Jār*, deals with politics contemporary with the author, blaming the Yu ʻfirid ruler for having put him in prison. *Al-Iklīl* also contains many specimens of South Arabic poetry, including al-Hamdānī's own. His Diwān, with the commentary of Ibn Khālawayh, is said to have comprised six volumes, but has not come down to us.

The Philologist

As a philologist, al-Hamdānī is interested in words for things, e.g., in his *ṣifa* it is the names of the flowers rather than the flowers themselves which are the object of his interest. In his *K. al-Jawharatayn* he discusses different words for gold and silver and for gold and silver coins and their sides and parts with their etymologies. In this context he explains the South Arabian mīmation and the formation of words of four radicals with *-m* as the fourth radical as originating in the *mā l-ibhāmīya*. In his *ṣifa* he treats the spoken language of 113 different parts of the Arab peninsula and whether their language is correct or not or even ununderstandable. The best Arabic is spoken by, i.a., the Hamdān and by the nomads in the ḥijāz and Najd as far as Syria, whereas in ʻAdan the common people not only speak bad but are even stupid, and the Mahra are as foreigners, impossible to understand (actually, the South Arabic Mahrī dialect is also today not understood by those speaking a North Arabic dialect). Al-Hamdānī also illustrates his verdicts by examples, e.g. when he says that the Sarw ḥimyar say *ya bna m- ʻamm* instead of *ya bna l-ʻamm* and *sima*' instead of *isma* '- also other tribes have a definite article with *-m* instead of *-l*. Some tribes are said to speak ḥimyarite. Al-Hamdānī gives in *al-Iklīl* some further examples to illustrate the ḥimyarite language and even some text samples.

Quotations from book 9 of *al-Iklīl* in a later work (the commentary on Nashwān's ḥimyaritic *qaṣīda*) show that al-Hamdānī had a certain knowledge of the South Arabic script, which he reproduces in a table in book 8 with the (North) Arabic equivalents, but that he did not understand the inscriptions.

Al-Hamdānī's own language, by the way, does not seem quite to have followed the rules of the classical grammar. Al-Qifṭi tells us that *lamma dakhala l-ḥusayn b. Khālawayh al-Hamadhānī an-Naḥwī ilā l-Yaman wa'-aqāma bi-hā bi-Dhamār, jama'a diwān shi ʻrihi* (*ya ʻni shi ʻr al-Hamdānī*) *wa- ʻarrabahu wa-a ʻrabahu* ("When ḥ. b. Kh. al-H. the Grammarian came to Dh., he collected his (sc. al-Hamdānī's) poetry and made it into correct and clear Arabic"). And at least his *Kitāb al-Jawharatayn* shows in fact deviations from the classical norm and traces of the author's spoken language.

The *Faqīh*

Al-Hamdānī was also interested in law. In a work that has not been preserved but has been mentioned by al-Qifṭī, *Kitāb al-Ya ʻsūb*, he is said to have written about the legal rules concerning hunting. The legal chapter in the *Kitāb al-Jawharatayn* has been omitted in the manuscript with the exception of the title, *bāb ḥukūmat al-'iyār wa-fiqhihi wa-mā'ashbahahu*. Only short comments on gold and silver in the Hadith, on the prohibition of interest and of two purchases in one or the selling of gold for gold and silver for silver, and on the question of whether it is allowed to change God's creation are found in other chapters of the *Kitāb al-Jawharatayn*. The idea that gold as God's creation should be worked as it is without being refined is refuted by al-Hamdānī who compares it with wheat and sugar-cane which are also of God's creation but are worked and used in different ways.

The Historian

Al-Hamdānī's geography is supplemented by his historical work, *al-Iklīl*. This work was written in 332/944 while its author was living as the guest of Sayyid Hamdān, Abū Jaʿfar ad-Dahhāk, in the castle of Tayfum in Rayda. It consisted of ten books: books 1, 2 and 10 deal with the beginning of genealogy and present genealogies of South Arabian tribes, and book 8 describes the old castles of pre-Islamic South Arabia. These books are extant today. Of those not preserved, book 3 is said to deal with the merits of the South Arabian tribes, books 4–6 with the history of South Arabia before Islam, book 7 contained a critique of false traditions, and book 9 South Arabian inscriptions. Al-Hamdānī's sources were Abū Naṣr Muḥammad b. ʿAbdallāh b. Saʿīd al-Yaharī al-ḥanbaṣī, the learned lord of the castle ḥanbaṣ, the archives (*sijill*) of the Banū Khawlān in ṣaʿda and oral popular tradition and written information from different sides, e.g. from the legendary ʿUbayd b. Sharya al-Jurhumī, the collector of legends Wahb b. Munabbih and the famous genealogist Hishām b. Muḥammad al-Kalbī. *Al-Iklīl* (The Crown) is quoted in al-Bakrī's *Muʿjam ma staʿjam*. Another historical work of al-Hamdānī, *Kitāb al-Ayyām*, to which he refers in his *ṣifa*, has not been recovered. That so many of al-Hamdānī's historical writings were lost is, according to al-Qifṭī, because members of tribes not favourably mentioned had destroyed all the copies they could find.

The Philosopher

The two works, *Ṣifat Jazīrat al-ʿArab* and *al-Iklīl* have made al-Hamdānī known as a geographer and a historian. But that he was also said to be one of only two famous Arab philosophers – the other was ▶ al-Kindī – is difficult to understand. Al-Kindī is well known as a famous philosopher, but why al-Hamdānī? After two other works by al-Hamdānī have become known, however, it is easier to understand the appreciation of the philosopher al-Hamdānī. As a philosopher, al-Hamdānī was interested, in his book on gold and silver, *Kitāb al-Jawharatayn al-ʿatīqatayn* (see below), in the generation and corruption of matter, in the transmutation of one element into another and in the influence of the heavenly bodies upon the earth. He was a follower of the Greek philosophers, and he quotes the works of Aristotle concerning the generation of heat. But in his astronomical work *Sarāʿir al-ḥikma* (see below) he opposes Aristotle, maintaining that each part of the celestial sphere is connected with a corresponding part of the earth.

The celestial sphere is divided according to the signs of the Zodiac, and this division also governs that of the seasons. In his *Kitāb al-Jawharatayn* al-Hamdānī gives a survey of the seasons with the qualities (warm, cold, dry and moist), elements (fire, water, earth and air) and cardinal humours (blood, phlegm, black and yellow bile) belonging to each season, and he also tells us which substances are related to which planet or sign of the Zodiac: lead, e.g. belongs to Saturn and to Capricorn. The influence of the planets on their substances varies according to their positions and the season of the year. The influence occurs also according to similarity: fire can influence only what already contains fire.

When al-Hamdānī compares the earth as round and globular and situated in the middle of the likewise round and globular sphere with the centre in the circle, he is repeating a comparison already to be found in a quotation by Archimedes from Aristarchos. Also in his historical work, ancient conceptions of the world as being eternal or created are said to be discussed. Some influence from the theory of atoms seems to be found in expressions such as *ijtimāʿ* for having a three-dimensional body, properly signifying the fusion of atoms into a body, and the repeated use of the word *ajzāʿ*, particles, atoms.

The Aristotelian theory of the generation of substances from the four elements under the influence of the heavenly bodies forms the basis of alchemy. The theory is that the different matters consist of a mixture of the four elements. According to their purity and proportions and the influence of the planets the metals arise in the earth. Of the metals, gold is the most pure, containing the elements in ideal proportions. Thus it ought to be possible to imitate the processes of nature by artificial means, removing the impurities and restoring the ideal proportions and thereby to obtain gold.

The alchemists used sulphur, being hot and dry, and mercury, being cold and moist, as representing the elements. It appeared, however, that no mixing of sulphur and mercury results in gold. The alchemists then presumed ideal forms of sulphur and mercury, not existing in the natural world. In order to accelerate the transformation which happens very slowly in nature, they used an elixir, having the same effect as yeast, and to produce this elixir the alchemists used a lot of methods, such as distillation and sublimation, boiling and calcination, amalgamation, etc. by means of crucibles, retorts and distilling-apparatuses, thus laying the foundations of chemistry. Later alchemists made this procedure into a ritual with an allegorical meaning, and a secret art.

The Muslim scholars had different opinions about alchemy. The great physician ► al-Rāzi (d. 313 or 323 H) tried to transmute metals, and he classified the matters he used according to their natures and properties. The great scientists ► al-Bīrūnī and Ibn Sīna (both fifth century H) believed in the generation of matter and in the sulphur-mercury theory, but they were opposed to alchemy because they were of the opinion that art was not able to imitate nature.

The Astronomer

In Greek and Islamic tradition you cannot separate the philosopher, the scientist and the doctor, and the views which I have mentioned are closely related to astronomy and astrology, chemistry and medicine, subjects on which al-Hamdānī was also productive.

Al-Hamdānī is also said to have compiled astronomical tables, *az-Zīj* – he mentions *Tanbīh az-Zīj* – and a book on horoscopes and the projection of rays (*Kitāb at-ṭāliʿ wal-maṭāriʾ*. In a medicinal work, *al-Quwā*, which is lost, he showed the influence of the planets upon the temperature of the earth. It is also said that pieces on astronomy and physics are scattered through his historical work.

Of his astronomical work, *Sarā ʻir al-ḥikma fi ʻilm an-nujūm*, al-Qifṭī says, quoting ṣā'id al-Andalusī, that its aim is *at-ta'rīf bi-jumal hay ʻat al-aflāk wa-maqādīr ḥarakāt al-kawākib wa-tabyīn ʻilm aḥkām an-nujūm wa-stifa' ḍurūbihi* "the definition of the total form of the celestial bodys, the extent of the movements of the stars, the exposition of astronomy, and the exhaustive treatment of its kinds". It is also quoted by Abū Marwānal-Istijī, according to ṣā ʻid one of the best astrologers in al-Andalus. However, only the tenth chapter of this work has been recovered in two manuscripts in al-Yaman. In this work several Greek scholars are cited – Dorotheos of Sidon, Ptolemy, Valens, Hipparchos and the mythical Hermes Trismegistos – as also the Indian astronomical work Sindhind as well as its Arabic translator al-Fazārī and Persian astronomical works but also Islamic scholars, such as Māshā'allāh, Abū Ma ʻshar, Abū Muḥammad b. Nawbakht, Sulaymān b. ʻIṣma.

The Economist

We have seen that al-Hamdānī's historical and geographical works were intended to be complementary to each other. In the same way his book on gold and silver, *Kitāb al-Jawharatayn al-ʿatīqatayn min aṣ-ṣafrāʾ wal-bayḍāʾ*, belonged to a trilogy on South Arabic economy, the parts of

A

which were also complementary. Part 1 dealt with agriculture, part 2 with camel breeding and part 3 with gold and silver, i.e. the three kinds of property: landed property, cattle and precious metals. Only the part dealing with gold and silver has been preserved. Here gold and silver are mentioned as a form of investment, and its advantages in this respect are praised, above all that it is easy to take along.

The Metallurgist

In the *Kitāb al-Jawharatayn* the *Qurʾān* and the *Tradition* are quoted but so are popular traditions. An abundance of Persian expressions for substances and tools show that al-Hamdānī also had inherited an Iranian tradition with which he had personal contact. He says that Persian tribes, which had immigrated into al-Yaman already before Islam, were working the mines in South Arabia. They were called *furs al-maʿdin* and enjoyed a good position and property in Ṣanʿāʾ.

Al-Hamdānī also learnt about metallurgy and minting from specialists among his compatriots. The art of forging is very old in al-Yaman. It perhaps has its origin in the connections of al-Yaman with India – the Indian steel and the Indian swords made from it are often mentioned in Arabic poetry and by al-Hamdānī. The art of forging swords and armours is traced back by tradition to the Tubbaʿ, the kings of ḥimyar, and the swords of al-Yaman are famous in Arabic poetry. Another important source of his knowledge was the master of the mints in Ṣanʿāʾ and ṣaʿda and his sons, one of whom was to succeed him in the office.

Al-Hamdānī's *Kitāb al-Jawharatayn* is the oldest and most comprehensive of the four Arabic works on gold, silver and minting known to us (the other three are *Kashf al-asrār* by Ibn Baʿra, a manual of the Egyptian mint of the seventh century H, *ad-Dawḥa al-mushtabika fī ḍawābiṭ dār as-sikka* by ʿAlī b. Yūsuf al-ḥakīm, a manual of the mint in Fās of the eighth century H, and a manual of the mint in Marrākush from the 990s H). It abounds in technical and chemical information which extends from the extraction of ore from the mines to the minting of coins. It also contains valuable information about gold and silver mines in Arabia, Africa and Iran. It also mentions the use of gold and silver for gilding and silvering and for ornaments and of gold leaf for decorating pages of the *Qurʾān*. It describes glass and methods of counterfeiting. Also the use of other metals such as iron and mercury and the sickness caused by some substances and their use are dealt with. The main subject of the book is, however, the fabrication of coins.

The fabrication of coins can be divided into three stages: the fabrication of the dies, the fabrication of the flans and the stamping of the flans. According to al-Hamdānī the die was made from hardened steel, its surface filed and the inscription engraved with an iron stylus. The die was pegged and holed in order to hold its two halves in a fixed position and to achieve a fixed relationship between the coin's obverse and reverse.

The flans were made after the gold and silver had been purified. The impurities in the gold ore were separated from the gold by means of sulphur, and the gold left in the separated impurities was collected by amalgamation with mercury. Silver was also extracted by amalgamation and otherwise purified by heating while supplying air at the same time, so that the lead in the silver ore combined with the oxygen in the air and was separated as lead oxide. Al-Hamdānī describes three methods to fabricate the flans. One was lamination: the cutting of flans from moulded bars. A second method consisted of casting the flans in moulds of clay. The third method consisted of pouring molten silver or gold into water. Thus small round pieces of metal were obtained which were hammered flat and used as flans, in spite of their different size.

The Physician

Al-Qiftī calls al-Hamdānī *aṭ-ṭabīb* (physician), and one of his books, *al-Quwā*, is said to be a medical work, but we do not know its content. That al-Hamdānī was interested in medicine is, however, clear also from *Kitāb al-Jawharatayn*, which contains some medical information.

The pain of burns is mitigated by means of gold. Rash is treated with water containing gold. Chips of gold and silver are ingredients in important remedies. The oculists use dross of gold and silver. Silver slag removes the stink of the sweating of the axillae and is used in salves to close wounds. Verdigris, made from copper and wine vinegar, is used in many remedies and in colours. Antimony heals wounds and stops haemorrhage from the cerebral membranes, and mixed with fat it is used for burns. Mercury is used against colic but can also increase colic, causing constipation and death. There are also some general remarks on the influence of compound drugs on the body and the difference between medicine for internal and external application. Some of the information is borrowed from Dioscorides' materia medica.

Al-Hamdānī also mentions damages caused by different substances. The mercury vapour produced by gilding and amalgamating causes hemiplegia and convulsions. Since mercury is moist and cold the remedy ought to be something warm, such as wine. The fumes of lead, which evaporate when silver is purified, affect the brain, and the vapours of the substances used for purifying the gold dry out the nose and saliva, cause cutaneous fissures and affect the brain. Therefore, a wall is put between the furnace and the workers, or the workers cover their noses – early examples of safety precautions for workers. Fumes from lead and copper injure the teeth, weaken the bladder and cause a pain in the waist. The fume from the manure used when silver amalgam is heated causes headaches, and other fumes from the furnace give rise to jaundice, disturbed vision, attacks of sickness, abdominal pains, and headaches.

The Man

Intellectually, al-Hamdānī was a man of independent thought. We have seen that he did not simply reproduce the learning of others. As a geographer he relied mainly on his own observations, travelling extensively over the country he was going to describe. He had his own opinion about the colour of the skin of the peoples in the tropical countries, which was contrary to that of Ptolemy. He had his own division of the world with more climata than the usual seven. He contrasted the opinion of the Greeks concerning the extension of the inhabited world with that of the Indians and the Chinese and exposed in detail the differences between the Greek, Indians and Arabs concerning latitude and longitude. He also contrasted two theories concerning the seasons, their qualities and the cause of these qualities.

Morally, al-Hamdānī was a man of courage and strong passions. Although a Muslim, he dared to attack the tribe of the Prophet, and his strong stand for the Yaman can also be seen in the absence of descriptions of Makka and al-Madīna from his *ṣifa*. He was not afraid of taking part in the political turmoil of his days, and prison did not frighten him and did not break him down. Nothing in his writings, however, gives the impression that he was but a pious Muslim, well versed in the *Qurʾān* and the Hadīth.

References

Works by al-Hamdānī

Al-Iklīl, 1–2: facsimile edition Berlin, 1943. 1. Ed. O. Löfgren, Uppsala: Almqvist & Wiksells Boktryckeri AB 1954, 1965 (Bibliotheca Ekmaniana 58:1–2); 1–2 ed. M. b. ʿA. al-Akwaʿ al-ḥiwālī, al-Qāhira 1383/1963, 1386/1966. *Südarabisches Muštabih*. Verzeichnis homonymer und homographer Eigennamen aus dem Berliner Unikum des Iklīl. Herausgegeben von O. Löfgren. Uppsala: Almqvist & Wiksells Boktryckeri AB etc, 1953. (Bibliotheca Ekmaniana 57). Trans. N. A. Faris; 8: partial Ed. & German translation D. H. Müller, *Die Burgen und Schlösser Südarabiens nach dem Iklīl des Hamdānī* (Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, philos.-hist. Cl. 94: 1, Jahrgang 1879, Wien 1879, 335–423, 97: 4–6, Jahrgang 1880, Wien 1881, 955–1050; Ed. A. M. al-Karmalī, Baghdad 1931; Ed. N. A. Faris, Princeton 1940 (review by J. Fück, *Zeitschrift der Deutschen Morgenländischen Gesellschaft*, 96/1942: 158 f., G. Levi della Vida, *Orientalia*, NS 9/1940:160 ff., O. Löfgren, Moslem World, 32/1942: 92–94, R. Paret, *Orientalistische Literatur-Zeitung*, 42/1939:32 ff.); Ed. M. ʿA. al-Akwaʿ al-ḥiwālī, Dimashq: Maṭbaʿat al-Kātib al-ʿArabī 1399/1979; Trans. N. A. Faris, *The Antiquities of South Arabia*. Princeton: Princeton University Press, 1938 (review by O. Löfgren, *Moslem World*, 29/1939: 295–297).10: Ed. M. al-D. al-Khatīb, Cairo 1949.

Kitāb al-Jawharatayn al-ʿatīqatayn al-māʾiʿatayn min aṣ-ṣafrāʾ wal-bayḍāʾ, Die beiden Edelmetalle Gold und Silber. Ed. with German introduction and translation Chr. Toll: Uppsala, Acta Universitgatis Upsaliensis, Studia Upsaliensia, 1, 1968. Reviews: *Hamburger Beiträge zur Numismatik* 7/1968–69 (1972). 926 (Spuler); *Majallat Majmaʿ al-lugʿa al-ʿarabīya bi-Dimashq* 1389/1969: 3: 554–568=*al-ʿArab (ar-Riyāḍ)* 4/1389/1969:267–280 (ḥamad al-Jāsir); *Lychnos* 1969–70: 469 f. (Lewin); *Arabica* 17/1970: 319 f. (Lecomte); *BSOAS* 33/1970: 445 f. (Mattock); *Janus* 57/1970: 63–65 (Hermelink); *JESHO* 13/1970: 326 f. (Cahen); *Judaica* (Zürich) 26/1970: 246; *Islam* 48/1971: 90-9 (Ullmann); *Sudhoffs Archiv* 55/1971: 418–22 (Goltz); *Survey of numismatic research* 1966–71, 2, N.Y. 1973, 326 och n. 86 (Mitchell Brown); *OLZ* 69/1974: 59–62 (Klein-Franke); *JAOS* 96/1976: 297 f. (Luther). Cited in: Allan, J. W., *Persian metal technology 700–1300 AD*, London 1979, passim; Garbers, K., & J. Weyer, *Quellengeschichtliches Lesebuch zur Chemie und Alchemie der Araber im Mittelalter*, Hamburg 1980, 22–25, 81–83. 2d ed. (without translation and with introduction in Arabic) Ṣanʿāʾ: Wizārat al-I'lām wath-taqāfa 15:3, 1985; Ed. M. M. ash-Shuʿaybī, Damascus 1982; Ed. H. al-Jāsir, ar-Riyāḍ 1408/1987.

Sarāʾir al-ḥikma. (1979?). The secrets of wisdom. 10th maqāla, (M. b.ʿA. al-Akwaʿ al-ḥiwālī, Ed.). Ṣanʿāʾ.

Ṣifat jazīrat al-ʿarab (D. H. Müller, Ed., pp. 1–2). Leiden, Netherlands: E.J. Brill, 1884, 1891. Deutsche Morgenländische Gesellschaft, Kraus Reprint Ltd., 1966. Rpt. Amsterdam 1968; Ed. M. b. ʿA. b. B. an-Najdī, Cairo 1953; Ed. M. ʿA. al-Akwaʿ al-ḥiwālī, ar-Riyād 1394/1974; partial German translation L. Forrer, *Südarabien*, Leipzig 1942, reprint Nendeln (Abhandlungen für die Kunde des Morgenlandes 27:3).

Works on al-Hamdānī Primary Sources

Al-Qiftī. (1369/1950). *Inbāh ar-ruwāh ʿalā anbāh an-nuḥāh* (M. A. Ibrāhīm, Ed., pp. 279–284). 1, al-Qāhira, Egypt: Dār al-Kutub.

Al-Qiftī. (1903). *Taʾrīkh al-ḥukamāʾ* (J. Lippert, Ed., p. 163). Leipzig, Germany.

As-Suyūṭī. (1326). *Bughyat al-wuʿāh fī ṭabaqāt al-lughawiyyīn wan-nuḥāh* (p. 217). Cairo, Egypt.

Az-Ziriklī, Kh. (1986). *al-Aʿlām*, 2, Bayrūt, Lebanon. 179.

Ṣāʿid b. Ṣāʿid al-Andalusī, *Ṭabaqāt al-umam*. Ed. L. Cheikho, Beyrouth 1912. 58–59; Trans. R. Blachère, *Livre des catégories des nations*, Paris 1935 (Publications de l'Institut des Hautes-Ètudes Marocaines 28), 114–116.

Yāqūt. (1927). *Irshād al-arīb ilā maʿrifat al-adīb al-maʿrūf bi-Muʿjam al-udabāʾ* (D. S. Margoliouth, Ed., 2nd ed.). London, 6:3, 9 (Gibb Memorial Series); Ed. al-Qāhira, 7 (1944): 230–231.

Secondary Literature

ʿAbdallāh, Y. M. (1975). *Die Personennamen in al-Hamdānī's al-Iklīl und ihre Parallelen in den altsüdarabischen Inschriften*. Tübingen. Diss.

ʿAbdallāh, Y. M. (1986/1407). Tarjamat al-Hamdānī, siyāgha jadīda. In taḥqīq Y. M. ʿAbdallāh (Eds.), *Al-Hamdānī, Lisān al-Yaman* (pp. 185–198). Ṣanʿāʾ, Yemen: Jāmiʿat Ṣanʿāʾ.

Al-Akwaʿ, I. (1986/1407). Makhālīf al-Yaman ʿinda l-Hamdānī. *Al-Hamdānī, Lisān al-Yaman*, taḥqīq Y. M. ʿAbdallāh (pp. 25–52). Sanʿāʾ, Yemen: Jāmiʿat Ṣanʿāʾ.

Al-Akwaʿ, M. ʿA. (1986/1407). Lisān al-Yaman al-Hamdānī wa-awwaliyyātuhu allatī tafarrada bihā. *Al-Hamdānī, Lisān al-Yaman* (taḥqīq Y. M. ʿAbdallāh, Ed., pp. 111–115). Ṣanʿāʾ, Yemen: Jāmiʿat Ṣanʿāʾ.

Al-Ayyūbī, H. (1986/1407). Al-Hamdānī, al-lugha wal-wāqiʿ. *Al-Hamdānī, Lisān al-Yaman* (taḥqīq Y. M. ʿAbdallāh, Ed., pp. 117–138). Ṣanʿāʾ, Yemen: University of Sanaa.

Al-Jāsir, H. (1951). *Majallat al-Majmaʿ al-ʿilmī bi-Dimashq* (pp. 533–544). (on *K. al-Jawharatayn*).

Al-Jāsir, H. (1378/1958). Aqdam kitāb makhṭūṭ ʿan at-taʿdīn ʿind al-ʿarab. *Qāfilat az-zayt (az-Ẓahrān)* 6(2), 7–8.

Al-Jāsir, H. (1394/1974). *Muqaddimat ṣifat Jazīrat al-ʿArab lil-Hamdānī* taḥqīq M. b. ʿA. al-Akwaʿ, ar-Riyāḍ.

Al-Qāḍī, W. (1986/1407). ṣūra min an-nathr al-fannī al-mubakkir fi l-Yaman ʿalā ḍawʾ kitāb al-Hamdānī ṣifat jazīrat al-ʿarab: numūdhaj Bishr b. abī Kubār al-Balawī. In taḥqīq Y. M. ʿAbdallāh (Ed.), *Al-Hamdānī, Lisān al-Yaman* (pp. 139–184). Ṣanʿāʾ, Yemen.

As-Sayyid, R. (1986/1407). Al-Yamāniyya wa-l-Qaḥṭāniyya fi l-Islām, dirāsa fī fikr al-Hamdānī as-siyāsī. In taḥqīq Y. M. ʿAbdallāh (Ed.), *Al-Hamdānī, Lisān al-Yaman* (pp. 53–71). Ṣanʿāʾ, Yemen.

Ash-Shayba, ʿA. (1986/1407). Ahammiyyat al-Hamdānī lil-jughrafiyya at-taʿrīkhiyya lil-Yaman al-qadīm. In taḥqīq Y. M ʿAbdallāh (Ed.), *Al-Hamdānī, Lisān al-Yaman* (pp. 73–82). Ṣanʿāʾ, Yemen.

Bāfaqīh, M. ʿA. (1986/1407). Al-Hamdānī wal-mathāmina. In taḥqīq Y. M. ʿAbdallāh (Ed.), *Al-Hamdānī, Lisān al-Yaman* (pp. 99–110). Ṣanʿāʾ, Yemen: Jāmiʿat Ṣanʿāʾ.

Beeston, A. F. L. (1986/1407). Hamdānī and the Tabābiʿa. In Y. M. Abdallah (Ed.), *Al-Hamdānī, a great Yemeni scholar* (pp. 5–15). Ṣanʿāʾ, Yemen: University of Sanaa.

Brockelmann, C. (1943). *Geschichte der arabischen Litteratur* (2nd ed., Vol. 1, pp. 263–264). Leiden, Netherlands: E. J. Brill. Suppl. 1, Leiden 1937, 409.

Dunlop, D. M. (1957). Sources of gold and silver in Islam according to al-Hamdānī. *Studia Islamica, 8*, 29–49.

Duri, ʿAbd al-ʿAziz. (1983). *The rise of historical writing among the Arabs* (pp. 15–17). Princeton, NJ.

Hamdani, A. (1986/1407). Al-Hamdānī [at] the outset of the domination of the Hamdān over Yaman. In Y. M. Abdallah (Ed.), *Al-Hamdānī, a great Yemeni scholar* (pp. 159–167). Ṣanʿāʾ, Yemen.

King, D. A. (1983). *Mathematical astronomy in medieval Yemen* (pp. 19–20). Malibu, CA: Undena Publications.

Löfgren, O. (1935). *Ein Hamdānī-Fund. Über das Berliner Unicum der beiden ersten Bücher des Iklīl*. Uppsala, Sweden: AB Lundeqvistska Bokhandeln. (Uppsala Universitets Årsskrift 1935:7). Review by G. Levi della Vida, Orientalia NS 6/1937: 394.

Löfgren, O. (1943). Über eine neuentdeckte bessere Textüberlieferung von al-Hamdānī's Iklīl VIII. *Orientalia, NS 12*, 135–145.

Löfgren, O. (1971). *al-Hamdānī*. *Encyclopaedia of Islam* (2nd ed., Vol. 3, pp. 124–125). Leiden, Netherland: E.J. Brill.

Löfgren, O. (1981). ʾAlqama b. Dhī Gadan und seine Dichtung nach der Iklīl-Auswahl in der Biblioteca Ambrosiana. In R. G. Stiegner (Ed.), *Al-Hudhud, Festschrift Maria Höfner zum 80. Geburtstag* (pp. 199–209). Graz, Austria: Karl-Franzens-Universität Graz.

Löfgren, O. (1986/1407). Hamdānī-discoveries. In Y. M. Abdallah (Ed.), *Al-Hamdānī, a great Yemeni scholar* (pp. 121–127). Ṣanʿāʾ, Yemen: University of Sanaa.

Madelung, W. (1986/1407). Al-Hamdānī's description of Northern Yemen in the light of chronicles of the 4th/10th and 5th/11th centuries. *Al-Hamdānī, a great Yemeni scholar* (Y. M. Abdallah, Ed., 47–59). Ṣanʿāʾ, Yemen.

Miquel, A. (1967). *La géographie humaine du monde musulman jusquʾau milieu du 11e siècle*, Paris etc., 1, 1973, 247–253 and index; 2, 1975, 33–56 and index; 3, 1980, index.

Piotrovsky, M. (1986/1407). Al-Hamdani and the Qahtanide epos. *Al-Hamdānī, a great Yemeni scholar* (Y. M. Abdallah, Ed., pp. 17–25). Ṣanʿāʾ, Yemen.

Pirenne, J. (1986/1407). Who was the Suleyman visited by al-Hamdani's Bilqis, queen of Himyar?. In Y. M. Abdallah (Ed.), *Al-Hamdānī, a great Yemeni scholar* (pp. 27–45). Ṣanʿāʾ, Yemen.

Robin, C. (1986/1407). Nihm, nubdha fi l-jughrāfiyya at-taʾrīkhiyya wafqan li-muʿṭayāt al-Hamdānī. In Y. M. ʿAbdallāh (Ed.), *Al-Hamdānī, Lisān al-Yaman*, taḥqīq (pp. 83–98). Ṣanʿāʾ, Yemen.

Robin, C. (1991). Les langues de l'Arabie au Xe siècle de l'ère chrétienne. Robin, Chr., & al., *L'Arabie antique de Karibʾīl à Mahomet* (pp. 103–108). Nouvelles données sur l'histoire des Arabes grâce aux inscriptions, Aix-en-Provence.

Ryckmans, J. (1986/1407). The Arabic letter-order according to al-Hamdānī. In Y. M. Abdallah (Ed.), *Al-Hamdānī, a great Yemeni scholar* (pp. 85–90). Ṣanʿāʾ, Yemen.

Sayyid, A. F. (1974). *Maṣādir taʾrīkh al-Yaman fi l-ʿaṣr al-islāmī*, al-Qāhira (pp. 68–76).

Scholten, A. (1976). *Länderbeschreibung und Länderkunde im islamischen Kulturraum des 10. Jahrhunderts* (pp. 45–57). Paderborn, Germany.

Sezgin, F. (1975). *Geschichte des arabischen Schrifttums* (Vol. 2). Leiden, Netherlands: E.J. Brill. 650; 7, 1979, 164–165, 272–274.

Toll, C. (1969). Einige metrologische und metallurgische Termini im Arabischen. *Orientalia Suecana, 18*, 142–152. on *Kitāb al-Jawharatayn*.

Toll, C. (1970–1971). Minting technique according to Arabic literary sources. *Orientalia Suecana 19–20*, 125–139 (on *Kitāb al-Jawharatayn*).

Toll, C. (1972). al-Hamdānī. *Dictionary of scientific biography* (6th ed, pp. 79–80). New York.

Toll, C. (1984a). Dialektale Züge in al-Hamdānī's Kitāb al-Jawharatayn. *Zeitschrift für arabische Linguistik, 13*, 16–26.

Toll, C. (1984b). Al-Hamdānī as a scholar. *Arabica, 31*, 307–317. *Al-Hamdānī, a great Yemeni scholar*, ed. Y. M. Abdallah, Ṣanʿāʾ 1986/1407, 47–59.

Toll, C. (1989). The 10th Maqāla of al-Hamdānī's Sarāʿir al-ḥikma. *On both sides of al-Mandab*, Ethiopian, South-Arabic and Islamic Studies presented to Oscar Löfgren (U. Ehrensvärd & Chr. Toll, Eds.). Stockholm: Swedish Research Institute in Istanbul. (Transactions Vol. 2).

Toll, C. (1990). Was bedeutet *brnz* bei al-Hamdānī? In E. Keck et al. (Eds.), *Living waters, Scandinavian orientalistic studies presented to F. Løkkegaard* (pp. 365–368). Copenhagen, Denmark: Museum Tusculanum Press.

Toll, C. The fabrication of Arabic coins. *Sigtuna papers*. Stockholm: Kungl. Vitterhets Historie och Antikvitets Akademien, & London: Spink & Son, (Commentationes de nummis saeculorum IX–XI in Suecia repertis, NS 6), Ed. K. Jonsson and B. Malmer, 1990. 331–333 (on *K. al-Jawharatayn*).

Toll, C. (1994). Al-Hamdānī – the Linnæus of al-Yaman. An Arabic philosopher and scholar a thousand years ago. In B. Knutsson (Ed.), *Yemen – present and past* (pp. 107–116). Lund, Germany: Lund University Press (Lund Middle Eastern and North African Studies 1).

Toll, C. (1997). Al-Hamdānī. In H. Selin et al. (Eds.), *Encyclopaedia of the history of science, technology and medicine in non-western cultures* (pp. 393–394). Dordrecht, Netherlands: Kluwer Academic Publishers.

Wade, R. (1986/1407). Some of the archaeological sites mentioned by Hamdani. In Y. M. Abdallah (Ed.), *Al-Hamdānī, a great Yemeni scholar* (pp. 169–172). Ṣanʿāʾ, Yemen.

Wiedemann, E. (1909). Naturschilderungen bei al-Hamdānī. *Beiträge zur Kenntnis des Orients, 7*, 18–29.

Wilson, R. (1981). Al-Hamdānī's description of Hāshid and Bakhīl. *Proceedings of the seminar for Arabian studies* 11.

Wilson, R. (1986/1407). An examination of place-names on Northern Yemen in the *Ṣifat Jazirat al-ʿArab. Al-Hamdānī, a great Yemeni scholar* (Y. M. Abdallah, Ed., pp. 173–189). Ṣanʿāʾ, Yemen.

Zayd, ʿA. M. (1981). *Muʿtazilat al-Yaman*. Bayrūt, Lebanon (a section on al-Hamdānī).

Zayd, A. M. (1981). An-NaẒariyya as-siyāsiyya fī fikr al-Hamdānī. *Al-Iklīl, 1*(3-4), 47–51.

Al-Hāshimī

F. Jamil Ragep

ʿAlī ibn Sulaymān al-Hāshimī flourished some time in the second half of the ninth century, probably somewhere in the central lands of Islam. Virtually nothing is known about him other than the fact that he wrote a rather uncritical work on *zījes* (astronomical handbooks) that nevertheless preserves a great deal of otherwise unknown or little known information. This book, *Kitāb fī ʿilal al-zījāt* (Explanation of Zījes), was written at a time before Ptolemaic astronomy had become the dominant astronomical tradition in Eastern Islam. As such, it contains considerable material about the Indian and Persian astronomical traditions, at least insofar as they were received and preserved during this early period of Islamic science.

Hāshimī mentions some 16 *zījes*, of which 2 are Greek (Ptolemy's *Almagest* and Theon's *Canon*, which is based upon it); 7 are Indian or derived mainly from Indian sources (the *Arjabhar*, the ► *Zīj al-Arkand*, the *Zīj al-Jāmiʿ*, the *Zīj al-Hazūr*, the *Zīj al-Sindhind* of al-Fazārī [eighth century] as well as a second *zīj* by him, and the *Zīj* of Yaʿqub ibn ṭariq [eighth century]); 2 are Persian but mainly Indian in inspiration (the *Zīj al-Shāh* of Khusro Anūshirwān and the *Zīj al-Shāh* of Yazdigird III); and 5 are from the ninth century and use material from these three traditions in varying degrees (the *Zīj al-Sindhind* of ► al-Khwārizmī, the *Zīj al-Mumtaḥan* of ► Yaḥyā ibn abī Manṣūr, the first Arabic *zīj* that was principally Ptolemaic, two *zījes* of Ḥabash, one mainly Indian, the other mainly Ptolemaic, and the *Zīj al-Hazārāt* of Abū Maʿshar).

Besides its importance as a historical resource, Hāshimī's work provides some valuable clues about the state of Islamic science during this early period. It is clear that the impressive number of astronomical works floating about made a work explaining them desirable, giving evidence for the vitality of science during this period. The influx of "foreign" knowledge had its detractors, though, and Hāshimī felt compelled, in a passing comment, to affirm that the cycles of Indian astronomy were not from their prophets, whatever might be claimed; nor were they for the purpose of "soothsaying", something he knows would be unIslamic. Rather he asserts that they are mathematically derivable and as such safe, an interesting and not atypical way of handling religious opposition to astronomy in Islam.

This makes the subsequent history of Islamic astronomy all the more remarkable. Indian astronomy with its cycles and computational tradition, but lacking a full-blown cosmology would, at first glance, seem to be a much more congenial tradition for Islam, which had its own religious cosmology and metaphysics. In fact Hāshimī implies as much in introducing the *Sindhind*; he also reports that Shāh Anūshirwān (sixth century) preferred Indian to Ptolemaic astronomy. So the subsequent predominance and triumph in Islam of Ptolemaic astronomy, based ultimately on Aristotelian physical principles and cosmology, was a remarkable occurrence indeed.

See Also

- ► Abū Maʿshar
- ► al-Khwārizmī
- ► *Almagest*: Its Reception and Transmission in the Islamic World
- ► Yaḥyā ibn abī Manṣūr
- ► *Zīj*

References

al-Hāshimī, ʿAlī ibn Sulaymān. (1981). *The book of the reasons behind astronomical tables (Kitāb fī ʿilal al-zījāt)*. A Facsimile Reproduction of the Unique Arabic Text Contained in the Bodleian MS Arch. Seld. A. 11 with a Trans. by Fuad I. Haddad and E. S. Kennedy and a Commentary by David Pingree and E. S. Kennedy. Delmar, New York: Scholars' Facsimiles and Reprints.

Al-Idrīsī

Sayyid Maqbul Ahmad

Abū ʿAbd Allāh Muḥammad ibn Muḥammad ibn ʿAbd Allāh ibn Idrīs, known as al-Sharīf al-Idrīsī, was one of the great Arab geographers of medieval Islam. He was born in Ceuta (Morocco) in AH 493/AD 1100 and died there in AH 560/AD 1166. Al-Idrīsī belonged to a ruling family, the Alavī Idrīsīs, who were claimants to the caliphate and had ruled in the region around Ceuta from AD 789 to 985. His ancestors were the nobles of Malaga, Spain who, unable to maintain their authority there, migrated to Ceuta in the eleventh century. Al-Idrīsī was educated in Cordoba and began traveling at a very early age. At the age of 16, he visited Asia Minor and then traveled in southern France, England, Spain, and Morocco.

This was a period of the growing power of the Normans in Europe and the Mediterranean region. It is said that Roger II (1097–1154), the Norman ruler, invited al-Idrīsī to come and stay with him in Palermo (Sicily), saying he would be safe from Muslim kings who were trying to murder him. Al-Idrīsī accepted the king's invitation and went to Palermo sometime in AD 1138 and stayed there until after the death of Roger in AD 1154. Then he returned to Ceuta.

Sicily at this time was an important center, where Arab-Islamic and Western European cultures intermingled. Roger himself was very interested in the promotion of arts and sciences, and we learn from al-Idrīsī that he was also interested in geography and astronomy. Roger gave al-Idrīsī an important task, probably from political motives, which was to construct a world map. Roger was still engaged in expanding his empire in North Africa, and thought al-Idrīsī would be a suitable person for this task. Although he was well traveled in North Africa and Europe, al-Idrīsī was not a geographer in the true sense of the word at this stage. But he began constructing the map under the patronage and supervision of Roger. Finding that the courtiers at his palace did not possess sufficient knowledge of the geography of the world, Roger sent envoys to different regions to collect fresh data. After the information was acquired, al-Idrīsī utilized only such data on which there was unanimity; the rest was discarded. He also used the Arabic geographical works which were available to him, such as the Arabic version of Claudius Ptolemy's (ca. AD 90–186) *Geography* (Arabic *Jughrāfiya*), *Kitāb ṣūrat al-Arḍ* (Book on Routes and Kingdoms) by Ibn Hawqal, *Al-Masālik wa'l Mamālik* by ▶ Ibn Khurdādhbih (AH 232/AD 846), and the lost work of al-Jayhānī entitled *Kitāb al-Masālik wa'l Mamālik*. Thus it seems that al-Idrīsī had a vast amount of geographical material on the known world at his disposal.

He worked on the map for 15 years, basing it primarily on Ptolemy's map, with some modifications. When it was completed, Roger asked him to have it carved on a round silver disc, which al-Idrīsī did with great skill with the help of artisans. The silver map had all the physical features and names of places drawn on it. Roger was so pleased with al-Idrīsī's performance that he asked him to write a book on world geography. He produced the voluminous compendium *Nuzhat al-Muṣtāq fi ikhtirāq al-ʾAfāq*, the full Arabic text of which has now been published as *Opus Geographicum* under the auspices of the Italian Institute of the Middle and Far East in Rome and the Institute of Oriental Studies at Naples University. Although the silver map has not survived, the original world map has. The *Nuzhat* is supposed to be a description of this world map. Al-Idrīsī divided the known world into seven climes (*iqlīm*) running parallel to the equator up to 64°N latitude and divided each of the climes into ten longitudinal sections. Thus there are 70 odd sectional maps, and the arrangement of the book follows the 70 divisions. In many cases, there is more information in the book than is depicted on the maps. Al-Idrīsī's world map is the most detailed and largest map drawn by any Muslim cartographer. His book is indeed a mine of information on physical, topographical, human, cultural, and political geography. From the world map and the book, one can see that his knowledge of Europe, North Africa, and West and Central Asia was much deeper and more correct and extensive than it was of South Asia or the Far East.

Al-Idrīsī had a mathematical basis for his map, but he did not provide latitudes or longitudes as al-Maghribī did, who followed the pattern of al-Idrīsī. As he tried to include all the information at his disposal, some distortions were bound to take place, especially in the northern and southern regions. For example, the shapes and positions of the islands in the Indian Ocean were distorted. Even with these errors, his book is an encyclopedia of geographical knowledge of medieval times, and was an important geographical textbook for a long time.

References

Ahmad, S. (1960). *Maqbul. India as described by al-Sharīf al-Idrīsī in His 'Kitāb Nuzhat al-Muṣtāq fi ikhtirāq al-ʾĀfāq'*. Leiden, Netherland: E. J. Brill.

Ahmad, S. (1970–1980). al-Idrīsī. *Dictionary of scientific biography* (C. C. Gillispie, Ed., Vol. 7, pp. 7–9). New York: Charles Scribner's Sons.

Ahmad, S. (1992). Cartography of al-Sharīf al-Idrīsī. *The history of cartography*. Vol. 2, Book 1. *Cartography in the traditional Islamic and south Asian Societies* (pp. 156–176). Chicago: University of Chicago Press.

Ahmad, S. (1995). *A history of Arab-Islamic geography*. Mafraq, Jordan: Al al-Bayt University.

al-Idrīsī. *Opus Geographicum* (E. Cerulli and A. Bombaci, Eds., 1970). Naples, Italy: Istituto Universitario Orientale di Napoli.

Oman, G. (1960). al-Idrīsī. *Encyclopaedia of Islam*. Vol. 3. Leiden: E. J. Brill, 1960. 1032-5.

Oman, G. (1961). Notizie bibiliografiche sul geografo arabo al-Idrīsī (XII secolo) e sulle sue opere. *Annali dell'Istituto Universitario Orientale di Napoli, 11*, 2561.

al-Jabarti

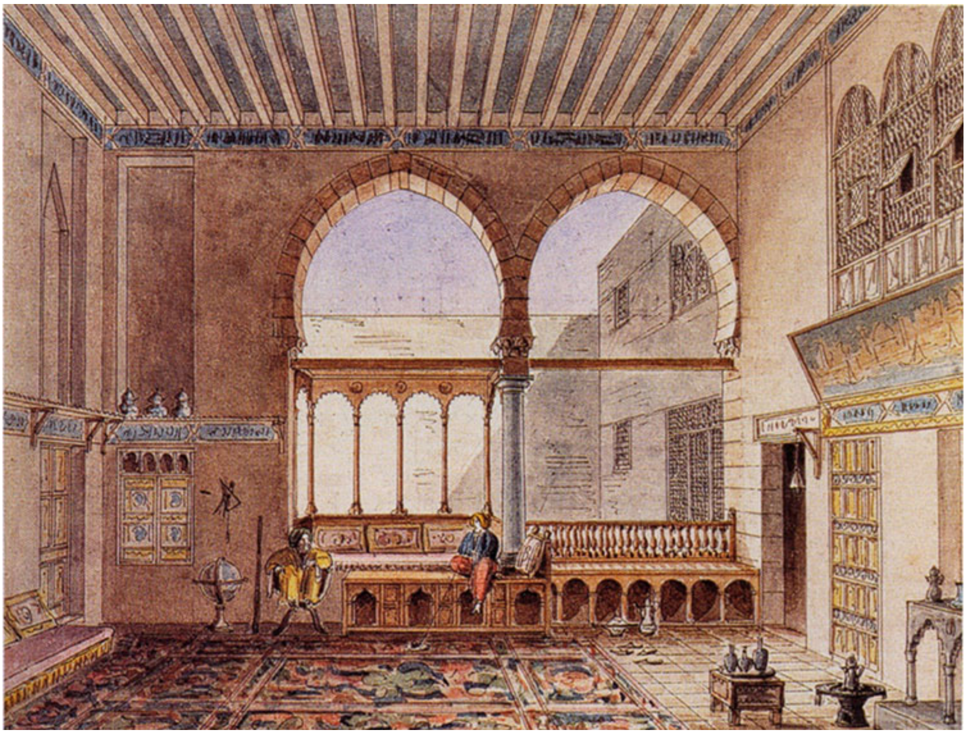
Jane H. Murphy
Colorado College, Colorado Springs, CO, USA

Abd al-Raḥmān al-Jabartī (1753–1825 CE) was born and died in Cairo. He was a prominent member of the Islamic religious scholarly class (the *ulamāʾ*) and witness to both Bonaparte's invasion and the short-lived French occupation of Egypt (1798–1801). He also experienced the rise to power in Egypt of the Albanian military commander, Mehmet Ali Pasha (1769–1849), who would ultimate declare himself Khedive of Egypt as Ottoman forces reestablished themselves in the years following the negotiated French withdrawal (Fig. 1).

Al-Jabartī is widely cited in modern scholarship because of three works, written in his native Arabic, that addressed eighteenth and early nineteenth-century Egypt and the dramatic figures of Bonaparte and Mehmet Ali. We have extant copies of both of al-Jabartī's accounts of the French occupation, one written 7 months into the occupation and another version penned following French withdrawal. His major work, and by far the lengthiest manuscript, chronicled Egypt from the start of the twelfth century *Hijri* (the Islamic calendric system, corresponding to 1688 CE) and continued, with the author circulating updates, to the end of al-Jabartī's life. Despite the ostensible breadth of the chronicle, spanning more than 130 years, the vast majority of the text dealt with the period of al-Jabartī's lifetime. Whether completely accurate or not, al-Jabartī claimed that "most of the events [in the four volumes] are tribulations which we have experienced and matters which we have witnessed." This work interwove accounts of events in Cairo and its environs, organized chronologically, with biographies of important figures who had died in the same year. He entitled his major work, *'Ajā'ib al-āthār fil-tarājim wal-akhbār* (*Marvels of Evidence Concerning Lives and Events*), although it is known in English as al-Jabartī's *History of Egypt*.

Historians of Arab and Ottoman society have long turned to al-Jabartī's texts for evidence concerning many aspects of daily life in an Arab-Ottoman city over the eighteenth and early nineteenth centuries. Despite such reliance on his work, however, al-Jabartī himself remains little studied, and the first critical edition of his major work has just been published by Shmuel Moreh.

Al-Jabartī's biographies followed many of the conventions of Islamic biographical dictionaries,



al-Jabarti, Fig. 1 There is much we do not know about al-Jabartī's family and life; however, by his own account, he grew up in the prosperity of a family that owned three houses in and around Cairo and many male and female slaves. Al-Jabartī reported he was the only one of his father's forty children to survive past adolescence. *Interior view of Cairene home believed to be that of al-Jabartī seated on the left. Watercolor, Pascal Coste*

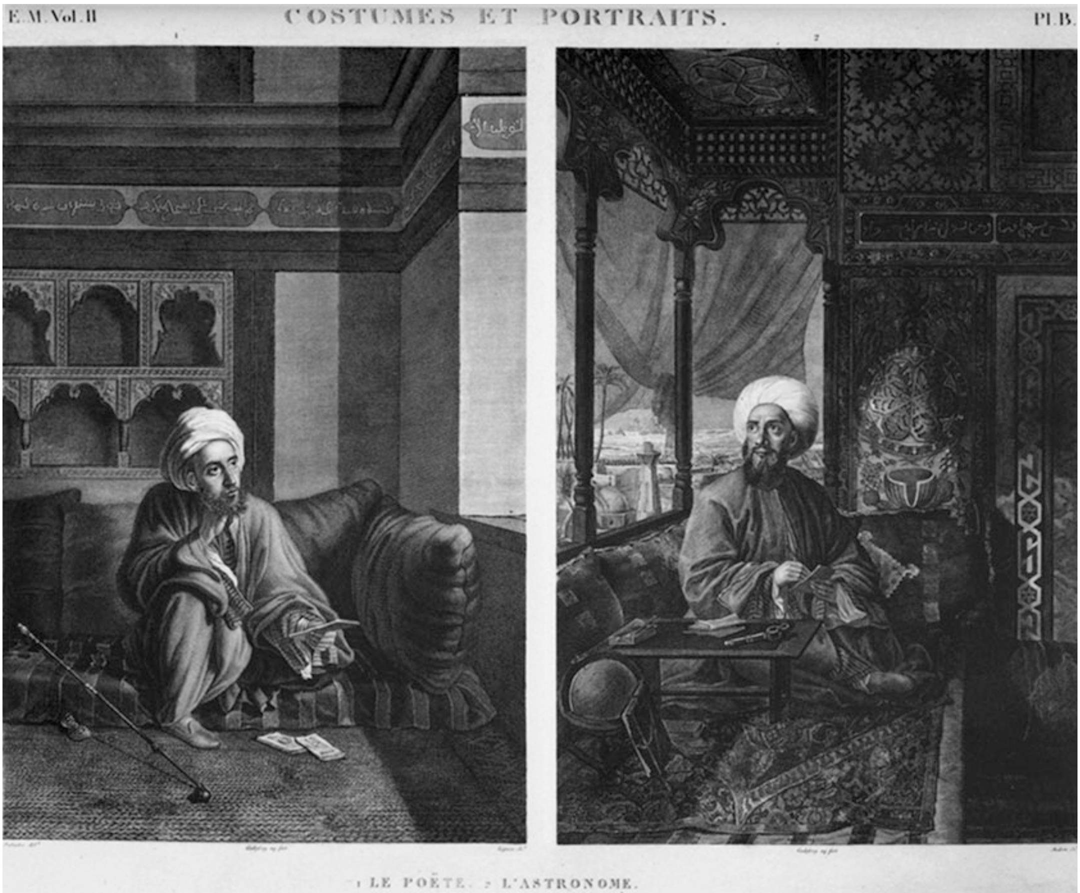
giving information about the texts studied and written, the teachers and students, of various members of the religious scholarly class and high-ranking members of the military and government classes. In the course of these accounts of lives and events, al-Jabartī provided more than 600 biographies. Many biographies recounted students and scholars of what he called the "well-known sciences" of Islamic jurisprudence and theology. However, al-Jabartī's text provided sustained attention to patrons and students pursuing what he and others from the period called "the less common sciences," investigations including branches of mathematics, weights and measures, astronomy, astrology, timekeeping, medicine, and various forms of divination. These practitioners made up more than one in eight of his biographies and were often the subject of detailed and effusive praise. While al-Jabartī's text did not exclusively focus on such figures, they formed a significant element of his chronicle of Egypt and have begun to attract the attention of historians of science (Fig. 2).

Al-Jabartī's views on French science had already attracted the attention of an earlier generation of historians. Because al-Jabartī chronicled the French occupation of Egypt, leaving to posterity a rare account of European occupation from the receiving end, scholars have used his work to understand European and Islamic encounters quite broadly. Bonaparte self-consciously sought to bring European sciences to Egypt – or rather, since he and others believed that many of the sciences had their origins in Pharaonic Egypt, they spoke of "returning" the sciences to their homeland – and the French staged a number of marvels and popular scientific demonstrations in Cairo during their occupation. Al-Jabartī's responses have been used to gauge Muslim attitudes to European science quite broadly (Fig. 3).

al-Jabarti, Fig. 2 (**a**) and (**b**) Commissioned instruments from the eighteenth century: a sundial produced for Cairo by a scholar noted by al-Jabartī. (Marble sundial, 1188 A. H./1774 C.E., Cairo Museum of Islamic Art, no. 12630). A luxury illuminated box descripting the proper direction of prayer for cities under Ottoman control. (Round wooden box with illustration of the Ka'ba, a map of the Islamic world and a compass, 1152 A.H./1739 C.E., Cairo, Museum of Islamic Art, no. 3348)

Bonaparte made scientific expertise central to his plans for turning Egypt into a French colony. He enlisted 120 scholars and engineers to accompany his troops in the invasion and tasked them with establishing a scientific institute in Cairo, which they did almost immediately. French *savants*, as they were called at that time, also staged scientific demonstrations and marvels of the kind that were sweeping towns and cities across eighteenth-century Europe and beyond. Electricity and "new" chemistry engaged audiences around the world, from Philadelphia to Edo. From Bonaparte's memoirs, it appears he envisioned the cumulative force of these displays alongside his military strength leading the Cairene elite to willingly become Frenchmen. In this, Bonaparte did not prove prescient (Fig. 4).

Al-Jabartī's French contemporaries voiced frustration at the difficulties they faced in their occupation, from continued uprisings in Cairo to disappointing responses to marvels like the *montgolfière* balloon. Edmé François Jomard was present at the first balloon's launch, and his assessment is often quoted to show the lack of curiosity or even antagonism toward science among the local population: "The Africans, uneasy to show emotion and well-guarded against the arts of the Europeans," were seen walking along al-Azbakiya square "not even deigning to lift their heads." However, al-Jabartī's report was quite different. He claimed that, "The people, as usual, raised a great din about [the announced balloon launch]. On the afternoon of this day the people and many

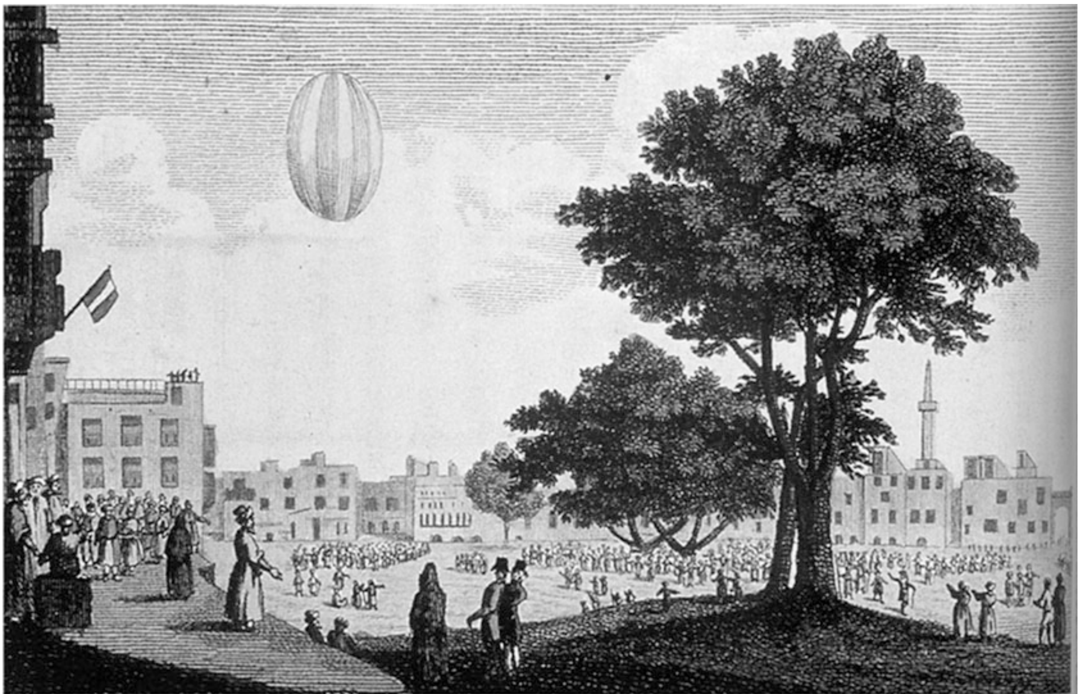


al-Jabarti, Fig. 3 Andre Raymond suggested that al-Jabartī was the model for the astronomer in this French engraving that circulated in Europe as part of the massive *Description of Egypt*

Frenchmen assembled to observe this marvel." Al-Jabartī was present and took evident pleasure in describing the shortcomings of the balloon that soon tipped over and crashed to the ground. "The French were embarrassed at its fall. Their claim that this apparatus is like a vessel in which people sit and travel to other countries in order to discover news and other falsifications did not appear to be true. On the contrary, it turned out that it is like kites which household servants build for festivals and happy occasions."

The scientific marvels put on by Berthollet, Conte, and others have been examined in terms of al-Jabartī's reaction to, in the words of one modern scholar, "European science and technology [which] had developed to an extent that the Islamic world could not imagine" after the "atrophy of the military power and the culture of Islam." Another modern scholar has concluded that "[t]heir apparent indifference is without doubt a sort of self-protection, as if this imported science threatened their identity."

Recent scholarship challenging the picture of European science as so easily disentangled from European colonialism has questioned the claim that al-Jabartī's opposition to French colonization or his criticism of some French displays should be equated with hostility toward scientific enterprises in general or even everything that the French shared with him. Al-Jabartī described the French astronomical instruments, for example, in glowing detail. Moreover, scholars have begun to pay attention to al-Jabartī's own study of medicine and astronomy and the extensive network of patrons,



Envol d'une montgolfière au Caire, d'après J. B. Breton.

al-Jabarti, Fig. 4 One French public marvel was a hot air balloon launched in a fashionable district of Cairo. Al-Jabartī also recorded circle shocks demonstrating the Leyden jar's effects and Berthollet's chemical transformations of various liquids and powders into colored smoke and solids

scholars, and teachers of the sciences that are recorded in his writings. Manuscript catalogs show that al-Jabartī was not alone in these interests. We have thousands of extant manuscripts in astronomy, astrology, mathematical topics, divination, and medicine from eighteenth-century Cairo alone.

In fact, there are so many manuscripts of this sort in multiple libraries that they have not all been cataloged, much less studied. Ultimately, we will reach a clearer understanding of al-Jabartī, and why certain practices and practitioners garnered his praise or disdain when a sharper image of the wide range of Arabo-Ottoman scientific study emerges from these manuscripts.

References

Al-Jabartī, A. A. R. (1994). *Abd al-Rahman al-Jabartī's History of Egypt* (T. Philipp & M. Perlmann, Trans.). 4 vols. Stuttgart, Germany: Franz Steiner Verlag, Stuttgart.

al-Jabartī, Abd al-Raḥmān, & Moreh, S. (Trans.). (1975). *Tārīkh muddat al-Faransīs bi-Miṣr: Muḥarram – Rajab 1213 H, 15 Yūniyū – Dīsimbir 1798*. The Netherlands: Brill, Leiden.

al-Jabartī, Abd al-Raḥmān, Louis Antoine Fauvelet de Bourrienne, Said, E. W., & Tignor, R. L. (Eds.). (1993). *Napoleon in Egypt: Al-Jabartī's chronicle of the first seven months of the French occupation, 1798*. Princeton, NJ: M. Wiener.

al-Jabartī, Abd al-Raḥmān, Philipp, T., & Perlmann, M. (1994). *Abd al-Raḥmān al-Jabartī's History of Egypt: Ajā'ib al-Āthār fī 'l-Tarājim wa'l-Akhbār*. Stuttgart, Germany: Franz Steiner Verlag Stuttgart.

al-Sayyid Marsot, A. L. (1973). The political and economic functions of the 'Ulama' in the 18th century. *Journal of the Economic and Social History of the Orient, 16*(Parts II–III), 130–154.

Ayalon, D. (1960). The historian al-Jabartī and his background. *Bulletin of the School of Oriental and African Studies, 23*(2), 217–249.

Behrens-Abouseif, D. (1989). The image of the physician in Arab biographies of the post-classical age. *Der Islam, 66*, 331–343.

Delanoue, G. (1978). Abd al-Rahman al-Jabartī un historien egyptien entre deux mondes. In C.-A. Julien et al. (Eds.), *Les Africains* (Vol. X, pp. 121–149). Paris: Editions J.A.

Gibb, H. A. R., & Bowen, H. (1950). *Islamic society and the West; a study of the impact of Western civilization on Moslem culture in the Near East*. London/New York: Oxford University Press.

Gran, P. (1979). *Islamic roots of capitalism: Egypt, 1760–1840*. Austin, TX: University of Texas Press.

Gran, P. (1997). Egypt, 1760–1815: A period of enlightenment? Reflections on the origins of modern Egyptian history. In T. Abdullah et al. (Eds.), *Arab and Islamic studies in honor of Marsden Jones* (pp. 73–94). Cairo, Egypt: American University in Cairo Press.

Livingston, J. W. (1997). Shaykhs Jabartī and Attar: Reaction and response to Western science in Egypt. *Der Islam, 74*(1), 92–106.

Philipp, T., & Schwald, G. (1994). *A guide to Abd al-Raḥmān al-Jabartī's History of Egypt: 'Ajā'ib al-āthār fī 'l-tarājim wa'l-akhbār*. Stuttgart, Germany: Franz Steiner Verlag.

Al-Jawharī

Sonja Brentjes

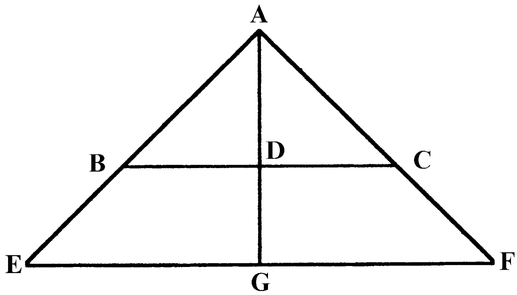
Probably of Iranian origin, al-ʿAbbās Ibn Saʿīd al-Jawharī was one of the court astronomers/astrologers of Caliph ▶ al-Maʾmūn (r. 813–833) in charge of the construction of astronomical instruments. He participated in astronomical observations carried out in Baghdad in 829–830 and in Damascus in 832–833. He is said to have composed an astronomical handbook (▶ *Zīj*), which is lost, except for indirect references (Sezgin, 1973). In his house in Baghdad, meetings were held at which the participants discussed Ptolemy's *Almagest*, Euclid's *Elements*, and problems derived from the two books. A not yet studied manuscript, *Kalām fī maʿrifat buʿd al-shams ʿan markaz al-arḍ* (Speech about the Knowledge of the Distance between the Sun and the Center of the Earth), might be an extract of his *Zīj* or an independent astronomical treatise. In astrology, he was considered an expert at horoscopes determining an individual's length of life.

His main achievements in the mathematical sciences are in geometry. He edited or commented on the *Elements*. Extracts of this work are preserved as independent manuscripts containing fragments of his *Ziyādāt fī'l-maqāla al-khāmisa min kitāb Uqlīdis* (Additions to Book V of Euclid's Book) and as quotations of his attempted proof of the parallel postulate (Book I) in Naṣīr al-Dīn al-Ṭūsī's *al-Risāla al-shāfiya ʿān al-shakk fī'l-khuṭūṭ al-mutawāziya* (The Healing Treatise on the Doubt Concerning Parallel Lines). In this treatise, al-Ṭūsī also cites one of al-Jawharī's additions to Book I, namely that the angles contained by three lines drawn from one point in different directions equal four right angles.

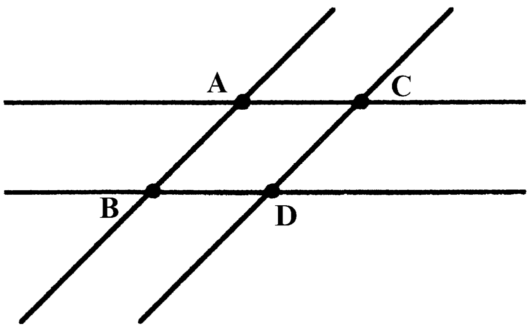
Al-Jawharī's attempted proof of the postulate was contained in the same edition of the *Elements* as the aforementioned additional proposition. It evidently was inspired by the proofs of Simplikios (sixth century) and Aghānīs/Aghānyūs (Agapios?, fl. ca. 511), since he used the same variant of the so-called Eudoxos-Archimedes axiom as Aghānīs and at least two propositions attributed by ʿAlam al-Dīn Qayṭar (d. 1251) to Simplikios. Since both proofs were contained in Simplikios' commentary on the definitions, postulates, and axioms, its Arabic translation obviously was made in the first half of the ninth century.

The theorem upon which al-Jawharī's proof is built states principally that if a triangle ABC is divided by a line AD and this line and the two sides AB and AC are extended and cut by a line EF such that $AB = BE$ and $AC = CF$, then $AD = DG$ with G being the point of intersection between line EF and the extension of line AD (see Fig. 1).

The proof of this proposition and consequently the proof of the postulate ultimately depend upon two propositions possibly introduced by al-Jawharī himself. The problem of the whole proof lies in the incomplete proof of the second part of the first of the two theorems, which al-Ṭūsī had already discovered. This second part states principally that the distance between one point of a line and its "corresponding" point on a second, parallel line always equals the distance between a second point on the first line and its "corresponding" point on the second line,



Al-Jawharī, Fig. 1 Jawharī's theorem



Al-Jawharī, Fig. 2 The distance between one point of a line and its corresponding point on a second, parallel line always equals the distance between a second point on the first line and its corresponding point on the second

$AC = BD$ (Fig. 2). Al-Jawharī's proof of this part not only treats a special case, but also fails to prove the equality of the two joining lines.

The fragment of al-Jawharī's additions to Book V contains three propositions which try to prove Euclid's definitions V, 5 (identity of ratios), V, 7 (one ratio > a second ratio), and the negation of definition V, 5. This illustrates how difficult those definitions were. Usually, a definition is not proven, since it was regarded as an evident assumption or a statement agreed upon between scholars. Al-Jawharī's explanations dressed as formal proofs do not really clarify those definitions, since all he did was simply to repeat them for special objects, namely, natural numbers.

Al-Jawharī is also credited with the translation from Persian into Arabic of a book about poison of supposed Indian origin, the so-called *Kitāb al-Shānāk* (The Book of Shānāk), for ► al-Maʾmūn.

See Also

- ► *Almagest*: Its Reception and Transmission in the Islamic World
- ► al-Maʾmūn
- ► Astronomical Instruments in the Islamic World
- ► Naṣīr al-Dīn al-Ṭūsī
- ► *Zīj*

References

Primary Sources

al-Ṭūsī, Naṣīr al-Dīn. (1359). *al-Risāla al-shāfiya ʿān al-shakk fīʾl-khuṭūṭ al-mutawāziya*. Hyderabad, Dār al-Maʿārif. 17–24.

de Young, G. (1997). Al-Jawhari's additions to book V of Euclid's "elements". *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften Bd, 11*, 153–178.

Ibn al-Qifṭī. (1903) In Lippert, J. (Ed.), *Taʾrīkh al-ḥukamāʾ*. Leipzig, Germany: Harrassowitz.

Kalām fī maʿrifat buʿd al-shams ʿan al-arḍ. MS Bairūt, American University 223.

Zīyādāt fī l-maqāla al-khāmisa min kitāb Uqlīdis. MS Tunis, Aḥmadīya 16167; MS Istanbul, Feyzullāh 1359; Tehran, Dānishkadehi Adab. Ğ 284; Hyderabad, Osmaniya University Library A 510.

Secondary Sources

Jaouiche, K. (1986). *La théorie des parallèles en pays d'Islam: contribution à la préhistoire des géometries non-euclidiennes*. Paris: J. Vrin.

Kennedy, E. S. (1956). A survey of Islamic astronomical tables. *Transactions of the American Philosophical Society, 46*(2), 123–177.

Rosenfeld, B. A. (1988). *A history of non-Euclidean geometry. Evolution of the concept of a geometric space*. New York: Springer.

Sabra, A. S. (1969). Simplicius's proof of Euclid's parallels postulate. *Journal of the Warburg and Courtauld Institutes, 32*, 1–24.

Sabra, A. S. (1973). al-Jawharī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. VII, pp. 79–80). New York: Charles Scribner's Sons.

Sezgin, F. (1970). Geschichte des Arabischen Schrifttums. Leiden, Netherlands: Brill. Vols. III, V, and VI, 1970, 1973, and 1974.

Al-Jazarī

Donald R. Hill

Al-Jazarī, Badīʾ al-Zamān Abū'l-ʻIzz Ismaʿil ibn Al-Razzāz, was an engineer who worked in al-Jazira during the latter part of the twelfth century. His reputation rests upon his book, *Kitāb fī maʿrifat al-ḥiyal alhan-dasiyya* (The Book of Knowledge of Ingenious Mechanical Devices), which he composed in 1206 on the orders of his master Nāsir al-Dīn Maḥmūd, a prince of the Artuqid dynasty of Diyar Bakr. All that we know of his life is what he tells us in the introduction to his book, namely that at the time of writing he had been in the service of the ruling family for 25 years. The book is divided into six categories (*nawʿ*). Each of the first four contains ten chapters (*shakl*), and the last two consist of only five each. The categories are as follows:

1. Water clocks and candle clocks
2. Vessels and pitchers for use in carousals or celebrations
3. Vessels and basins for hand washing and phlebotomy
4. Fountains and musical automata
5. Water lifting machines
6. Miscellaneous

There are many illustrations, both of general arrangements and detailed drawings, and these are of considerable assistance in understanding the text, which contains many technical expressions that have since fallen into disuse. Some 13 manuscript copies, made between the thirteenth and the eighteenth centuries, are extant to bear witness to the widespread appreciation of the book in the Islamic world.

There are, however, no references to al-Jazarī in the standard Arabic biographical works of the Middle Ages, and there is no known translation into a European language before the twentieth century.

Only one of the complete machines, a twin cylinder pump driven by a paddle-wheel, can be said to have direct relevance to the development of mechanical technology. Many of the devices, however, embody techniques and mechanisms that are of great significance, since a number of them entered the general vocabulary of European engineering at various times from the thirteenth century onward. Some of these ideas may have been received directly from al-Jazarī's work, but evidence is lacking. Indeed, it seems probable that a large part of the Islamic mechanical tradition – especially water clocks and their associated mechanisms and automata – had been transmitted to Europe before al-Jazarī's book was composed. Even leaving aside the question of direct transmission, we still have a document of the greatest historical importance. First, it confirms the existence of a tradition of mechanical engineering in the Eastern Mediterranean and the Middle East from Hellenistic times up to the thirteenth century. Al-Jazarī was well aware that he was continuing this tradition and was scrupulous in acknowledging the work of his predecessors, including Apollonius of Byzantium, the Pseudo-Archimedes, the ▶ Banū Mūsā (ninth century), Hibat Allah ibn al-ḥusayn (d. 1139–1140), and a certain Yūnus al-Asṭurlābī.

Other writings and constructions, whose originators were unknown to al-Jazarī, are also mentioned.

Second, his use of and improvement upon the earlier works, together with his meticulous descriptions of the construction and operation of each device, enables us to make an accurate assessment of mechanical technology by the close of the twelfth century.

See Also

- ▶ Banū Mūsā
- ▶ Engineering
- ▶ Technology in the Islamic World

References

al-Hassan, A. Y. (Ed.). (1981). *Kitāb al-ḥiyal (The Arabic edition)*. Aleppo, Syria: Institute for the History of Arabic Science.

Hill, D. R. (1991). Arabic mechanical engineering: Survey of the historical sources. *Arabic Sciences and Philosophy, 1*(2), 167–186.

Hill, D. R. (Trans.) (1979). *The book of ingenious devices by the Banū Mūsā* (The English edition of *Kitāb al-ḥiyal*). Dordrecht, The Netherlands: Reidel.

King, D. A., & Hill, D. R. (Eds.). (1998). *Studies in medieval Islamic technology: From Philo to al-Jazari, from Alexandria to Diyar Bakr*. Aldershot, UK: Ashgate.

Al-Jurjānī

E. Ruth Harvey

Abū'l-Fadā'il Ismā'īl ibn al-ḥusayn al-Jurjānī, Zayn al-Dīn, sometimes called Sayyid Ismā'īl, was the most eminent Persian physician after ▶ Ibn Sīnā (Avicenna), and the author of the first great medical compilation written in Persian. Born at Jurjan, 50-mile east of modern Gurgan, east of the Caspian, he was a pupil of Ibn Abī ṣādiq (d. 1066–1077), who had himself been a pupil of Ibn Sīnā. In 1110 al-Jurjānī entered the service of the ruler of Khwarizm (modern Khiva), the Khwārizmshāh Quṭb al-Dīn Muhammad (d. 1127) and his son Atsiz; later he moved to Marw (Merv) and served the rival sultan Sanjar. Al-Jurjānī died at Marw in about 1136 (AH 531).

Al-Jurjānī's great work is entitled *Dhakhīra-i-Khwārazmshāhī* (The Thesaurus of the King of Kharazm). Comparable in size and scope to Avicenna's *Canon*, the *Thesaurus* is a compendium of medical knowledge and clinical practice. It rapidly became a classic and established the medical and scientific vocabulary in Persian; its influence was extensive and long-lasting. It was translated into Hebrew, Urdu, and Turkish, and remained in use until the nineteenth century. There are many manuscripts, both complete and fragmentary, but no available modern edition (although Keshavarz records an Indian edition of 1865–1866, and one produced in Tehran in 1965).

In addition to the *Thesaurus*, al-Jurjānī composed other works in Persian which appear to be, in the main, abridgements of it. Chief among these is the condensed version called *Mukhtaṣar-i Khuffī-i ʿAlāʾī* (Abridgement for the Boots of Alāʾ) in two long volumes for Shah Atsiz to carry in his tall riding boots. This work was printed in Agra (1852) and Cawnpore (1891), but neither edition is readily available. There are several manuscripts in Turkey, one in the British Library, and an Arabic translation in Paris and at the University of California.

The *al-Agrāḍ al-ṭibbīya* (Aims of Medicine), composed for the vizier of Atsiz, is partly another abridgement of the *Thesaurus* combined with an account of the symptoms and treatment of local diseases. The *Yadgar i-ṭibb* (or Remembrancer) is largely on pharmacology.

Al-Jurjānī's works have not been much studied, and the relationships between the various texts and translations have not been worked out. A work in Arabic, *Zubdat al-ṭibb* (Essence of Medicine), is frequently assigned to him; this is presumably a translation of one of the Persian treatises mentioned above, but it is not clear which one. Some of the other manuscript works ascribed to al-Jurjānī are probably excerpts from his lengthy books.

See Also

▶ Ibn Sīnā (Avicenna)

References

Browne, E. G. (1921). *Arabian medicine*. Cambridge, UK: Cambridge University Press.

Elgood, C. (1951). *A medical history of Persia and the eastern Caliphate*. Cambridge, UK: Cambridge University Press.

Elgood, C. (1970). *Safavid medical practice*. London: Luzac.

Ibn Abī Uṣaybiʿah. (1965). *ʿUyūn al-Anbā fī ṭabaqāt al-aṭibbāʾ*. Beirut, Lebanon: Dār Maktabat al-Ḥayāh.
Naficy, A. (1933). *La Médecine en Perse, des origins à nos jours; ses fondements théoriques d'apres l'encyclopé die medicale de Gorgani*. Paris: Éditions Vega.
Schacht, J. (1965). al-Djurdjani. *The encyclopaedia of Islam* (New ed, Vol. 2, p. 603). Leiden, Netherlands: Brill.

Al-Karajī

Jacques Sesiano

Al-Karajī Abū Bakr Muḥammad was a Persian mathematician and engineer. He held (ca. 1010–1015) an official position in Baghdad during which time he wrote his three main works.

1. His *al-Fakhrīfī'l-jabr wa 'l-muqābala* (Glorious on Algebra) contains an exposition of algebra and auxiliary topics (e.g. summing series of integers). The next and larger part is a collection of problems: some are commercial and recreational, but for the most part they belong to indeterminate algebra. All of the latter sorts are taken from Diophantus or ▶ Abū Kāmil.
2. The *Badīʿ fī'l-ḥisāb* (Wonderful on Calculation) is more original. After restating many of Euclid's theorems, al-Karajī shows how to calculate with square, cubic, and biquadratic roots and with their sums, then how to extract the root of a polynomial in x (this is the earliest known mention of the procedure). A second part contains problems on indeterminate algebra. Here, al-Karajī has taken the basic methods used by Diophantus in his problems and classified them, the result being a useful introduction to Diophantus's algebra.
3. The composition of the *Kāfī fī'l-ḥisāb* (Sufficient on Calculation) belongs to the usual duty of a mathematician holding an official position: to write a simple textbook in a way accessible to civil servants and containing the elements of arithmetic with integers and fractions (common and sexagesimal), the extraction of square roots, the determination of areas and volumes, and elementary algebra. All this is illustrated by numerous examples.
4. The *ʿIlal al-jabr wa'l-muqābala* (Grounds of Algebra) is a small compendium on basic algebra (reckoning with roots, solving the basic six forms of the equations of the first two degrees), without resort to any geometrical demonstrations.
5. The *Inbāṭ al-miyāh al-khafīyah* (Locating Hidden Waters) was written after al-Karajī's return to Persia. It is concerned with finding subterranean water, extracting it, and transporting it in accordance with the soil's configuration.

Other, lost works of al-Karajī's are known to have dealt with indeterminate algebra, arithmetic, inheritance algebra, and the construction of buildings. Another contained the first known explanation of the arithmetical (Pascal's) triangle; the passage in question survived through al-Samaʾwal's *Bāhir* (twelfth century), which heavily drew from the *Badīʿ*.

Although much of his work was taken from others' writings, there is no doubt that al-Karajī was quite an able and influential mathematician. However, the quality of his writings is uneven, as he seems to have worked hastily sometimes.

References

al-Karajī. (1941). *Inbāṭ al-miyāh al-khafīyah*. Hyderabad, India: Osmania University.
al-Karajī. (1991). *ʿIlal al-jabr wa'l-muqābala*. Ankara (*Atatürk kültūr merkezi*).
Anbouba, A. (1964). *L'Algèbre al-Badīʿ d'al-Karagī*. Beirut, Lebanon: Université libanaise.
Hochheim, A. (1878–1880). *Kâfī fīl ḥisâb* (Genügendes über Arithmetik). Halle, Germany: Nebert.
Sesiano, J. (1977). Le traitement des équations indéterminées dans le Badīʿ fi'l ḥisāb d'Abū Bakr al-Karajī. *Archive for History of Exact Sciences, 17*, 297–379.
Woepcke, F. (1853). *Extrait du Fakhrî*. Paris: Duprat.

Al-Kāshī

Boris A. Rosenfeld
PA, USA

Al-Kāshī, or al-Kāshānī (Ghiyāth al-Dīn Jamshīd ibn Masʿūd al-Kāshī (al-Kāshānī)), was a Persian mathematician and astronomer. He was born in Kāshān in northern Iran and worked at first in Herat (now in Afghanistan) at the court of *khāqān* ("khān of khāns" Shāhrukh, the son of Tīmur). In 1417 he was invited by Ulugh Beg, the son of Shāhrukh, the ruler of Samarqand (now in Uzbekistan), to become the director of his astronomical observatory. His scientific treatises were mostly written in Arabic and partly in Persian. Al-Kāshī died in Samarqand in about 1430.

Al-Kāshī's main mathematical work is *Miftāḥ al-ḥisāb* (Key of Arithmetic). This work, written in the tradition of Arabic mathematical texts, contains five books: (1) Arithmetic of Integers, (2) Arithmetic of Fractions, (3) Arithmetic of Astronomers, (4) Geometry, and (5) Algebra.

In book 1, al-Kāshī considers duplication (multiplication by 2), mediation (division into 2), addition, subtraction, multiplication, and division. As Naṣīr al-Dīn al-Ṭūsī (1201–1274) did in his arithmetic treatise, he also considers extraction of roots of arbitrary integer powers by means of what we now call the Ruffini-Horner method and expresses the approximate value of the root by means of "Newton's binomial formula" for $(a + b)^n$. In book 2, al-Kāshī introduces decimal fractions and calls the digits of these fractions "decimal minutes," "decimal seconds," "decimal thirds," etc. The arithmetic of astronomers considered in book 3 is the arithmetic of sexagesimal fractions borrowed by Islamic astronomers from Ptolemy, who in turn had borrowed them from Babylonian astronomers. Islamic astronomers designated figures from 1 to 59 by means of letters and zero by ō. Like the ancient Babylonians, al-Kāshī extended the sexagesimal system onto integers and called the sexagesimal digits "raised," "twice raised," "three times raised," etc. In book 4, the rules of mensuration of many plane and solid figures, including buildings, cupolas, and stalactite surfaces, are formulated. In book 5, besides explaining the algebraic solution of quadratic equations and equations reducible to them, al-Kāshī discusses the solutions of equations by means of the rule of two errors, actions with roots, algebraic identities, and Thābit ibn Qurra's rule for the determination of amicable numbers. Al-Kāshī claims that he wrote an algebraic treatise with the classification of equations of the fourth degree and that for every type he proposed the solution by means of the intersection of conics more general than the conics by means of which ʿUmar al-Khayyām solved cubic equations. This algebraic treatise is not extant and since the number of these equations does not coincide with those mentioned by al-Kāshī, this treatise was not finished.

The *al-Risāla al-muḥīṭiyya* (Treatise on Circumference) is devoted to the calculation of the ratio of circumferences of circles to their radii (now this ratio is designated by 2π). Al-Kāshī calculates the perimeters of regular inscribed and circumscribed polygons with 3.2^{28} sides. The number of sides is chosen on the condition that the difference between these polygons for the great circle of the sphere of fixed stars must be less than the "width of a horse hair." The result is expressed in sexagesimal and decimal fractions.

In the *Risāla al-watar wa'l-jayb* (Treatise on Chord and Sine), al-Kāshī calculates the sin 1° according to the known sin 3°. This problem was necessary for the composition of the tables of sines with five sexagesimal digits in Ulugh Beg's *Zīj-i Ulugh Beg* (Ulugh Beg's *Astronomical Tables*). This problem was reduced to the cubic equation $4x^3 + q = 3x$ $(x = \sin 1°, q = \sin 3°)$ and was solved by the method of successive approximations:

$$x_1 = \frac{q}{3'}, \quad x_2 = \left(\frac{q + 4x_1^3}{3}\right), \ldots$$

Boris A. Rosenfeld: deceased

In the field of astronomy, al-Kāshī was the author of *Zīj-i Khāqānī* (Khāqān Astronomical Tables) written in 1413–1414 in Herat. He also composed a treatise on astronomical instruments written in 1416 dedicated to the ruler of Iṣf āḥān Iskandar, who was the nephew of Shāhrukh, and was one of the authors of Ulugh Beg's *Astronomical Tables*. He was also the translator of the last tables from Persian into Arabic. In the treatise *Nuzha al-ḥadāiq* (Delight of Gardens), al-Kāshī describes an instrument for the representation of the movements of planets which he invented. He was also the author of numerous other astronomical treatises.

References

Bagheri, M. (1997). A newly found letter of al-Kashi on scientific life in Samarkand. *Historia Mathematica, 24*, 241–256.

Bagheri, M. (2000). A new treatise by al-Kashi on the depression of the visible Horizon from China to Paris: 2000 years transmission of mathematical ideas. In *Proceedings of a conference held in Bellagio*, Italy, 8–12 May 2000. Stuttgart: Steiner, pp. 357–368.

Cooper, G. M. (2007). Khafrī: Shams al-Dīn Muḥammad ibn Aḥmad al-Khafrī al-Kāshī. In *The biographical encyclopedia of astronomers* (pp. 623–624). New York: Springer.

Dold-Samplonius, Y. (1996). How al-Kashi measures the Muqarnas: A second look. In F. Menso (Ed.), *Mathematische Probleme im Mittelalter: Der lateinische und arabische Sprachbereich* (pp. 57–90). Wiesbaden: Harrassowitz.

Ǧamšīd, b. Masʿūd al-Kāṣī. (1953). Der Lehrbrief über der Kreisum-fang (ar-Risāla al-Muḥīṭiyyaa). In A. S. von Herausg (Ed.), *Übersetzt und erläutert von P*. Luckey. Berlin: Akademie-Verlag.

Jamshīd Ghiyāth al-Dīn al-Kāshī. (1956). *Key of arithmetics. Treatise on circumference*. Moscow: Gostehizdat (Arabic with Russian translations by B. A. Rosenfeld).

Kennedy, E. S. (1960). *The planetary equatorium of Jamshīd Ghiyāth al-Dīn al-Kāshī*. Princeton: Princeton University Press.

Luckey, P. (1951). *Die Rechenkunst bei Ǧamšīd b. Masʿūd al-Kāšī mit Rückblicken auf die ältere Geschichte des Rechnen*s (Abhandlungen für die Kunde des Morgenlandes, Bd. 31). Wiesbaden: F. Steiner.

Matvievskaya, G. P., & Rosenfeld, B. A. (1983). *Mathematicians and astronomers of Medieval Islam and their works (8–17th centuries) (in Russian)* (pp. 480–486). Moscow: Nauka.

Van Dalen, B. (2006). Taking latitude with Ptolemy: Jamshīd al-Kāshī's novel geometric model of the motions of the inferior planets. *Archive for History of Exact Sciences, 60*, 353–377. *Abstracta Iranica. Revue bibliographique pour le domaine irano-aryen* (Vol. 29).

Youschkevitch, A., & Rosenfeld, B. (1973). Al-Kāshī (or al-Kāshāni). In C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 7, pp. 255–262). New York: Scribner.

Al-Khalīlī

David A. King
Frankfurt University, Frankfurt am Main, Germany

Al-Khalīlī, Shams al-Dīn Abū ʿAbdallāh Muḥammad ibn Muḥammad, lived in Damascus, ca. 1365. He was an astronomer associated with the Umayyad Mosque in the center of Damascus. A colleague of the astronomer Ibn al-Shāṭir, he was also a *muwaqqit* – that is, an astronomer concerned with *ʿilm al-mīqāt*, the science of timekeeping by the sun and stars and regulating the astronomically defined times of Muslim prayer. Al-Khalīlī's major work, which represents the culmination of the medieval Islamic achievement in the mathematical solution of the problems of spherical astronomy, was a set of tables for astronomical timekeeping. Some of these tables were used in Damascus until the nineteenth century, and they were also used in Cairo and Istanbul for several centuries. The main sets of tables survive in numerous manuscripts, but they were not investigated until the 1970s.

Al-Khalīlī's tables can be categorized as follows:

- Tables for reckoning time by the sun, for the latitude of Damascus
- Tables for regulating the times of Muslim prayer, for the latitude of Damascus
- Tables of auxiliary mathematical functions for timekeeping by the sun for all latitudes
- Tables of auxiliary mathematical functions for solving the problems of spherical astronomy for all latitudes

- A table displaying the *qibla*, that is, the direction of Mecca, as a function of terrestrial latitude and longitude
- Tables for converting lunar ecliptic coordinates to equatorial coordinates

The first two sets of tables correspond to those in the large corpus of spherical astronomical tables computed for Cairo that are generally attributed to the tenth-century Egyptian astronomer Ibn Yūnus.

Al-Khalīlī's fourth set of tables was designed to solve all the standard problems of spherical astronomy, and they are particularly useful for those problems that, in modern terms, involve the use of the cosine rule for spherical triangles. Al-Khalīlī tabulated three functions and gave detailed instructions for their application. The functions are as follows:

$$f_\phi(\theta) = \frac{\sin\theta}{\cos\phi} \text{ and } g_\phi(\theta) = \sin\theta \tan\phi,$$
$$K(x,y) = \arccos\left(\frac{x}{R\cos y}\right),$$

computed for appropriate domains. The entries in these tables, which number over 13,000, were computed to two sexagesimal digits and are invariably accurate. An example of the use of these functions is the rule outlined by al-Khalīlī for finding the hour-angle t for given solar or stellar altitude h, declination δ, and terrestrial latitude φ. This may be represented as:

$$t(h,\delta,\phi) = K\left\{\left(f_\phi(h) - g_\phi(\delta)\right), \delta\right\},$$

and it is not difficult to show the equivalence of al-Khalīlī's rule to the modern formula

$$t = \arccos\left(\frac{\sin h - \sin\delta \sin\phi}{\cos\delta \cos\phi}\right).$$

These auxiliary tables were used for several centuries in Damascus, Cairo, and Istanbul, the three main centers of astronomical timekeeping in the Muslim world.

Al-Khalīlī's computational ability is best revealed by his *qibla* table. The determination of the *qibla* for a given locality is one of the most complicated problems of medieval Islamic trigonometry. If (L, φ) and (L_M, φ_M) represent the longitude and latitude of a given locality and of Mecca, respectively, and $\Delta L = |L - L_M|$, then the modern formula for $q(L, \varphi)$, the direction of Mecca for the locality, measured from the south, is

$$q = \arccos\left(\frac{\sin\phi \cos\Delta L - \cos\phi \tan\phi_M}{\sin\Delta L}\right).$$

Al-Khalīlī computed $q(\varphi, L)$ to two sexagesimal digits for the domains $\varphi = 10°, 11°, \ldots, 56°$ and $\Delta L = 1°, 2°, \ldots, 60°$; the vast majority of the 2,880 entries are either accurately computed or in error by $\pm 1'$ or $\pm 2'$. Several other *qibla* tables based on approximate formulas are known from the medieval period. Al-Khalīlī's splendid qibla table does not appear to have been widely used by later Muslim astronomers.

See Also

- ▶ Ibn al-Shāṭir
- ▶ Ibn Yūnus
- ▶ *Qibla* and Islamic Prayer Times
- ▶ Sexagesimal System

References

Primary Sources

MS Paris B.N. ar. 2558, copied in 1408 (contains all of the tables in al-Khalīlī's major set).

Secondary Sources

King, D. A. (1973). Al-Khalīlī's auxiliary tables for solving problems of spherical astronomy. *Journal for the History of Astronomy, 4*, 99–110. Reprint in King, D. A. *Islamic mathematical astronomy* (2nd Rev. ed.). London: Variorum, 1986, Aldershot: Variorum, 1993, XI.

King, D. A. (1975). Al-Khalīlī's Qibla table. *Journal of Near Eastern Studies, 34*, 81–122. Reprint in Islamic Mathematical Astronomy (2nd Rev. ed.). London: Variorum, 1986, Aldershot: Variorum, 1993, XIII.

King, D. A. (1978). Al-Khalīlī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 15, pp. 259–261). New York: Charles Scribner's Sons.

King, D. A. (1983). The Astronomy of the Mamluks. *Isis, 74*, 531–555. Reprint in Islamic Mathematical Astronomy (2nd Rev. ed.). London: Variorum, Aldershot: Variorum, 1993, III.

King, D. A. (1993) L'astronomie en Syrie à l'époque islamique. In S. Cluzan et al. (ed), *Syrie-mémoire et civilisation* (pp. 392–4 and 440). Paris: Institut du Monde Arabe.

King, D. A. *In synchrony with the heavens: Studies in astronomical timekeeping and instrumentation in Medieval Islamic civilization*. Vol. 1. *The call of the Muezzin (Studies I–IX)*. Leiden: Brill, 2004; Vol. 2. *Instruments of mass calculation (Studies X–XVIII)*. Leiden: Brill, 2005, especially I-9.4.5 and II-9-10.

Van Brummelen, G. (1991). The numerical structure of al-Khalīlī's auxiliary tables. *Physis-Rivista Internazionale di Storia della Scienza*, N.S., *28*, 667–97.

Al-Kharaqī

Boris A. Rosenfeld
PA, USA

Abū Muḥammad ʿAbd al-Jabbār ibn ʿAbd al-Jabbār al-Kharaqī was a Persian astronomer, mathematician, and geographer. He was born at Kharaq near Marw and worked at Marw at the court of Saljuq Sultan Sanjar (1118–1157). Al-Kharaqī wrote in Arabic.

His main work was *Muntahā al-idrāk fī taqāsīm al-aflāk* (The Highest Understanding of the Divisions of Celestial Spheres). The work consists of three books: astronomical, geographical, and chronological. It is written in the tradition of Arabic astronomical textbooks initiated by al-Farghānī, continued by Ibn al-Haytham, and widely spread after al-Kharaqī in the form of Arabic and Persian books on the science of cosmography (*ʿilm al-hayʿa*). In these books, the planets are considered not as supported by imaginary circles according to Ptolemy's *Almagest* but as supported by massive material spheres in which they move in tubes.

His *Kitāb al-tabṣira fī ʿilm al-hayʿa* (Introduction to the Science of Cosmography), written in the same tradition, is the shortened version of the first work and contains two separate books, "On the Heavens" and "On the Earth."

Al-Kharaqī was also the author of two lost mathematical treatises, *al-Risala al-shāmila* (Comprehensive Treatise), devoted to arithmetic, and *al-Risala al-maghribiyya* (The North African Treatise), on the "calculus of dirham and dinar."

Boris A. Rosenfeld: deceased

See Also

▶ *Almagest*: Its Reception and Transmission in the Islamic World
▶ Hay'a
▶ Ibn Al-Haytham (Alhazen)

References

Langermann, Y. T. (2007). Kharaqī: Shams al-Dīn Abū Bakr Muḥammad ibn Aḥmad al-Kharaqī. In *The biographical encyclopedia of astronomers* (pp. 627–628). New York: Springer.

Matvievskaya, G. P., & Rosenfeld, B. A. (1983). *Mathematicians and astronomers of medieval Islam and their works (8th-17th c.)* (pp. 325–326). Moscow: Nauka (in Russian).

Sarton, G. (1927). *Introduction to the history of science* (Vol. 2, pp. 204–205). Baltimore: Williams & Wilkins.

Wiedemann, E., & Kohl, K. (1970). Einleitung zu Werken von al-Charaqi. In E. Wiedemann (Ed.), *Aufsätze zur arabischen Wissenschaftsgeschichte* (Vol. 2, pp. 628–643). Hildesheim/New York: Olns.

al-Khayyām

Jeffrey A. Oaks
Department of Mathematics and Computer Science, The University of Indianapolis, Indianapolis, IN, USA

Ghiyāth al-Dīn Abū'l-Fatḥ 'Umar ibn Ibrāhīm al-Khayyāmī (Khayyām) al-Naysābūrī (Nīshāpūrī) was a Persian mathematician, astronomer, poet, and philosopher who remained faithful to Aristotle in his scientific and philosophical works. He was born ca. 1048 CE in Nīshāpūr, now in northeastern Iran, and he spent his early years in Balkh. He then moved to Bukhārā where he remained until about 1070. There, he wrote three works on music and mathematics. The *al-Qāwl ʿalā ajnās allatī bi'l-arbaʿa* (*Reasoning on kinds [formed] by fourths*) treats ratios in music. In the lost *Mushkilāt al-ḥisāb* (*Problems in arithmetic*), al-Khayyām proved rules for extracting square, cube, and higher roots with Indian numerals. The proofs were based in the number theory books in Euclid's *Elements*, and the rules for higher roots were of his own invention.

Al-Khayyām's most important work from this period is the *Risāla fī taqsīm rubʿ al-dāʾira* (*Treatise on the division of a quadrant of a circle*). In it, he poses the problem of dividing a quadrant of a circle in such a way that a certain ratio is satisfied. He reduces this to a problem about a right triangle which he solves by algebra. By making one line ten and another "a thing" (like our x), he sets up a quartic equation that simplifies to the cubic equation $x^3 + 200x = 20x^2 + 2000$. Following traditional Arabic algebra, this is expressed in words as "a cube and 200 things equals 20 *māl*s and 2000 in number." (The Arabic word *māl* commonly means "sum of money" or "possession." In algebra, it was the name given to the second power of the unknown.) Using the "numbers" (coefficients) of the terms, he constructs a semicircle and a hyperbola, and the solution to the equation is a line extending to their intersection.

Al-Khayyām would mention in his later book on algebra that Abū Jaʿfar al-Khāzin and other mathematicians had also applied algebra to problems in geometry in which the resulting cubic equation was solved by intersecting conic sections. Seeing that any equation of degree three or less simplifies to one of only 25 types, he pauses in the middle of the solution of his triangle problem to outline his future project of providing each of these equations with a solution. There are 25 equations rather than our single $ax^3 + bx^2 + cx + d = 0$ because the solutions utilize the "numbers" of the terms, and these must be positive. For example, the equations $x^3 + ax = b$ and $x^3 = ax + b$ were regarded as being different types.

It was about 1070 that al-Khayyām reached Samarkand. There, under the patronage of the judge Abū Ṭāhir, he realized this algebraic project with his now famous *Risāla fī'l-barāhīn ʿala masāʾil al-jabr wa'l-muqābala* (*Treatise on proofs of the problems of algebra*). In it, he presents the 25 equations with solutions and proofs. He gives geometrical solutions to each equation in the form of a constructed line. And while he had previously maintained that algebra belongs purely to geometry, he now also gives arithmetical solutions where possible (arithmetical solutions to irreducible cubic equations were first found in sixteenth-century Italy). These are worked out by the same kind of algorithm already common in practical algebra.

Al-Khayyām worked within the framework of Aristotle's division of the genus of "quantity" into discrete and continuous. Numbers are discrete and consist only of positive integers, while geometrical magnitudes are continuous. This might have posed an obstacle to applying algebra to geometry, since traditional Arabic algebra is a numerical problem-solving technique in which the numbers can be any quantity that arise in calculation, including fractions and irrational roots. Al-Khayyām solved this incongruity by positing a unit line and regarding the numbers of the algebraists as the dimensionless measures of continuous magnitudes. So a "number" like $3\frac{1}{2}$ or $\sqrt{2}$ could be the length of a line, the area of a plane figure, or the volume of a solid. This foundational shift had no effect on the practice of algebra since it merely justified the calculations that were already being performed. Al-Khayyām's idea of "continuous numbers" resurfaced later in the third part of his commentary on Euclid's *Elements* (see below). His fidelity to Aristotle meant of course that his arithmetical solutions were restricted to positive integers (Oaks 2011).

Al-Khayyām's book gave algebra the proper foundation and the necessary rules to make it a legitimate and practical tool for problem-solving in the mathematics of the Greek tradition. Faced with a problem in geometry or arithmetic, one names an unknown magnitude or number "a thing" or some other algebraic term. The conditions of the problem are then applied to set up an equation, which is simplified to one of the 25 types. One then looks up the equation type in al-Khayyām's book. If the original problem is in geometry, then the construction is followed. If the original problem is in arithmetic, then one follows the numerical algorithm. Throughout the algebraic solution, the powers of the unknown ("thing," *māl*, "cube," *māl māl*, etc.) are al-Khayyām's dimensionless "continuous numbers," and the geometric solutions utilize only the "coefficients" of the equation. It is only in the proofs of the geometric constructions that the first three powers are represented as geometric magnitudes of dimension 1, 2, and 3.

In 1074, al-Khayyām and other scientists were invited to the court of the Saljūq sultan Jalāl al-Dīn Malik Shāh in the newly founded capital of Isfahan (now in central Iran). There, they were charged with the construction and operation of an observatory. The *Zīj Mālikshāhī* (*Mālik Shāh astronomical tables*), of which only a fragment survives, was likely based on their observations. Another work probably related to the observations is al-Khayyām's calendar, known to us only through later secondhand reports. This "Malikī" or "Jalālī" calendar was named for its patron and was completed by 1079. It was a solar calendar in which the new year is placed at start of Aries. Leap days were usually added every fourth year, but sometimes at the end of a 5-year cycle. We lack enough details to understand precisely how this calendar functioned, but it was perhaps more accurate than our Gregorian calendar. It was never put into use.

In 1077, al-Khayyām completed his commentary on Euclid's *Elements*. The *Sharḥ ma ashkala min muṣādarāt kitāb Uqlīdis* (*Commentary on difficulties with foundations in Euclid's book*) addresses three problems: Euclid's fifth postulate, the definition of proportional ratios in Book V, and the compounding (i.e., multiplication) of ratios. In the first part, al-Khayyām criticizes on philosophical grounds Ibn al-Haytham's use of motion to produce a line. For his own solution to the problem, he replaces Euclid's fifth postulate with a postulate that converging lines must intersect and that they cannot diverge in the direction of convergence. He then states and proves a sequence of eight propositions which are intended to replace Euclid's proposition I.29.

In the second part of his commentary, al-Khayyām proposes to replace Eudoxus' definition of proportional ratios, which is based on equimultiples, with a definition based on anthyphairesis. In this scheme, two ratios are said to be equal if repeated subtractions yield the same sequence of numbers. Al-Māhānī (9th c.) and al-Nayrīzī (early 10th c.) had made similar proposals before.

The last part of the commentary addresses the compounding of ratios. Just as in his work on algebra, al-Khayyām posits a unit measure for continuous magnitudes which allows him to work with his concept of continuous number. His proofs rely on the dimensionless character of these numbers, so that any proportion $a : b : c : d$ can be converted into the equality of the products $ad = bc$ and that the product of the unit by any number results in that very number (in magnitudes, this would increase the dimension). Contrary to what some historians have suggested, al-Khayyām's continuous numbers were not grounded in ratios. It just happens that in this book they appear in connection with ratios. Further, while these numbers may resemble our modern real numbers, their ontological foundation was entirely different.

Court politics shifted with the death of the sultan in 1092. The observatory was closed and al-Khayyām found himself out of favor. He remained in Isfahan, though, and in this period he composed his history of Persian solar calendar reforms, the *Naurūz-nāma*.

Sometime after 1118, al-Khayyām left Isfahan for Merv, the capital of the Seljuk sultan Sanjar, where he probably wrote his two works on mechanics, *Mizān al-ḥikam* (*Balance of wisdoms*) and *Fī'l-qusṭas al-mustaqīm* (*On correct* *portions*). Both are reproduced in the *Book of the Balance of Wisdom* of his student al-Khāzinī in 1121. In the first of these works, al-Khayyām solves the problem of determining the portion of gold in an alloy of gold and silver by both geometry and algebra. In the algebraic solution he calls the weight of the portion of gold in air "a thing," then sets up and solves the linear equation $10\frac{3}{4} - 1\frac{1}{10}x = 10\frac{1}{2} - 1\frac{1}{20}x$ (all expressed in words, of course).

Poetry and Philosophy

Al-Khayyām initiated a kind of literary tradition when he authored a collection of quatrains (*rubāʿiyāt*) in Persian. Over the generations the collection assumed a degree of fluidity, with many quatrains being added by various (usually anonymous) hands. Religious authorities found evidence in al-Khayyām's poetry to accuse him of "freethinking," and we are told by al-Qifṭī (13th c.) that in his later years, al-Khayyām was compelled to make a pilgrimage to Mecca to appease them.

Al-Khayyām also authored five works on philosophy, beginning with his *Risāla al-kawn wa'l-taklīf* (*Treatise on being and duty*) in 1080. These works, which are not very original, show him to be a follower of Ibn Sīnā's brand of Aristotelianism. Al-Khayyām died in his birthtown of Nīshāpūr, probably in 1131. Biographical details of al-Khayyām are taken largely from (Youschkevitch & Rosenfeld, 1973). Editions and French translations of his mathematical works are found in (Rashed & Vahabzadeh, 1999).

References

Oaks, J. (2011). Al-Khayyām's scientific revision of algebra. *Suhayl, 10*, 47–75.

Rashed, R., & Vahabzadeh, B. (1999). *Al-Khayyām mathé maticien*. Paris: Blanchard.

Youschkevitch, A. P., & Rosenfeld, B. A. (1973). Al-Khayyāmī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 7, pp. 323–334). New York: Charles Scribner's Sons.

Al-Khāzinī

Julio Samsó

Abū'l-Fatḥ (or Abū Manṣūr) ʿAbd al-Raḥmān (also called in some sources ʿAbd al-Raḥmān Manṣūr) was an astronomer and expert in mechanics and scientific instruments. He lived in Marw (Khurāsān) ca. 1115–ca. 1131. A slave (and later a freedman) of Byzantine origin, he was bought by a treasurer (*khāzin*) of the Seljuk court at Marw, called Abū'l-ḥusayn (or Abū'l-ḥasan) ʿAlī ibn Muḥammad al-Khāzin al-Marwāzī, who gave him a good scientific education.

As an astronomer his main work is his *al-Zīj al-Sanjarī*, an astronomical handbook with tables, compiled between ca. 1118 and ca. 1131 and dedicated to the Seljuk Sultan Sanjar ibn Malikshāh (1118–1157). This ▶ zīj seems to be influenced by the work of Thābit ibn Qurra, ▶ al-Battānī and ▶ al-Bīrūnī, but parts of it seem to have been checked against a limited number of his own observations (planetary, solar, and lunar in moments of conjunctions and eclipses) made in Marw. He is credited with a careful determination of the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), but he adopts the Battanian value of $23°35'$ and concludes (against al-Battānī and most of the successive Islamic astronomical tradition) that this parameter is a constant. His *zīj* includes a rich chronological section and a lot of materials related to the theory of Indian cycles. It also contains very important developments on the theory of planetary visibility as well as a very elaborate set of eclipse tables. He seems to have been interested by the problem of *qibla* determination (attempting to figure out the direction to Mecca) and the canons of his *zīj* mention a double entry *qibla* table computed for each integer degree of difference in latitude (from 1° to 30°) and in longitude (from 1° to 60°) between Mecca and other localities. This *qibla* table seems to be lost and the one ascribed to al-Khāzinī by the fourteenth century author al-Mustawfi does not seem to have anything to do with our author. Al-Khāzinī's *Zīj* was used in Byzantium by Georges Chrysoccoces (fl. ca. 1335–1346) and Theodore Meliteniotes (fl. ca. 1360–1388).

Among his minor astronomical works we find his treatise on instruments (*Risāla fī-l-ālāt*) which deals with observational instruments as well as with analog computers and simple helps for the naked eye. Furthermore, his short treatise on "the sphere that rotates by itself with a motion equal to the motion of the celestial sphere" (*Maqāla li'l-Khāzinīfīittiḥād kura tadūru bi-dhātihā bi-ḥaraka musāwiya li-ḥarakat al-falak wa maʿrifat al-ʿamal bihā sākina wa mutaḥarrika*) -probably the earliest of all his extant works – shows the link between his interest both in astronomy and in applied mechanics. It describes a solid sphere, marked with the stars and the standard celestial circles and half sunk in a box, the rotation of which is propelled by a weight falling in a leaking reservoir of sand. Similar devices were known and built in Classical Antiquity.

The most important of al-Khāzinī's works is probably his *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom), a treatise on the physical principles that underlie the hydrostatic balance as well as the construction and use of the instrument. This work was written in 1121–1122 and dedicated to Sultan Sanjar: the instrument it describes was meant for Sanjar's treasure, for its main application was to discriminate accurately between pure and adulterated metals as well as between real gems and fakes. A similar balance, also called *mīzān al-ḥikma*, had been built by al-Khāzinī's predecessor al-Asfizārī also for Sanjar, but its scales had been destroyed. Al-Khāzini's book is a long work, divided into 8 books and 80 chapters, and its quotations bear witness to the Classical sources on pure and applied mechanics that reached the Islamic lands (Aristotle and the pseudo-Aristotelian treatise on mechanical problems, Euclid, Archimedes, Menelaus) as well as to the development of the discipline in Islamic civilization (Muḥammad ibn Zakariyyāʾ ▶ al-Rāzī, ▶ al-Bīrūnī, Ibn al-Haytham, Abū Sahl al-Qūhī, ʿUmar al-Khayyām). There is nothing specifically new in al-Khāzinī's physical ideas which derive mainly from Aristotle and Archimedes, but his treatise has the obvious interest of its very careful description of a highly precise instrument with which he has been able to calculate tables of the specific gravities of many substances, both metallic, and nonmetallic, attaining, in some cases, results which are correct to within 1 %.

See Also

▶ Thābit ibn Qurra
▶ *Zīj*

References

Hall, R. E. (1973). *Al-Khāzinī. Dictionary of scientific biography* (Vol. VII, pp. 335–351). New York: Charles Scribner's Sons.

Kennedy, E. S. (1956). A survey of Islamic astronomical tables. *Transactions of the American Philosophical Society (Philadelphia), 46*(2), 37–39.

King, D. A. (1986). The earliest Islamic mathematical methods and tables for finding the direction of Mecca. *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften, 3*, 134–138. A corrected version of this paper appears in D.A. King, Astronomy in the Service of Islam. Aldershot: Variorum Reprints, 1993, No. XIV.

Lorch, R. (1980a). The *Qibla*-table attributed to al-Khāzinī. *Journal for the History of Arabic Science, 4*(2), 259–264.

Lorch, R. (1980b). Al-Khāzinī's sphere that rotates by itself. *Journal for the History of Arabic Science, 4*(2), 287–29.

Al-Khujandī

Sevim Tekeli

Abū Maḥmūd ḥāmid ibn al-Khiḍr al Khujandī (ca. 990) was a mathematician and astronomer who lived and worked under the patronage of the Buwayhid ruler, Fakhr al-Dawla (978–997).

In mathematics he worked on equations of the third degree and tried to show, although in an imperfect manner, that the sum of two cubed numbers cannot be another cube $a^3 + b^3 \neq c^3$. His name is included among others such as Abū'l-Wafā al-Buzjanī (940–997), Abū Nasr Manṣūr ibn ʿAlī ibn Irāq (ca. 1000), and ▶ Naṣīr al-Dīn al-Ṭūsī (1201–1274) to whom the discovery of the sine law is attributed. The sine law says that if ABC is any triangle, then $\frac{c}{b} = \frac{\sin C}{\sin B}$.

Although we do not have any reliable information on whether al-Khujandī founded an observatory on Jabal Tabrūk, in the vicinity of Rayy, he tells us that he made observations on planets for Fakhr al-Dawla with armillary spheres and other instruments and prepared a ▶ zīj (astronomical handbook with tables) entitled *al-Fakhrī* based on these observations. According to E. S. Kennedy an incomplete copy of a *zīj* in the Library of the Iranian Parliament (Tehran Ms. 181) may be attributed to al-Khujandī.

His fame depends on an important instrument constructed for the measurement of the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). This instrument surpassed all previous ones in size. Al-Khujandī praises his instrument and says that it is of his own invention. It is a 60° of meridian arc and is called *al-suds al-Fakhrī*, after Fakhr al-Dawla. Although *suds* means the sixth part of a circle (i.e., to say sextant), in reality it is constructed in place of a mural quadrant. As the distance between the summer solstice and the winter solstice is about 47°, a 60° of meridian arc is enough for observations of the sun. It has a radius of about 20 m, and each degree was subdivided into 360 equal parts. Therefore each 10 s portion was distinguished on the scale, and with it the limit of precision had been pushed to seconds.

This arc was constructed between two walls erected on the meridian. On the arched ceiling there was a hole through which the sun's rays passed and there were projections on the divisions of the arc. ▶ Al-Bīrūnī tells us that the aperture sank by about a span, and caused a slight displacement of the center of the arc.

In 384 H (AD 994), al-Khujandī observed the summer solstice in the presence of a group of scientists. They gave their written testimony concerning the observations. Although the cloudy weather prevented his observing the winter solstice, he calculated the position of the sun from the observations made preceding the solstice. The result was 23°32′19″. According to al-Bīrūnī, displacement of the center of the arc also affected the result. By comparing this result to the Indian astronomers' and Ptolemy's he deduced that the obliquity of the ecliptic was decreasing. He also fixed the latitude of Rayy (35°34′39″).

He describes a kind of astrolabe which is called *shāmila* (universal instrument) in his *Risāla fī Aʿmāl al-ʿāmma* (Treatise on the Construction of the Universal Instrument). The astrolabe, which carried a stereographic projection of the heavens on a circular plate, is a portable instrument. As we know from existing specimens, they ranged in size from 2 in. to 2 ft in diameter. They were used to measure the altitudes of the sun and to show the places of the stars in certain latitudes. Khujandī's *shāmila* could be used over a larger territory than former ones. He also provides methods of projection concerning intersections of circles of the azimuth by the equator and *muqanṭarāt*. Abū Naṣr Manṣūr mentions al-Khujandī's two methods on this topic. Al-Birūnī, in his *Tahdīd Nihāyāt al-Amākin* (Limit of Ends of Places), states that al-Khujandī was unique in his age for his constructions of astrolabes and other astronomical instruments.

References

Kennedy, E. S. (1956). A survey of Islamic astronomical tables. *Transactions of the American Philosophical Society, 46*(Pt. 2), 133.

Samsó, J. (1969). *Entudios Sobre Abū Naṣr Manṣur ībn Alī ibn Iraq* (pp. 89–93). Barcelona, Spain: Asociación para la Historia of de la Ciencia Española.

Samsó, J. (1986). Al-Khudjandī. *Encyclopedia of Islam* (Vol. 5, pp. 46–47). Leiden, The Netherlands: E. J. Brill.

Sarton, G. (1927). *Introduction to the history of science*. Baltimore: Williams and Wilkins.

Sayili, A. (1960). *The observatory in Islam*. Ankara, Turkey: Turkish Historical Society.
Tekeli, S. (1958). Nasirüddin, Takiyüddin ve Tycho Brahe'nin Rasat Aletlerinin Mukayesesi. *Ankara Üniversitesi, Dil ve Tarih-Coğrafya Fakültesi Dergisi 16*(3–4), 301–393.
Tekeli, S. (1973). Al-Khujandī. *Dictionary of scientific biography* (Vol. 7, pp. 352–354). New York: Scribner's.
Wiedemen, E. (1919). Über den Sextant des al-Chogendī. *Archive für Geschichte der Naturwissenchaften und der Technik, 2*, 148–151.

Al-Khwārizmī

Jacques Sesiano

Al-Khwārizmī, Muḥammad ibn Mūsā, is the earliest Islamic mathematician and astronomer of fame, and his works had considerable influence in the medieval world. His name suggests that he was of Persian origin, but his treatises were written in Baghdād during the caliphat of ► al-Maʾmūn (813–833).

The *Algebra* (possibly *al-Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa'l muqābala*), al-Khwārizmī's best known work, consists of four parts of very unequal length. The first part explains the fundamentals of algebra: the resolution of the six basic types of equations of first and second degree (with positive coefficients and at least one positive solution), then basic algebraic reckoning (with expressions involving an unknown or square roots); then, six examples of problems each ending with one of the six equations, and lastly various other problems of the same kind. This structure as well as some characteristic features (no symbolism, numbers written in words, illustrations of algebraic rules by geometrical figures) remained customary in early textbooks on algebra. The second part contains a few considerations on the application of the rule of three to commercial transactions. Part 3 covered surfaces and volumes of elementary plane and solid figures, mostly without any use of algebra. The lengthy part 4 is devoted to the application of algebraic methods (or simple arithmetic) to the sharing out of estates in accordance with wills and Islamic legal requirements regarding the parts due to heirs.

Several Latin translations of parts 1 and 2 were made in the Middle Ages.

The *Arithmetic* (possibly *Kitāb al-ḥisāb al-hindī*) exposes the newly introduced Indian positional system of numerals and its use in arithmetical operations and (square) root extraction, for integers and fractions, both common and sexagesimal. This work is lost in Arabic, but has survived in two Latin translations.

The ► *Zīj al-sindhind* (Astronomical Tables), al-Khwārizmī's best known work in astronomy, is a set of tables based mainly on Indian material. Instructions on the use of the various tables are provided; with their help, one can determine the mean motion of the seven known celestial bodies, also daily motions, sizes, and eclipses of the sun and moon; calendric and trigonometrical tables are included. We do not know the original text, since only a Latin translation of a later reworking has come down to us.

The *Kitāb ṣūrat al-arḍ* (Geography) is a list of longitudes and latitudes of cities, mountains (geographical points along), sea coasts, islands, center points of regions and countries, and detailed courses of rivers. The information is drawn from Ptolemy's *Geography*, but improvements are found, mostly, of course, for the regions under Islamic rule or traveled through by Arabian merchants.

The *Istikhrāj taʾrikh al-yahūd* (Calendar of the Jews) is the oldest extant description of the modern Jewish calendar. After reporting that God inspired it to Moses (its Mesopotamian origin was unknown to al-Khwārizmī), we are told about the year and the intercalation of seven intercalary months within the 19 year (Metonic) cycle and how to determine on which day *rosh ha-shana* falls. Next we are given the positions of the celestial bodies at the beginning of three eras (Adam, Temple of Jerusalem, and Alexander). Finally, we are taught how to determine the mean positions of the sun and moon for any given date and the time elapsed since their last conjunction.

The *Kitāb al-ʿamal biʾl-asturlāb* (On the Use of the Astrolabe) contains short instructions, but perhaps not in their original form. We are taught how to find altitudes of celestial bodies, and how to determine time or latitudes from celestial observations.

The purpose of another minor work, *Kitāb al-rukhāma* (On the Sundial), is to explain the construction of a plane sundial; the appended tables are given for various latitudes besides that of Baghdād.

A *Kitāb al-taʾrīkh* (Chronicle) is known by quotations from other historians; it reported purely historical events and covered at least the years 632–826.

As to lost works, a short treatise *Kitāb ʿamal al-asṭur-lāb* (On the Construction of the Astrolabe) is attributed by Arabian bibliographers to al-Khwārizmī (it may be extant as an anonymous work). At the end of his *Algebra*, ▶ Abū Kāmil explains a short way for calculating the result of the duplication on the chessboard's cells $\left(1+2+2^2+\cdots+2^{63}=2^{64}-1\right)$, which he attributes to al-Khwārizmī but which appears in no known work of his. Another lost work was concerned with the rule of false position.

Al-Khwārizmī has enjoyed a great reputation, particularly as the first algebraist. Although he seems not to have made a great number of original contributions, he was a learned man of great versatility and didactical ability. His role was primarily that of a disseminator of science in early Islamic times. As some of his works were studied in eleventh century Spain, he played the same role for the Christian world through Latin translations. The latinization of his misread Arabic name as *algorizmus*, later misread as *algoritmus*, later misinterpreted as *algorithmus*, has kept his name if not his fame alive until the present time.

See Also

▶ Algebra in China
▶ Astrolabe
▶ Sundials in Islam

References

al-Khwarizmi, Abu Jafar Muhammad ibn Musa, sec. IX. (1997). *Die älteste lateinische Schrift über das indische Rechnen nach al-Hwarizmi. Edition, Übersetzung und Kommentar von Menso Folkerts unter Mitarbeit von Paul Kunitzsch*. München: Verlag der Bayerischen Akademie der Wissenschaften.

King, D. (1983). *Al-Khwārizmī and new trends in mathematical astronomy in the ninth century*. New York: Hagop Kevorkian Center for Near Eastern Studies.

Mukhammed ibn Musa al Khorezmi, k 1200-letiyu so dnia roždieniya. (1983). Moscow: Nauka.

Tamborini, M. (1999). *De cubo et rebus aequalibus numero: la genesi del metodo analitico nella teoria delle equazioni cubiche di Girolamo Cardano*. Milano, Italy: F. Angeli.

Toomer, G. (1973). Al-Khwārizmī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. VII, pp. 358–365). New York: Charles Scribner's Sons.

Al-Kindī

George N. Atiyeh

Al-Kindī, Abū Yūsuf Yaʿqūb ibn Isḥāq, was born ca. 801 in Kūfah and died ca. 866 in Baghdad.

Often called the Philosopher of the Arabs, little is known with certainty about the life of this early Muslim philosopher and scientist. He flourished in Baghdad, then capital of the Abbasid Empire and center of its intellectual life. Greek, Persian, and Indian works were being translated into Arabic and a multitude of religious and other thinkers were developing new and sophisticated schools of thought and literature. The *Mutakallimūn*, Islamic theologians, were actively engaged in controversies over God's attributes and freedom of the will as well as over the methodology of knowledge. During the life of al-Kindī, Baghdad experienced the political ascendancy and fall of the dialectical theological movement of the *Muʿtazilah*, a movement that used a rationalistic approach to defend the religious dogmas of Islam. Al-Kindī sympathized with some ideas of this movement such as the uniqueness of God, his justice, and the use of a rational approach in the defense of Islam against its opponents. Also like *al-Muʿtazilah*, al-Kindī looked at God as the ultimate source of all being, yet believed his creations were independent in their daily function.

Most of the works of al-Kindī have, unfortunately, disappeared. Ibn al-Nadīm (d. ca. 987), one of the earliest bibliographers of Islam, lists 242 works, mostly essays and epistles, dealing with a wide range of sciences: logic, metaphysics, mathematics, spherics, music, astronomy, geometry, medicine, astrology, theology, psychology, politics, meteorology, prognostics, and alchemy.

The scientific works of al-Kindī are by far the most numerous. In fact there are among the early Arabic authors many who considered him a mere scientist and not a philosopher. Z. al-Bayhaqī (d. 1169), who is often cited, referred to him as an engineer, and ► Ibn Khaldūn (d. 1406) did not list him among the philosophers. Whatever the case may be, one can find in al-Kindī's presently known works the outline of a philosophical system. Based on his treatise *Fī al-Falsafeh al-ula* (On First Philosophy), al-Kindī defined philosophy as the "knowledge of the realities of things according to human capacity." He stressed the cumulative character of philosophy and the duty to receive the truth gratefully from whatever source it comes. He distinguished between philosophy and theology proper as two different disciplines, both pursuing and reaching the same goal, which is truth. The first pursues it through arduous research and effort, the second through prophetic knowledge which is granted to certain individuals immediately and without any effort. He established the various divisions of philosophy on the basis of the different channels of human knowledge, the sense experience of material entities and that of rational cognition of immaterial ones. First philosophy or metaphysics is concerned with the First Principle, the True One, the Necessary and Uncaused Being who is eternal and infinite. Probably drawing upon the ideas of the pre-Islamic John Philoponus who championed the concept of creation ex nihilo, he opposed the Aristotelian theory of the eternity of the universe. The chief attribute of God, argued al-Kindī, is unity. God is the only real agent or cause in the world. Unlike the Muslim theologians, he did not ignore the role of secondary agents in the process of nature. He established the premise that the causes of generation and corruption are the heavenly bodies, which are superior to the physical bodies and possess intelligence.

The writing of al-Kindī on the soul and the intellect are neither numerous nor comprehensive. Besides his important short treatise *Risālah fī māʿiyat al-ʿaql* (On the Intellect), he wrote *Kalām fī al-nafs mukhtaṣar wajīz* (A Discourse on the Soul Abridged and Concise) where he explains the nature of the union between the soul and the body as different from the union between the elements. Inspired by Aristotelian, Plantonic, and Pythagorean sources, he considered the soul as the principle of life and only accidentally related to the body, being nobler in nature. In his *On the Intellect*, al-Kindī presents a Platonic interpretation of Aristotle's noetics. He defines the intellect as "a simple essence cognizant of things in their true realities." There are four intellects, the first of which is separate and seems to be construed in the image of Aristotle's active intellect. It exists outside the human soul and is the cause of "all intelligible thoughts and secondary intellects." The four intellects – the active, the potential, the habitual, and the manifest or acquired – played an important role in the history of medieval discussions on the nature of the intellect. In his *Risālah fī dafʿal-aḥzān* (On the Means to Drive Away Sadness), al-Kindī offers practical advice to overcome sorrow based on the principle that true riches are not material by nature. What causes sadness is the loss of externals and the failure to attain what we highly cherish. By despising external things and educating our souls to seek what is spiritual, we avoid the miseries of sorrow.

With many of his scientific works not available, it is difficult to offer a systematic exposition of al-Kindī's scientific works and contributions. They covered almost all fields of the physical sciences and went beyond the mere transmission of Hellenic scientific data by adding to it through observations of his own and some rudimentary experimentation. Al-Kindī took over the Greek scientific heritage which was available in translations or which he had helped to translate, and tried to assimilate, summarize, and at times develop it and experiment with it. In his classification of the sciences, he starts from the idea of a hierarchy of beings according to which the lower sciences deal with sensible beings and higher sciences with the nobler and intelligible beings. There is a close relationship, however, between science and philosophy, especially mathematics, which he considers preparatory and essential to the study of philosophy. He uses mathematical concepts and arguments when discussing infinity and plurality in proving his theory of the unity of God.

Al-Kindī was not satisfied with the role of the transmitter and commentator. In many of his scientific works we feel the surge of an investigative spirit. In works on optics, pharmacology, and music, for example, he provided new data and approaches, thus enhancing our knowledge of these subjects, among many others. At times, he sought to verify some statements through experimentation, as when he shot an arrow in the air to verify Aristotle's statement that substances expand when heated. In his work *Risālah fī ikhtilāf al-manaṣir* (*De Aspectus*), which is based on Euclid and Heron of Alexandria's optics, he rejected the Euclidean theory of the emission of light, and using geometrical arguments, he offered amendments so it conformed with observable data. Furthermore, al-Kindī gave an original interpretation independent from that of Aristotle of the azure blue we see in the sky. He argued that the color we actually see is the reflection of light from vapors and particles of dense bodies carried up into the atmosphere.

Likewise, al-Kindī, in his medical and pharmaceutical works, was a contributor of new ideas trying to improve upon the knowledge of antiquity. In his work on pharmacology *Risālah fī maʿrifat qūwah al-adwīyah al-murakkabah* (translated into Latin as *De medicinarum compositorum grabidus investigandis libellus*), he applied the principles of posology [the study of dosages]. He based the efficacy (*qūwah*) of compound medicine upon geometrical progression. He linked the degree of intensity with the numerical changes in the qualitative forces that produce them. The efficacy corresponds to the proportion of the sensible qualities: warm, cold, dry, and humid. If a compound medicine was to be warm in the first degree, it had to possess double the equable mixture. If it was to be warm in the second degree, it had to possess four times as much, etc.

The same tendency to improve on the ancient sciences is seen in his works on music. For example, he used the letters of the alphabet to designate the notes of the scale. Al-Kindī's musical works in Arabic on the theory of music paved the way for the *Kitāb al-musiqi al-kabir* (Great Book on Music) by al-Fārabī.

Al-Kindī's influence in medieval Europe might not be as great as the other Arabic philosophers such as Ibn Sīnā and Ibn Rushd; he was nevertheless a courageous intellectual and scientist. Whether he was the first philosopher in Islam is still not ascertainable in the absence of many of his philosophical works. There is no doubt, however, that he was the first in Islam to bridge the gap between philosophy and the Islamic dogma, thus establishing the conceptual framework that became characteristic of philosophy in Islam.

References

ʿAbd al-Hādī Abū Ridah. (1950–1953). *Rasāʿil al-Kindī l-falsafiyah* (Vol. 2). Cairo, Egypt: Dār al-Fikr alʿArabī.

Adamson, P. (2003). Al-Kindi and the Mutazila: Divine attributes, creation and freedom. *Arabic Sciences and Philosophy, 13*, 45–77.

al-Kindi, Abu Yusuf Ya'qub ibn Ishaq al-Sabbah, sec. IX. (1997). In. par J. Jolivet, & R. Rashed (Ed.), *Oeuvres philosophiques et scientifiques d'Al-Kindi*. Leiden, The Netherlands: Brill.

Atiyeh, G. N. (1967). *al-Kindi: The philosopher of the Arabs*. Islamabad, Pakistan: Islamic Research Institute.

Cortabarria, A. (1972). La classification des sciences chez Al-Kindi. *Mélanges de L'Institut dominican d'études Orientales, 11*, 49–76.

Cortabarria, A. (1977). Al-Kindi, Vu par Albert Le Grand. *Mélanges de L'Institut dominican d'études Orientales, 13*, 117–146.

d'Averny, M. T., & Hurdy, F. (1974). Al-Kindi, De radiis. *Archives d'histoire doctrinale et litteraire du moyen-age 41*, 139–260.

Demirhan Erdemir, A. (2002). A perspective of an English translation of Aqrabadhin of Abu Yusuf Yaqub Ibn Ishaq Al-Kindi and some results. *Journal of the International Society for the History of Islamic Medicine (ISHIM), 1*(1), 16–20.
Fakhri, M. (1970). *History of Islamic philosophy*. New York: Columbia University Press.
Ivry, A. L. (1974). *Al-Kindī's metaphysics*. Albany, NY: State University of New York Press.
Jolivet, J. (1971). *L'intellect selon Kindi*. Leiden, The Netherlands: Brill.
Levey, M. (1966). *The Medical Formulary or Aqrābadhin of al-Kindī*. Madison, WI: University of Wisconsin Press.
Prioreschi, P. (2002). Al-Kindi: A precursor of the scientific revolution. *Journal of the International Society for the History of Islamic Medicine (ISHIM), 1*(2), 17–20.
Rashed, R. (1993). Al-Kindī's commentary on archimedes' the measurement of the circle. *Arabic Science and Philosophy, 3*, 7–53.
Rashed, R. (1997). Le commentaire par al-Kindi de 'L'Optique' d'Euclide: un traité jusqu'ici inconnu. *Arabic Sciences and Philosophy, 7*(1), 9–56.
Rescher, N. (1964). *Al-Kindī: An annotated bibliography*. Pittsburgh, PA: University of Pittsburgh Press.
Ruffinengo, P. P. (1997). al-Kindi: Sull'intelletto, Sul sonno e la visione. *Medioevo, 23*, 337–394.
Travaglia, P. (1999). *Magic, causality and intentionality: The doctrine of rays in al-Kindi* (del Galluzzo Ed.). Firenze, Italy: Società internazionale per lo studio del medioevo latino (SISMEL).

Almagest: Its Reception and Transmission in the Islamic World

Paul Kunitzsch
University of Munich, Munich, Germany

Around AD 150, Ptolemy wrote his great handbook of astronomy called *Mathematike Syntaxis* (The Mathematical Composition) in the original Greek. Because of its importance, it soon received wide attention throughout the Hellenistic world. Its fame seems to have radiated into the Middle East, because there are hints that the work was known, and perhaps even translated partially or completely, into Middle Persian (Pahlavi) under the Sassanian ruler Shāhpur I (reigned AD 241–272). A second period of intensive contact of the Persians with Greek science was in the middle of the sixth century, after the closing of the Academy in Athens (AD 529), when several Greek scholars sought refuge in Persia. At this point, Ptolemy's work may again have been brought to the attention of Persian scholars. However, this was the first knowledge of the Arabs (who conquered the Middle East and established the Islamic empire of the caliphs around the middle of the seventh century) about Ptolemy and his work betrays Persian influence. The Arabs first knew Ptolemy's astronomical handbook under the title *Kitāb al-majasṭī* (The Book Almagest), which evidently derives from a Greek superlative (*Megiste* [scil. *Syntaxis*], The Greatest Composition). Under this title, the book was already known in Arabic-Islamic circles before the translations proper. It would seem that the Arabic spelling *al-majasṭī* is derived from a Middle Persian form rather than from the Greek directly – a Middle Persian spelling *mgstyk* is documented, and a form like this may have led to the Arabic spelling *al-majasṭī*. Later, in twelfth-century Spain, the Europeans translated Arabic scientific works into Latin and converted the Arabic *al-majasṭī* into Latin *almagesti*, and henceforth Ptolemy's work has been known in the West under this short title, Latinized from an Arabicized Greek word. It may be added that in the direct transmission, in Greek, the title *Megiste Syntaxis* has not yet been found – here we have only the forms *Mathematike Syntaxis* or *Megale Syntaxis* (The Great Composition).

Direct knowledge of the text of the *Almagest* in Arabic-Islamic science developed through a series of translations from Greek into Arabic. Before the Arabic translations, a translation was made into Syriac, the language common among Christian monks and scholars who later played the main role in the translation of Greek scientific works into Arabic. It is not known when and by whom this Syriac translation was made, but it is probable that the first translators of the work into Arabic knew and used the Syriac version. Still, in the twelfth century, Ibn al-Ṣalāḥ had the Syriac version to hand. A first Arabic translation of the Almagest was made some time around AD 800 – its text is now lost, but it was often cited by Arabic-Islamic astronomers and bibliographers as "the first" or "the old" or "the mamūnian" translation, after the caliph al-Maʾmūn, who patronized translations and scientific work in general. Traces of it are found in the astronomical work of al-Battānī (d. 929) and in Ibn al-Ṣalāḥ. A second translation was made in 827–828 by al-ḥajjāj ibn Yūsuf ibn Maṭar in cooperation with a Christian, Sergius the son of Elias. Of it, two manuscripts have survived until our times, one complete and the other fragmentary. About 50–60 years later, a third translation was made by Isḥāq ibn Ḥunayn (830–910). It was soon afterward revised by Thābit ibn Qurra (836–901) – of this revised version, ten manuscripts are still extant today.

The two versions of al-ḥajjāj and of Isḥāq revised by Thābit were received in Muslim Spain – they were both used by Gerard of Cremona for his translation of the Almagest into Latin (Toledo, ca. 1150–1180). Gerard's Arabo-Latin version then remained the standard version of the Almagest in Europe until Renaissance times.

In the following centuries, Arabic-Islamic astronomers not only studied the *Almagest* as their main source in astronomy, but they also wrote commentaries on the entire book or on problems of detail. Fuat Sezgin lists more than 30 commentaries, several of which were afterward commented upon themselves. Among the numerous commentators, two shall be named here. Ibn al-Ṣalāḥ (d. 1154) is important, because he had to hand five versions of the *Almagest* (the Syriac version, the "old" version, the version of al-ḥajjāj, the original of Isḥāq's version, and Isḥāq's version as revised by Thābit) from all of which he tried – by comparing the texts and by observing the stars – to establish the best values in longitude and latitude for a selected number of stars from the star catalog in the Almagest. Another famous commentator was Naṣīr al-Dīn al-Ṭūsī (1201–1274) who wrote revisions of many translated Greek mathematical and astronomical texts, which included the Almagest – his *Taḥrīr* (based on the version of Isḥāq as revised by Thābit) survives in numerous manuscripts, but is still unedited.

The last Oriental translation of the *Almagest*, from al-Ṭūsī's *Taḥrīr* into Sanskrit, was made in 1732, in Jaipur, India, by order of Maharaja Jai Singh II.

The title *al-majasṭī/Almagest* became so famous that other authors freely used the name for their own works, both in the East and in Europe, e.g., the *Kitāb al-majasṭī* (The Book Almagest) of the mathematician Abu'l-Wafāʾ al-Būzjānī (940–987 or 998), the *Almagestum novum* of the astronomer Giovanni Riccioli (1651), or even the *Almagestum Botanicum* of Leonard Plukenet (1696).

See Also

- ▶ Abū'l-Wafāʾ
- ▶ al-Battānī
- ▶ al-Maʾmūn
- ▶ Isḥāq ibn Ḥunayn
- ▶ Naṣīr al-Dīn al-Ṭūsī
- ▶ Thābit ibn Qurra

References

Almagest, Greek text: Ptolemaeus, *Opera*. Vol. i, Parts i–ii. Ed. J. L. Heiberg. Leipzig: Teubner, 1898. 1903 – English translation: Toomer, G. J. (1984). *Ptolemy's Almagest*. London: Duckworth – the star catalog alone. Arabic and Latin versions: Kunitzsch, P. (Ed.). (1986, 1990, 1991). *Der Sternkatalog des Almagest. Die arabisch – mittelalterliche Tradition*, i–iii. Wiesbaden: Harrassowitz.

Ibn al-Ṣalāḥ. (1975). *Zur Kritik der Koordinateniiberlieferung im Sternkatalog des Almagest* (P. Kunitzsch, Ed. and Trans.). Göttingen: Vandenhoeck & Ruprecht.

Kunitzsch, P. (1974a). New light on al-Battānī's Zīj. *Centaurus, 18*, 270–274. (Reprinted from *The Arabs and the stars,* by P. Kunitzsch, 1989, Northampton: Variorum Reprints) item v.

Kunitzsch, P. (1974b). *Der Almagest. Die Syntaxis Mathematica des Claudius Ptolemäus in arabisch-lateinischer Überlieferung*. Wiesbaden, Germany: Harrassowitz.

Kunitzsch, P. (2001). A hitherto unknown Arabic manuscript of the Almagest. *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften, 14*, 31–37. (Reprinted from *Stars and numbers,* by P. Kunitzsch, 2004, Ashgate: Variorum) item V.

Pedersen, O. (1974). *A survey of the Almagest*. Odense, Denmark: Odense University Press.

Plukenet, L. (1696). *Almagestum botanicum*. London: Sumptibus Autoris.

Riccioli, G. B. (1651). *Almagestum novum*. Bologna, Italy: Victorii Benetii.
Sezgin, F. (1978). *Geschichte des arabischen Schrifttums*. vi: *Astronomie bis ca. 430 H*. Leiden: Brill, pp. 88–94, 83 ff.
Toomer, G. J. (1975). Ptolemy. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. XI, pp. 186–206). New York: Scribner's.

Al-Māhānī

Yvonne Dold-Samplonius

Al-Māhānī, Abū ʿAbd Allāh Muḥammad ibn ʿĪsā, was born in Māhān, Kerman, Iran. He lived in Baghdad, ca. 860 and died ca. 880.

Little is known about al-Māhānī's life, and few of his works are extant. In the *ḥākimite Tables* Ibn Yūnus cites observations of conjunctions and lunar and solar eclipses made by al-Māhānī between 853 and 866. In the only extant astronomical work, *Maqāla fī Ma'rifat as-samt li-aiy sā'a aradta wa-fī aiy mauḍi' aradta* (On the Determination of the Azimuth for an Arbitrary Time and an Arbitrary Place), al-Māhānī added arithmetical solutions to two of the graphic ones. His method corresponds to the cosine formula in spherical trigonometry, and is later applied by ▶ al-Battānī.

Al-Māhānī worked on the fundamental problems of mathematics of his time and is especially known for his commentaries to Euclid's *Elements*, to Archimedes' *De Sphaera et Cylindro* (On Spheres and Cylinders), and to the *Sphaerica* by Menelaus. In the last treatise, now lost, he inserted explanatory remarks, modernized the language, especially the technical terms, and remodeled or replaced obscure proofs. It was revised and finished by Aḥmad ibn Abī Saʿīd al-Harawī in the tenth century. Al-Ṭūsī considered al-Māhānī's and al-Harawī's improvements valueless and used the edition by Abū Naṣr Manṣūr ibn ʿIrāq. This redaction, the most widely known Arabic edition, is included in the collection of the *Intermediate Books*. These were the books read between Euclid's *Elements* and Ptolemy's *Almagest*.

Of the commentaries to the *Elements* only those to Book V and to Book X are extant. In the former al-Māhānī compared magnitudes by comparing their expansion in continued fractions, referring to Thābit ibn Qurra. Ratio is defined as "the mutual behavior of two magnitudes when compared with one another by means of the Euclidian process of finding the greatest common measure." Two pairs of magnitudes were for him proportional when "the two series of quotients appearing in that process are identical." Essentially the same theory was worked out later by ▶ al-Nayrīzī. Neither established a connection with Euclid's definition, which was first done by Ibn al-Haytham. In the commentary to Book X al-Māhānī examined and classified not only quadratic irrationalities, but also those of the third order. In contrast with Euclid, for whom magnitudes were only lines, he considered integers and fractions alike as rational magnitudes, while regarding square and cube roots as irrational ones. Al-Māhānī then explicated the contents of Book X using rational and irrational numbers instead of geometric magnitudes.

According to al-Khayyāmī, al-Māhānī was the first to attempt an algebraic solution of the Archimedean problem of dividing a sphere by a plane into segments, the volumes of which are in a given ratio (*De Sphaera et Cylindro* II, 4). He expressed this problem in a cubic equation of the form $x^3 + a = cx^2$, but he could not proceed further. Al-Khayyāmī relates that the problem was thought unsolvable until al-Khāzin succeeded by using conic sections.

See Also

▶ al-Battānī
▶ Al-Nayrīzī
▶ *Elements*: Reception of Euclid's *Elements* in the Islamic World
▶ Ibn Al-Haytham (Alhazen)
▶ Ibn Yūnus
▶ Thābit ibn Qurra
▶ Umar al-Khayyām

References

Dold-Samplonius, Y. (1970). *al-Māhānī* (Dictionary of Scientific Biography, Vol. IX, pp. 21–22). New York: Charles Scribner's Sons.

Habash al-Hasib al Marwazi, A. B., Allah, A. sec. IX. (1999). *The melon-shaped astrolabe in Arabic astronomy*. (Texts Ed. with Trans. and Commentary by Kennedy, E.S., Kunitzsch, P., & Lorch, R.P.) Stuttgart: F. Steiner.

Matvievskaya, G. (1987). The theory of quadratic irrationals in medieval oriental mathematics. In D. A. King & S. George (Eds.), *From deferent to equant* (pp. 253–277). New York: New York Academy of Sciences.

Al-Majrīṭī

Emilia Calvo

Al-Majrīṭī Abū-l āsim Maslama ibn Aḥmad al-Faraḍī was born in Madrid, Spain in the second half of the tenth century and died in Cordoba ca. AD 1007. He settled early in Cordoba where he studied with Abū Ayyūb ibn ʿAbd al-Gāfir ibn Muḥammad and Abū Bakr ibn Abī ʿĪsà. He was engaged in making astronomical observations in about AD 979; he may have served as court astrologer.

He had a number of disciples who made his work known throughout the provinces of Spain. Among them were al-Kirmānī (d. AD 1066); Abū-l-Qāsim Aṣbagh, known as Ibn al-Samḥ (d. AD 1035) who is the author of a treatise on the construction and use of the astrolabe in 130 chapters and of the *Book of the Plates of the Seven Planets*, of which the original Arabic version is lost. [However, it was translated into Spanish and included in the *Libros del Saber de Astronomía*;] Abū-1-Qāsim Aḥmad known as Ibn al-ṣaffār (d. AD 1034), who is the author of a treatise on the astrolabe attributed in its Latin version to al-Majrīṭī; Ibn al-Khayyāṭ; al-Zahrāwī; and Abū Muslim ▶ ibn Khaldūn of Seville.

Maslama's most important work is the adaptation of al-Khwārizmī's astronomical tables (▶ *zīj*) which were elaborated ca. 830. This adaptation is not preserved in his original Arabic form but in a Latin translation made by Adelard of Bath (fl. 1116–1142) and revised by Robert of Chester. The work done by Maslama in this adaptation illustrated his high degree of astronomical and mathematical knowledge.

Another work is an Arabic commentary on Ptolemy's *Planispherium*, entitled *Tasṭīḥ basīṭ al-kura* (Projecting the Sphere onto a Plane), which deals with the stereographic projection on which the conventional astrolabe is based. This adaptation is only preserved in a Latin version by Hermann of Dalmatia (1143) and in a Hebrew abridgement. This work was the point of departure of a long series of Andalusian treatises on this topic. Maslama also knew the *Almagest* as well as al-Battānī's tables.

Maslama also wrote a treatise on *muʿāmalāt* (commercial arithmetic) which probably dealt with sales, cadastre (an official record of property ownership and value), and taxes using arithmetical, geometrical, and algebraic operations.

Some other works are attributed to him, such as *Rutbat al-ḥakīm* (The Rank of the Sage), composed after AD 1009, and *Ghāyat al-ḥakīm* (The Aim of the Sage), translated into Spanish in AD 1256 by order of Alfonso el Sabio and distributed throughout Europe under the name of *Picatrix*.

References

Neugebauer, O. (1962). *The astronomical tables of al-Khwārizmī (Translation with commentaries of the Latin Version)*. In H. Suter (Ed.). Supplemented by Corpus Christi College Ms 283. Copenhagen, Denmark: I Kommission hos Munksgaard.

Samsó, J. (1992). *Las ciencias de los Antiguos en al-Andalus* (pp. 84–98). Madrid, Spain: Mapfre.

Suter, H. (1914). *Die Astronomischen Tafeln des Muḥammed ibn Mūṣa al-Khwārizmī in der bearbeitung des Maslama ibn Aḥmed al-Madjrīṭī und der latein. Uebersetzung des Athelard von Bath.* Copenhagen, Denmark: A. F. Høst & Son.

Vernet, J. (1974). *Al-Majrīṭ. Dictionary of scientific biography* (Vol. 9, pp. 39–40). New York: Charles Scribner's Sons.

Vernet, J. (1986). Al-Majrīṭī. *Encyclopédie de l'Islam* (p. 1105). 2nd ed. Vol. 5. Leiden/Paris: E. J. Brill/G. P. Maisonneuve.
Vernet, J., & Catalá, M. A. (1965). Las obras matemáticas de Maslama de Madrid. *Al-Andalus, 30*, 15–45.

Al-Maʾmūn

Paul Kunitzsch
University of Munich, Munich, Germany

Al-Maʾmūn, Abul'-ʿAbbās ʿAbdallāh ibn Hārūn, was born in 786 in Baghdad, and died in 833 near Tarsus, in a campaign against the Byzantines.

Al-Maʾmūn was not himself a scientist. He was the seventh caliph of the dynasty of the Abbassids, son and second successor of the famous caliph Hārūn al-Rashīd (well known from the tales of the Arabian Nights). He ruled the Islamic empire from 813 to 833, at first from Marw (in the Eastern province of Khurāsān, where he was based before his accession), and from 819 from the capital of Baghdad (founded in 762 by the caliph al-Manṣūr). In the intellectual history of the Islamic world and in the history of science, al-Maʾmūn played an important role as an instigator and patron of many important activities. He was a firm adherent of the Muʿtazila, a rational school of Islamic theology which was strongly influenced by Greek philosophy; in 827 he declared Muʿtazilism the official doctrine for the whole empire. His interest in philosophy and the sciences manifested itself in many ways. He initiated and patronized the translation of scientific works, mostly from Greek, but also from Persian and Syriac, into Arabic. One translation (of several successive versions) of Ptolemy's *Almagest*, and two translations (also of several successive versions) of Euclid's *Elements* were distinctly called, after him, "the Maʾmūnian version(s)." In the *Elements*, the theorem I, 15 was given, after him, the nickname *al-maʾmūnī*, "the Maʾmūnian [theorem]." Later, in the medieval Latin translation, this degenerated into *elnefea*, *id est fuga* and, more contracted, *eleufuga* or *elefuga*. In 832 he founded the Bayt al-ḥikma (House of Wisdom, in continuation of a similar institution established earlier by his father Hārūn), which was established for collecting scientific texts, translation, and teaching. Further, on his order, astronomers carried out new measurements of many of the astronomical parameters transmitted in Greek texts, such as precession of the equinoxes, inclination of the ecliptic, length of the year, length of a degree of geographical latitude, geographical coordinates, etc. For many of these data, they arrived at remarkably better values. The results of the observations made by al-Maʾmūn's astronomers were laid down in a work called *al-Zīj al-mumtaḥan* (The Revised Tables, dated 829–830; in medieval Latin, *Tabulae probatae*); it is only preserved in a reworked form. These values were afterwards widely quoted and used by other Islamic and also medieval Western astronomers. From quotations in the *Elementa astronomica* of ▶ al-Farghānī (ninth century), al-Maʾmūn's name entered the West in the forms Almeon (Johannes Hispalensis's Latin translation of al-Farghānī's *Elementa*) and Maimon (Gerard of Cremona's translation of the same). On Riccioli's map of the moon (1651) a crater was called Almaeon (i.e., the aforementioned Almeon); as Almanon the name survives on modern charts, in permanent memory of this remarkable Eastern ruler.

See Also

▶ *Almagest*: Its Reception and Transmission in the Islamic World
▶ *Elements*: Reception of Euclid's *Elements* in the Islamic World
▶ Precession of the Equinoxes

References

Èche, Y. (1967). *Les bibliothèques arabes publiques et semi-publiques en Mesopotamie, en Syrie et en Egypte au moyen âge*. Damascus, Syria: Institut français de Damas.

Kennedy, E. S. (1956). A survey of islamic astronomical tables. *Transactions of the American Philosophical Society, NS, 46*, 123–177.
Rekaya, M. (1991). al-Maʾmūn b. Hārūn al-Rashīd. In M. Th. Houtsma (Ed.). *Encyclopaedia of Islam* (New ed., Vol. 6, pp. 331–339). Leiden, The Netherlands: Brill.
Sourdel, D. (1960). Bayt al-ḥikma. In M. Th. Houtsma (Ed.) *Encyclopaedia of Islam* (New ed., Vol. 1, p. 1141). Leiden, The Netherlands: Brill.
Vernet, J. (1956). Las 'Tabulae Probatae'. *Homenaje a J.M. Millás Vallicrosa, II* (pp. 501–522). Barcelona, Spain: Consejo Superior de Investigaciones Cientificas.
Yaḥyā ibn Abī Manṣūr. (1986). *The Verified Astronomical Tables for the Caliph al-Maʾmūn*. Facsimile edition of the Arabic text, from MS Escorial 927. Frankfurt am Main, Germany: Institute for the History of Arabic-Islamic Science.

Al-Māridīnī, Jamāl al-Dīn, and Badr al-Dīn

David A. King
Frankfurt University, Frankfurt am Main, Germany

Jamāl al-Dīn al-Māridīnī was a competent astronomer who lived in Damascus or Cairo ca. 1400. He authored numerous short treatises, mainly dealing with instruments. One of the most remarkable of these instruments is a universal quadrant, the only known example of which is from Spain ca. 1580, made by a craftsman in the Louvain tradition (now in the Adler Planetarium, Chicago). His name indicates that he or his family came from Mardin, now in southern Turkey, but biographical information is lacking; indeed it is not even clear where he worked. He is often confused with his grandson, Sibṭ al-Māridīnī.

Badr al-Dīn al-Māridīnī, known as Sibṭ al-Māridīnī, lived in Cairo, ca. 1460. He was a grandson (Arabic *sibṭ*) of Jamāl al-Māridīnī and was one of the leading astronomers in Cairo. He compiled a large number of treatises, including many short works on the standard instruments of his time, the trigonometric and astrolabic quadrant and sundials. These treatises became extremely popular and exist in hundreds of copies. In fact they were studied by everyone in Egypt who was interested in astronomy in the succeeding centuries. As a result of this, more significant works were forgotten and the level of astronomy declined.

References

King, D. A. (1974). An analog computer for solving problems of spherical astronomy: The Shakkāziyya Quadrant of Jamāl al-Dīn al-Māridīnī. *Archives Internationales d'Histoire des Sciences, 24*, 219–242 (Reprint in King, D. A. *Islamic astronomical instruments*. London: Variorum, 1987. Reprint in Aldershot: Variorum, 1995, X.).
King, D. A. (1986a). *A survey of the scientific manuscripts in the Egyptían National Library*. Winona Lake, IN: Eisenbrauns; nos. C47 (Jamāl al-Dīn) and C97 (Badr al-Dīn).
King, D. A. (1986b). The astronomy of the Mamluks. *Isis, 74*, 531–555 (Reprint in King, D. A. *Islamic mathematical astronomy*. London: Variorum, 2nd rev. ed. Aldershot: Variorum, 1993, III.).
King, D. A. *In Synchrony with the Heavens: Studies in Astronomical Timekeeping and Instrumentation in Medieval Islamic Civilization*. Vol. 1: *The Call of the Muezzin (Studies I-IX)*. Leiden: Brill, 2004; Vol. 2: *Instruments of Mass Calculation (Studies X–XVIII)*. Leiden: Brill, 2005, especially X-6.5 on the Spanish quadrant.
Suter, H. (1900). *Die Mathematiker und Astronomen der Araber und ihre Werke*. Leipzig. (Reprint in Amsterdam: Oriental, 1982; nos. 421 (Jamāl al-Dīn) and 445 (Badr al-Dīn)).

Al-Masʿūdī (Abuʾ ʻl ḥasan ʿAlī Ibn al-ḥusayn al-Masʿūdī)

Mushtaqur Rahman

In the tenth century A.D. Muslims were arguably the leaders of world sciences, including geography. Many Muslim geographers, including al-Masʿūdī, established the principles of science and research in geography. Al-Masʿūdī's geographic curiosity took him as far as China and Madagascar. His conceptual orientation, which combined geography and history to explain cultural history, made him an outstanding scholar.

Not much is known about al-Masʿūdī's early life and education, except that he was born in Baghdad in A.D. 893 and died in Old Cairo, Egypt, in A.D. 956. His two surviving books, *Murūj al-dhahab wa-Maʿādin al-Jawhar* (Meadows of Gold) and *Kitāb al-tanbīh waʾl Ishraf* (Book of Indication and Revision) provide no biographical information. Presumably, his early education was with historians, philosophers, scientists, *ḥadīth* specialists (those who study the words of the Prophet Muḥammad), grammarians, and literary critics. He began his travels at the age of 23 to seek geographic knowledge and ended them when he was 56 years old. He lived and traveled during a period of Islamic Renaissance in many fields including geography.

In his book, al-Masʿūdī described the shape of the earth, seas and their depths, islands, mountains and rivers, mines, marshes, and lakes. He also provided information on inhabited areas and explained why land and sea changed their forms.

As a historian and geographer, al-Masʿūdī broadened the concept of geography by including all the known branches of geography in his discussions. In doing so he benefited equally from the scholarly works of both Muslims and non-Muslims. He quoted quite extensively from Greek, Persian, and Indian sources. Al-Masʿūdī also studied people within their own habitats. To him, "nature" (*ṭabīʿā*) meant the processes of the external physical world. He related those processes to humans in the universe, the activity of God in history, and the growth and development of societies.

An aspect of the development of Arabic geographic literature of his period was the production of maritime literature and travel accounts. Al-Masʿūdī also made important contributions to the field of oceanography, but his reputation as a scholar and scientist is based on his two surviving books on history and natural history.

Al-Masʿūdī had a universal outlook. He focused on a wide range of topics dealing with Islamic and non-Islamic cultural histories and provided elaborate cultural, historical, geographical, ethnological, climatic, and maritime descriptions of the known world of his time. He was a cultural geographer of the first order, and far ahead of his time.

References

Ahmad, M. H. S. (1979). *Al-Masʿūdī and his world* (pp. 1–17). London: Ithaca Press.

Khalidi, T. (1970). *Masʿūdī's theory and practice of history*. Ph.D. Dissertation, University of Chicago.

Nasr, S. H. (1968). *Science and civilization in Islam* (pp. 47–48). Cambridge, MA: Harvard University Press.

Sarton, G. (1927). *The times of al-Masʿūdī. Introduction to the History of Science* (Vol. 1, pp. 619–620). Baltimore: Williams and Wilkins.

Sezgin, U. (1997). Pharaonische Wunderwerke bei Ibn Wassif as-Sabi' und al-Mas'udi: Einige Reminiszenzen an Ägyptens vergangene Grösse und an Meisterwerke der alexandrinischen Gelehrten in arabischen Texten des 10. Jahrhunderts n. Chr. *Teil II/Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften, 11*, 189–249.

Siddiqi, A. H. (1990). Al-Masʿūdī's geographic concept. *International Journal of Islamic and Arabic Studies, 7*(2), 43–71.

Sprenger, A. (Trans.). (1941). *Al-Masʿūdī's historical encyclopedia. Meadows of Gold and Mines and gems* (Vol. 1). London: W. H. Allen.

Al-Muqaddasī

Mushtaqur Rahman

Born at Al-Bayt al-Muqaddas (Jerusalem) in A.D. 946, al-Muqaddasī (Shams ad-Dīn Abū ʿAbdallāh Muḥammad ibn Aḥmad ibn Abī Bakr al-Bannāʾ), also called al-Maqdisī, made important contributions in regional geography. In his early days he studied Muslim history, especially its political and cultural aspects, civilization, religion, and jurisprudence. To seek knowledge he visited distinguished scholars, met the men of science, and studied in royal libraries at a fairly young age.

Among other Arab geographers of the time, al-Muqaddasī's definition of a region was probably the most original and produced one of the most valuable treatises in Arabic literature, *Kitāb aḥsan-al taqāsim fī maʿrifat al-aqālim* (The Best Divisions for the Classification of Regions). Though al-Muqaddasī belonged to the Balkhī school, he was critical of it and felt that they disregarded real geography. He argued that scientific geography must be based on observation. He critically examined the information presented by Al-Jayhānī, al-Balkhī, Ibn al-Faqīh, al-Jahiz, and others and questioned their methods of acquiring information, their objectives, and their misrepresentations and selectivity of information. Then al-Muqaddasī stated:

> I have endeavored not to repeat anything other writers have written, nor narrated any particulars they narrated, except where it was necessary, in order neither to deny their right nor myself to be guilty of plagiarism, for in any case those alone will be able to appreciate my book who examine the works of those authors or who have travelled through the country, and are men of education and intelligence.

Al-Muqaddasī claimed that no one who had treated geography before him adopted his method or provided the information he did. In order to achieve his objective, he traveled through the Muslim world, with the exception of Spain and Sindh, conversed with scholars, and waited on princes. He discussed matters with judges, studied under doctors of law, frequented the society of men of letters, and associated with people of all classes until he attained what he wanted.

In his book, *Aḥsan al-taqāsim*, al-Muqaddasī divided the Muslim empire into 14 divisions, and treated the Arab world separately from the non-Arab world. Then he described the districts in each division, identifying their capitals and principal cities and giving their towns and villages in due order. Information which did not fit into either the Arab or non-Arab context was treated separately. While treating the regions in their entirety, Al-Muqaddasī provided a regional framework, and can rightly be called the father of regional geography.

See Also

► Balkhī School of Arab Geographers
► Geography in the Islamic World

References

Beasley, G. R. (1987). *The dawn of modern geography* (Vol. 1). London: John Murray.
Le Strange, G. (1905). *The lands of the eastern caliphate*. Cambridge, UK: Cambridge University Press.
Ranking, G. S. A., & Arzoo R. F. (Trans.). (1897–1910). *Aḥsan-al taqāsim fī maʿrifat al-aqālim*. Calcutta, West Bengal: Bibliotheca Indica.
Siddiqi, A. H. (1987). Al-Muqaddasī's treatment of regional geography. *International Journal of Islamic and Arabic Studies, 4*(2), 1–13.

Al-Muʾtaman ibn Hūd

Jan P. Hogendijk

Yūsuf Al-Muʾtaman ibn Hūd was the king of the kingdom of Zaragoza in Northern Spain from 1081 until his death in 1085. He lived in the Aljafería palace in Zaragoza, which was built by his father Aḥmad al-Muqtadir ibn Hūd (r. 1041–1081), and which is now the site of the Parliament of Aragon. Al-Muʾtaman was interested in mathematics, optics, and philosophy. He wrote a very long mathematical work, the *Kitāb al-Istikmāl* (Book of Perfection), of which large parts have recently been identified in four anonymous Arabic manuscripts in Copenhagen, Leiden, Cairo, and Damascus. A revised version of the whole *Istikmāl* was recently discovered.

In the *Book of Perfection*, al-Muʾtaman divides most of pure mathematics according to a philosophical classification in five "species" (*anwāʿ*). Species 1 deals with arithmetic and the theory of numbers. Al-Muʾtaman summarizes the arithmetical books of Euclid's *Elements*, and he proves Thābit ibn Qurra's rule for amicable numbers. The remaining species 2–5 deal with geometry. Al-Muʾtaman summarizes the works of Greek authors such as the *Elements* and *Data* of Euclid (300 BCE), *On the Sphere and Cylinder* of Archimedes (250 BCE), and the ▶ Conics of Apollonius (200 BCE). He does the same for Arabic authors as well, such as the *Quadrature of the Parabola* (*Miṣāḥat al-qaṭʿ al-mukāfī*) by ▶ Ibrāhīm ibn Sinān (909–946) and the *Optics* (*Kitāb al-ManāẒir*), *On Analysis and Synthesis* (*Fīʾl-taḥlīl waʾl-tarkīb*), and *On Given Things* (*Fīʾl-maʿlūmāt*) by Ibn al-Haytham (965-ca. 1041). The summaries in the *Book of Perfection* show that al-Muʾtaman really understood these works. Often he was able to shorten and generalize their contents quite drastically.

Al-Muʾtaman does not mention his sources, and he does not tell us what his own contributions are. The *Book of Perfection* probably includes some original contributions, such as a construction of two mean proportionals between two given lines by means of a circle and a parabola. A few geometrical theorems occur in the *Book of Perfection* for the first time in history, such as the theorem of Ceva (hitherto named after Giovanni Ceva, who independently discovered it in 1678), and the general proof of the invariance of crossratios under a perspectivity (a special case was proved by Pappus of Alexandria in late antiquity). It seems that al-Muʾtaman intended to add to the *Book of Perfection* a second part on astronomy and optics, but he probably did not have the time to do so.

References

Djebbar, A. (1993). Deux mathématiciens peu connus de l'Espagne du XI e siècle: al-Mu'taman et Ibn Sayyid. In M. Folkerts & J. P. Hogendijk (Eds.), *Vestigia Mathematica. Studies in medieval and early modern mathematics in honour of H.L.L. Busard* (pp. 79–91). Amsterdam: Rodopi.

Djebbar, A. (1997). La redaction de l'Istikmal d'al-Muʾtaman (XI e siècle) par Ibn Sartāq, un mathématicien des XIII e-XIV e siècles. *Historia Mathematica, 24*, 185–192.

Hogendijk, J. P. (1991). The geometrical parts of the Istikmāl of al-Mu'taman ibn Hūd, an analytical table of contents. *Archives Internationales d'Histoire des Sciences, 41*, 207–281.

Al-Nayrīzī

Sonja Brentjes

Born in Persia, al-Nayrīzī spent most of his life in Baghdad. He was a court astronomer/astrologer of caliph al-Muʿtaḍid (r. 892–902), to whom he dedicated several treatises, among them *Al-Risāla fī aḥdāth al-jaww* (Treatise on Meteorological Phenomena) or *Al-Risāla fī maʿrifat ālāt yuʿlamu bihā abʿād al-ashyāʾal-shākhiṣ a fī l-hawāʾ wal-latī ʿalā basīṭ al-arḍ wa-aghwār al-audīya waʾl-abār wa-ʿurūḍ al-anhār* (Treatise on the Knowledge of Instruments through which Distances between Distinct Things in the Air or Set up on the Ground and the Depth of Valleys and Wells, and the Widths of Rivers Can be Known). He wrote commentaries on Ptolemy's (fl. ca. 127–167) *Almagest* and his astrological work *Tetrabiblos* and an astronomical handbook (*Zīj*), a longer and a shorter version. And he commented on Euclid's (fl. ca. 300 BCE) *Elements* and his astronomical work *Phainomena* and wrote independent works on the determination of the *qibla*, the direction of Mecca, the spherical astrolabe, methods for solving particular astronomical problems, and astrological subjects.

The longer version of his *Zīj* is said to have been based upon Indian astronomical tradition (*Sindhind*) and used data from the *Zīj* prepared for ▶ al-Maʾmūn (r. 813–833). This was criticized by Ibn Yūnus (d. 1009), who pointed out further differences in opinion, especially with respect to the theory of Mercury, the eclipse of the moon, and the parallax. His commentary on the *Almagest*, lost as are his handbooks and his commentary on the *Tetrabiblos*, was quoted by later authors like ▶ al-Bīrūnī or Ibn al-Haytham and even occasionally called the best work of this type.

His extant works on the *qibla* and the spherical astrolabe built on the works of earlier scholars are some of the very best summaries on the subject still available. Others of his extant works on astronomy, astrology, geodesy, and meteorology have not yet been seriously studied.

Al-Nayrīzī's commentary on the *Elements* translated by Gerard of Cremona (d. 1187) into Latin includes extracts of the lost Greek commentaries by Heron (second century?) and Simplikios (sixth century) and of Arabic treatises like Thābit Ibn Qurra's alternative proof of the Pythagorean theorem. He omitted Simplikios' own proof of the parallels postulate in favor of that by Aghānīs/Aghānyūs (Agapios?, fl. ca. 511), which is also preserved in his independently transmitted *Al-Risāla al-m u ṣādara al-mashhūra* (Treatise on the Proof of the Well-Known Postulate).

In Book V, al-Nayrīzī follows a theory of proportion adopted before him by ▶ al-Māhānī (d. ca. 880) and, perhaps, Thābit ibn Qurra, a theory based on definitions of ratio and proportion which compared the expansion of magnitudes in continued fractions.

The text of the *Elements* contained in the Arabic manuscripts of al-Nayrīzī's commentary was viewed for a long time as the second version made by al-ḥajjāj ibn Yūsuf ibn Maṭar. Although it is derived from a text of the ḥajjāj tradition, al-Nayrīzī evidently edited it using a text of the Isḥāq/Thābit tradition. He changed its language, didactical features, and even letter symbols used for diagrams. He incorporated references to earlier Euclidean theorems, definitions, postulates, or axioms as well as to propositions stated by the Greek commentators. In a similar manner, he edited those texts he added as comments.

See Also

- ▶ al-Bīrūnī
- ▶ *Almagest*: Its Reception and Transmission in the Islamic World
- ▶ al-Māhānī
- ▶ Ibn Al-Haytham (Alhazen)
- ▶ Ibn Yūnus
- ▶ *Qibla* and Islamic Prayer Times
- ▶ Thābit ibn Qurra
- ▶ *Zīj*

References

Primary Sources

Codex Leidensis 399,1. *Euclidis Elementa ex interpretatione Al-Hadschdschadschii cum commentariis al-Narizii*. Arabice et latine ediderunt R. O. Besthorn et J. L. Heiberg. Vols. 1 and 2. Copenhagen: Librarian Gyldendaliana, 1893. G. Junge, J. Raeder, W. Thomson. Copenhagen, 1932, Vol. 3, Pt. 2.

Schoy, Carl. Abhandlung von al-Faḍl b. ḥātim an-Nairîzî: Über die Richtung der Qibla. Sitzungsberichte der Bayerischen Akademie der Wissenschaften zu München. *Mathematisch-physikalische Klasse* (1922): 55–68.

Seemann, H. (1925). Das kugelförmige Astrolab nach den Mitteilungen von Alfons IX. von Kastilien und den vorhandenen arabischen Quellen. *Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin, 7*, 30–32.

Secondary Sources

Brentjes, S. (2001). Two comments on Euclid's 'Elements': On the relation between the Arabic text attributed to al-Nayrizi and the Latin text ascribed to Anaritius. *Centaurus, 43*(1), 17–55.

Dold-Samplonius, Y. (1974). Al-Māhānī. In C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. IX, pp. 21–22). New York: Charles Scribner's Sons.

Hogendijk, J. P. (2000a). Al-Nayrizi's mysterious determination of the azimuth of the Qibla at Baghdad. *SCIAMVS, 1*, 49–70.

Hogendijk, J. P. (2000). Al-Nayrizi's own proof of Euclid's parallel postulate. In *Sic itur ad astra. Studien zur Geschichte der Mathematik und Naturwissenschaft. Festschrift. Festschrift für den Arabisten Paul Kunitzsch zum 70 Geburtstag*. (pp. 252–265). Wiesbaden, Germany: Harrossowitz.

Jaouiche, K. (1986). *La théorie des parallèles en pays d'Islam: contribution à la préhistoire des géometries non-euclidiennes*. Paris: J. Vrin.

Kennedy, E. S. (1956). A survey of Islamic astronomical tables. *Transactions of the American Philosophical Society, 46.2*, 123–177.

Rosenfeld, B. (1988). *A history of non-Euclidean geometry. Evolution of the concept of a geometric space*. New York: Springer.

Sabra, A. S. (1969). Simplicius's proof of Euclid's parallels postulate. *Journal of the Warburg and Courtauld Institutes, 32*, 1–24.

Sabra, A. S. (1974). Al-Nayrīzī. In C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. IX, pp. 5–7). New York: Charles Scribner's Sons.

Sezgin, F. (1973). *Geschichte des Arabischen Schrifttums* (Vol. V). Leiden, Netherlands: E. J. Brill (Vol. VI, 1974).

Youschkevitch, A. A. P. (1964). *Die Mathematik im Mittelalter*. Leipzig, Germany: Teubner Verlag.

Alphabet

Sema'am I Salem

As far as we know, literacy goes back to about 3500 BCE. The earliest people to have left written symbols are the Sumerians, followed by the Egyptians. The earliest clay tablets unearthed in Mesopotamia are picture writings which have not yet been deciphered, but those written after 3200 BCE are clearly Sumerian and their content is well known. Their subject matter includes groups of words, accounts of deeds of sale, and some fragments of early literature.

The Sumerians wrote primarily on clay tablets, producing wedge-shaped characters, which became known as cuneiform script, from the Latin *cunus* (wedge). It is quite probable that the idea of writing was introduced into Egypt from Mesopotamia. Soon after the Sumerians invented their script, the Egyptians formulated their own system, which consists of picture word-signs, and which they called *m-d-w-n-t-r* (speech of the gods), and which is now known by its Greek name, hieroglyphs (sacred, carved letters). The Egyptians then produced a simplified version, which is known as Hieratic (sacred). When the common Egyptians, not only the priests, learned to write, they used a highly simplified form known by the Greek name demotic (popular). Several scholars consider the demotic script a first step toward alphabetic writing.

By about 2000 BCE other forms of writing began to appear in various parts of the Middle East. The Hittites, who lived in modern-day Turkey, introduced a new form of hieroglyphs, consisting of some 70 signs, each of which stood for a simple syllable, and about 100 word-signs. Similar forms of hieroglyphs, consisting of word-signs and syllable-signs, were also used in Crete, Cyprus, Lebanon, Palestine, and Syria. The early script uncovered in Crete is in the form of pictograms and was probably introduced into Crete from Egypt. Although it has not been completely deciphered, it is known that it contains the names of certain gods such as Zeus, Athena, and Poseidon.

All the word-sign methods of writing are complex and difficult to learn, and only professional scribes were able to read and write. To write a letter, keep an account, check a legal document, or read a will, an ordinary person had to rely on the services of trained scribes.

This monopoly on reading and writing persisted until the advent of the alphabet, whose invention is one of the most important and useful inventions of all time. The transformation from word or syllable writing to an alphabetic script is immense – it simplified the process of reading and writing to a degree that enabled a common person to master the art, thus freeing him from the need for professional scribes. Its value lies in its elegance and its simplicity, and in its ability to express all the vocal sounds needed in any language in about 2-dozen symbols.

There has always been speculation as to the origin of the alphabet, beginning with the early Greek and Latin authors, who credited the invention of the alphabet to practically every near-eastern country. Diodorus Sciculus states, "The Syrians are the discoverers of the letters, and the Phoenicians having learned them from the Syrians and then passed them to the Greeks." Pliny, on the one hand, claims that: "the invention of the letter is a Phoenician feat," and speaks also of a Mesopotamian origin. Tacitus maintains that the alphabet is of Egyptian origin, and adds, "The Phoenicians took all the credit for what they received before passing it on to others." The various views of the classical authors are mere speculations that demonstrate their awareness of the problem and their cognizance of the importance of the discovery.

Opinions as to the origin of the alphabet are still voiced. There are those who still believe that the alphabet is of Mesopotamian origin – they base their opinion on the Ugaritic script which dates back to about 1400 and which consists of 30 symbols representing 30 consonant letters written in cuneiform script.

The existence of an alphabet in a cuneiform script does not imply, in any way, that the idea of an alphabet originated in Mesopotamia, where there is no evidence that it ever existed. Of the half a million or so cuneiform tablets and fragments of tablets uncovered in Mesopotamia, there is not one that bears a sign of an alphabet.

By about 2000 BCE the Mesopotamian cuneiform system of writing was used throughout the Near East and particularly in Canaan, where the rulers were using it in their correspondence even with the pharaohs of Egypt. When the Ugaritic scribes were writing their alphabet using the wedge-shaped cuneiform signs, the Mesopotamians were still content with their word-symbols.

There are also contemporary scholars who believe that the alphabet is of Egyptian origin; they base their views on the yet undeciphered Sinaitic inscriptions uncovered in 1906 in the Sinai Desert by Sir William Flinders Petrie and which date back to about 1500 BCE. The discovery was hailed by many as the missing link between the alphabet and the Egyptian demotic writing, and led to the belief that the Canaanites learned their method of writing from their contacts with the Egyptians. A recent discovery in the land of Canaan showed that the so-called Proto-Sinaitic inscriptions were used by Semitic people as early as 1700 BCE, and they are purely a Semitic script. The Canaanites, who were working the Egyptian turquoise mines in southwestern Sinai, left symbols scribbled on rocks and stones, and some scholars believe that the Canaanite workers learned their signs from their Egyptian lords. The Sinaitic pseudo-hieroglyphic and proto-Canaanitic scripts may at best be considered a first attempt at the complex process that led to the alphabetic script.

The champions of an Egyptian origin support their claims by the presence of simple symbols in the Egyptian hieroglyphs that goes back to about 2000 BCE. Egyptian scribes, like many others, were introducing symbols, which stood for simple sounds or syllables and to a certain degree resemble the symbols of the alphabet. This pseudo-hieroglyph has so many signs that it is considered more syllabic than alphabetic, and instead of simplifying the Egyptian way of writing, it added to its complexity. The Egyptians priests could not relinquish their complex picture word-signs, and kept using them until about AD 500.

The uncovering of Minoan hieroglyphs and other Minoan pictograms in the beginning of this century suggested to the archeologist Sir Arthur Evans that the Phoenician alphabet was itself derived from Crete. On the basis of Evans' statement, and in spite of the fact that the excavations on the island revealed no alphabetic signs, Glasgow wrote, "We now know, for instance, that the art of writing came from Crete, Phoenicia being the medium."

Many of the supporters of non-Phoenician origins point out that some of the sounds assigned to the signs that make up the alphabet do not correspond to the Canaanite names represented by the signs. As a matter of fact a few of the signs, only two, do not correspond to any known objects, but as we shall see, all the rest do. The variations may be attributed to the whim of a scribe or scribes, who forsook fidelity in favor of beauty or simplicity. The alphabet evolved for several centuries before reaching its known Phoenician form.

The most probable origin of the invention of the alphabet is the land of Canaan. It seems that a scribe in Canaan conceived of the idea that a language might be written without the numerous signs used in Babylonian cuneiform or Egyptian hieroglyphs. It took a great deal of effort and insight to realize that complex words may be broken down into simple sounds, and that it does not take many of these simple sounds to write an entire language. This is tantamount to saying that the large number of words that forms a language are made up of various combinations of a relatively small number of simple sounds.

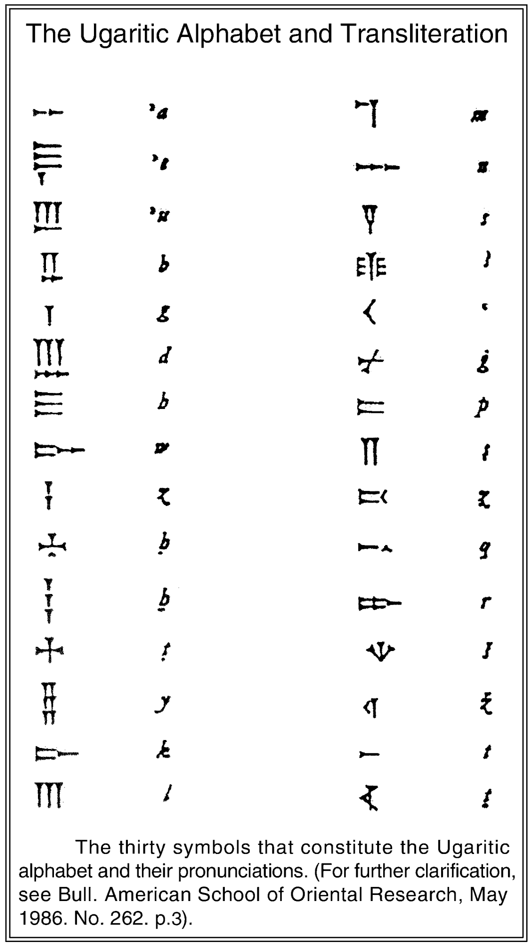
Each one of the simple sounds was represented by the picture of a familiar object, whose Canaanite name corresponds to the sound. Thus *beit* (house) stood for the *b* sound and *daleth* (door) stood for the *d* sound – the pictures stood for the simple sounds only and not for the word-sign. In a similar fashion all the consonants that form the language were represented. For reasons yet unknown, the vowels were not considered important enough to play a role in this scheme. This is why it is rather difficult to read modern-day Arabic and Hebrew scripts, where only the consonants are written.

In addition to the script uncovered in the Sinai desert, there are those unearthed in Byblos (Jbayl) and ascribed to the middle of the second millennium BCE. Other proto-Canaanite inscriptions were found in various parts of the Near East, such as Beit Shamesh, Gezer, Lakish, etc. The Gezer calendar is relatively recent – it dates to ca. 950 BCE. The alphabetic signs found in various localities are different – they do not resemble one another. This leads to the speculation that once the often-competing Canaanite clans knew of the magnificent invention, each group began to formulate its own symbols. Thus began the early stages of the alphabet of which several examples have been recovered, but many aspects of its early development are lost.

Except for the Ugaritic alphabet, which was written on clay tablets, the few early alphabetic signs found in the land of Canaan were scratched on stones or rocks. Toward the middle of the second millennium BCE Canaan was under the influence of Egypt, and the Canaanite scribes were writing on Egyptian papyrus. Unfortunately, in the relatively damp soil of Canaan, papyrus did not prove to be a durable material, and the early development of the alphabet written on it is lost; the real origins may never be known.

The earliest known pure "alphabetic" signs are the proto-Canaanitic scripts, and they may be considered as first attempts in a long process that led to what we call the Phoenician alphabet. However, on the whole, they do not suggest true alphabetic designations as a large number of the Sinaitic signs are syllabic rather than alphabetic. Although there are a few similarities between the Sinaitic and the Phoenician signs, many are very different, indicating that radical changes had taken place.

The Ugaritic alphabet may be considered a new way of writing the Canaanite script. The Ugaritic literature, written on clay tablets, is the earliest, most comprehensive alphabetic script that has survived. Furthermore, the order of the letters of the alphabet, at least the first few signs, support this possibility – the head of the Canaanite pantheon is El, whose epithet is *thor* (bull). It is most appropriate to put the head of the pantheon at the head of the alphabet, hence the first letter, *aleph*, meaning bull or ox. In the Canaanite mythology, the great gods dwell in large houses, and one often reads about the house of god, and the adobe of El is frequently mentioned. Thus the second letter of the alphabet, b, is represented by *beit* (house); and what is a house without a *daleth* (door), thus d is the fourth letter of the alphabet, followed by *hah* (window). There are several other such conjugate pairs in the Phoenician alphabet: *yad* and *kaff* (hand and palm), *mem* and *nahir* (water and river), and *rosh* and *shin* (head and tooth) (Fig. 1).

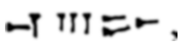


Alphabet, Fig. 1 The Ugaritic alphabet

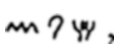
The earliest proto-Canaanitic symbols found in Phoenicia belong to the fourteenth century, and the first inscriptions of the Phoenician alphabet, which were left on arrowheads in Jbayl, belong to the twelfth century BCE. It is quite probable that the roots of the Phoenician alphabet go back to the Sinaitic proto-Canaanitic scripts. This hypothesis is strengthened by the few similarities between the Sinaitic and the early Phoenician signs and by the fact that they are listed in somewhat corresponding orders. Thus one may deduce that the formulation of the alphabet was a lengthy process culminated by the Phoenicians easy-to-reproduce form, which replaced the Sinaitic almost syllabic and the Ugaritic cumbersome cuneiform, with simple signs. There are indications that the scribes of Ugaritic, in their later writings, wrote from right to left and dropped a few of their consonants symbols. The Phoenicians continued the process of converging sounds to accommodate sound variations in their standard language, reducing the total number from 30 characters to 22.

Most recent authors attribute the origin of the alphabet to Phoenicia and more precisely to Jbayl. This is a definite possibility; the invention of the forms of the letters may have taken place in Jbayl. To compare the three scripts, let us reproduce the word "MLK" meaning king and written without vowels:

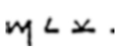
- Ugaritic



- Proto-Canaanitic



- Phoenician



Note the similarity between the Phoenician and the Latin letters. The simplicity of the Phoenician signs rendered them more accessible than all others, and by the end of the second millennium, the Phoenician alphabet became firmly established in the entire land of Canaan.

If doubt persists as to the origin of the invention of the alphabet, it is absolutely clear that the Phoenicians taught the letters to the Greeks and then to the rest of the known world. Some authors recognize the importance of this step and do not speak so much about the invention as about the diffusion of the alphabet. Herodotus is one such author and in one often quoted passage, he wrote, "These Phoenicians who came with Cadmus. . .among other kinds of learning, brought into Hellas the alphabet, which had hitherto been unknown, as I think, to the Greeks."

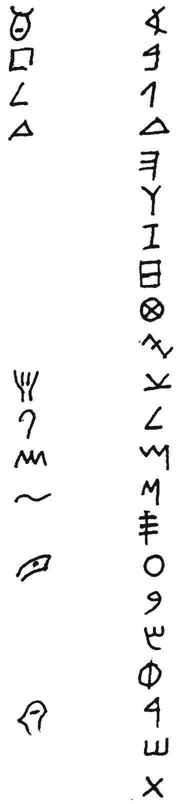
The vowels, sometimes erroneously referred to as a Greek contribution, were arrived at either by sheer misunderstanding or because some of the Phoenician consonants were not needed in the Greek language, and the Greeks themselves were having difficulty pronouncing them. Thus the Phoenician aspirate "hah" became a short "e" or *epsilon* in Greek, the aspirate "heth" became a long "e" or *eta*, the semiconsonantal "yad" or "yod" became an "i" or *iota*, and the throaty "ayn" became an "o" or *omicron* (Fig. 2).

The similarities between the old Phoenician and Greek alphabets are apparent; the order to the letters are basically the same and the names assigned to most symbols, which have no significance in Greek, are taken from Phoenician words. In the fifth century BCE the Greek scribes altered the shape of their letters by changing them into their mirror images. In general, minor changes took place whenever the alphabet was adapted to a new language.

The early Greeks expressed their gratitude to their benefactors by referring to their letters as *phoinikeia* (Phoenician objects). An inscription unearthed in Crete contains the verb *poiniazen* (to write) and the title *poinikastas* (scribe).

This alphabet soon spread into the Mediterranean region, or wherever Phoenician and later Greek trading posts were established. This helped in keeping records of commercial transactions and simplified the work of the Phoenicians, the sea traders of the ancient world. While the Phoenicians carried their alphabet with their goods and deposited both all over the Mediterranean world, Western Europe, and Northwest Africa, their cousins, the Arameans, moved with it

Alphabet, Fig. 2 The development of the alphabet



Caananitic (ca. 1500 BC)	Phoenician (ca. 1200 BC)	Picture represents	Meaning	Greek character	Greek name
		aleph	ox	α	alpha
		beit	house	β	beta
		gamma'	sickle	γ	gamma
		daleth	door	δ	delta
		hah	window	ϵ	epsilon
		waw	hook	ζ	zeta
		Zayn	–	η	eta
		heth	–	θ	theta
		teh	–	ι	iota
		yad	hand	κ	kappa
		kaff	palm	λ	lambda
		lamed	staff	μ	mu
		myi *or* mem	water	ν	nu
		nahir	river	ξ	xi
		samkeh	fish	o	omicron
		'ayn	eye	π	pi
		feh or peh	–	ρ	rho
		sad	–	σ	sigma
		quof	–	τ	tau
		rosh	head	υ	upsilon
		shin	tooth	ϕ	phi
		tā	cross	\	chi
				ψ	psi
				ω	omega

eastward, where it displaced most of the cuneiform script down the Euphrates and into Persia, then penetrated the western frontiers of India, furnishing the Indians with their Sanskrit alphabet.

The diffusion of the Phoenician alphabet, first into the Greek, then into the Roman cultures, provided the proper tool that fueled one of the greatest cultural explosions the world has ever known.

References

Abbudi, H. S. (1991). *Encyclopedia of Semitic civilizations*. Tripoli, Lebanon: Jarrus Press (in Arabic).

Alexander, P. (Ed.). (1986). *The lion encyclopedia of the bible*. Tring, UK: Lion Publishing.

Moscati, S. (1968). *The world of the phoenicians*. (A. Hamilton, Trans.). New York: Frederick A. Praeger.

Salem, S., & Salem, L. (1998). The development of the alphabet. *Dahesh Voice, 4*(1), 4–15.

Al-Qalaṣādī

Ahmed Djebbar

In the Islamic world of the fifteenth century there was a general halt in research and a lowering of the level of instruction. In mathematics this tendency resulted in a repetitive scientific production made up of poems or commentaries directed at an increasingly narrow public: teachers, *muwaqqits* (astronomers) charged with determining the hours of daily prayers, judicial functionaries, government bookkeepers, etc.

It is in light of this tendency that we can appreciate both the intellectual journey and the scientific contribution of al-Qalaṣādī, one of the last scholars of Andalusian origin who dedicated a large part of his life to disseminating – to the central Maghreb, to Ifriqiya, and to Egypt – what he knew of the Arab mathematical tradition of the preceding centuries.

ʿAlī ibn Muḥammad al-Qalaṣādī was born around 1412 in the Andalusian village of Basta. This small village, which is in the northeastern part of Grenada, was already prosperous in the time of the geographer ▶ al-Idrīsī (d. 1153) and continued to be so for two centuries.

We know nothing of al-Qalaṣadī's childhood except that he grew up in his birthplace where he learned the *Quʾrān* from his teacher Ibn ʿAzīz and where he received his first lessons in Arabic and probably also in mathematics. In the course of his adolescence he continued these studies and was taught grammar and mathematics from the arithmetic texts of Ibn al-Bannāʾ (d. 1321), as well as law, the science of inheritance, and calculation.

In 1436, at the age of 24, al-Qalaṣadī left his native village and began his first educational voyage, heading to Tlemcen, the first stop of a long journey to scientific centers in the Maghreb, al-Andalus, and Egypt. The educational voyage (*riḥla* in Arabic) was a medieval tradition, one of whose goals was to allow students to complete their education in various places, taking classes from famous professors.

Al-Qalaṣādī's stay in Tlemcan lasted 8 years. His most serious study of mathematics was with az-Zaydūrī (d. 1441). He himself says that az-Zaydūrī taught him the contents of two important texts of Ibn al-Bannāʾ: the *Kitāb al-Uṣūl wa l-muqaddimāt f i l-jabr wa'l-muqābala* (Book on the Foundations and Preliminaries in Algebra and Restauration) and the *Rafʿ al-ḥijāb ʿan wujūh aʿmāl al-hiṣab* (Lifting of Veil on the Science of Calculus Operations).

It also appears that the first scientific works of al-Qalaṣādī were written in Tlemcen, between 1436 and 1444. There were three commentaries on writings on the science of inheritance and a mathematics book entitled *al-Tabṣira* (The Book which Makes Things Intelligible).

In 1444, al-Qalaṣādī left Tlemcen for Tunis, which was at that time one of the most dynamic intellectual centers in the Maghreb. In the *madrasas* (colleges) where he studied, al-Qalaṣādī took courses in Malikite law, the Arabic language, grammar, and the rational sciences. At the same time, he devoted time to his own writing. He published three books on calculation: the *Kashf al-jilbāb ʿan ʿilm al-ḥisāb* (Unfolding the Secrets of the Science of Calculation) in 1445, the *Qānūn fi al-ḥisāb* (Canon of Mathematics), and his commentary entitled *Inkishāf al-jilbāb ʿan qānūn al-ḥisāb* (Explaining the Canon of Mathematics). He also published two works on traditional sciences, *al-Kulliyyāt fi al farā'iḍ* (Collection on Successional Division), and a commentary on it. At the end of his stay in Tunis, in 1447, it appears that he wrote his epistle on irrational numbers entitled *Risāla fi dhawāt al-asmāʾ wa 'l-munfaṣilāt* (Epistle on Binomials and Apothems).

On 30 May 1447, al-Qalaṣādī left Tunis and headed to Cairo and then to Mecca, where he wrote a commentary on the *Farā'iḍ* (Book on Successional Division) of Ibn al-ḥājib on traditional science. Returning from the pilgrimage, he again stayed in Cairo, teaching and taking classes from several professors, notably Shams al-Dīn al-Samarqandī in rational sciences.

In April 1449, al-Qalaṣādī left Cairo and returned to al-Andalus. In 1451 he returned to his native village of Basta, and then went to Grenada, where he stayed for 30 years. There he studied with eminent professors like the astronomer Ibrāhīm Ibn Futūḥ, who specialized in the study of astrolabes.

A deterioration of the political climate of the interior of the kingdom of Grenada and increasingly worrisome menaces from outside forced al-Qalaṣadī to leave the Andalus once and for all in 1483. He settled finally in Béja in Ifriqiya where he died in 1486, just 6 years before the fall of Grenada.

Mathematical Works of al-Qalaṣādī

Like some of his contemporaries in al-Andalus and the Maghreb, al-Qalaṣādī wrote on many different subjects. In almost all disciplines he also, again like many of his contemporaries, published numerous commentaries on classical texts. But he is, to my knowledge, the only scholar of his era to have written so many works on mathematics.

The mathematical development of al Qalaṣādī seems to have been centered basically on the science of calculation, on the processes of arithmetic and algebraic calculation and their application in the solving of abstract exercises and practical problems – e.g., problems of commercial transaction, monetary conversions, or the division of inheritances.

In algebra, he wrote chapters included in the arithmetical works already noted. In these chapters he treats algebraic operations and the resolution of the canonical equations of ▶ al-Khwārizmī. To that we must add his commentary on the algebraic poem of ▶ Ibn al-Yāsamīn.

In these texts one finds a peculiarity of the Maghrebian mathematical tradition, the utilization of a certain symbolism to express objects or algebraic concepts such as an unknown, different powers, or equality in equations. For a long time the invention of this symbolism was attributed to al-Qalaṣādī. But the results of recent research now permit us to affirm that this same algebraic symbolism was already in existence in this twelfth century, particularly in the work of Ibn al-Yāsamīn entitled *Talqīḥ al-af kār* (Fertilization of Thoughts), and that it was widely in use in the fourteenth century, in particular by ▶ Ibn Qunfudh (d. 1407). The work of al-Qalaṣādī bears witness to the persistence of these symbols and of their widespread use throughout the Maghreb.

In arithmetic, his writings deal essentially with the four arithmetic operations (applied to whole numbers, fractions, and irrational quadratics), with the extraction of the exact or approximate square root of a number, with the rule of three, with the method of false positives, and with other arithmetical procedures such as the breakdown of a number into prime factors and the calculation of the sums of series of natural numbers from their squares and cubes. Again, it is important to note that the techniques used by al-Qalaṣādī in these books are related to techniques already used in the works of al-ḥaṣṣār (twelfth century) and of Ibn al-Bannāʾ.

The fact that these themes are present in the works of al-Qalaṣādī and his method of treating them leads to the conclusion that in the fifteenth century, the mathematical traditions of al-Andalus and of the Maghreb were unified by being based upon each other. Moreover, if one compares the work of al-Qalaṣādī with that of Ibn al-Bannāʾ, one notices a certain continuity both in form and content. Because of this, one can argue that al-Qalaṣādī is more Maghrebian than Andalusian. This stamp of the Maghreb on the education and work of a scholar from al-Andalus of the importance of al-Qalaṣādī offers proof, moreover, of the decline of scientific activity in al-Andalus in the fourteenth and fifteenth centuries.

On the other hand, when one compares his different works in mathematics, one does not see a noticeable evolution from one book to another, but rather different formulations of classic themes and techniques. Al-Qalaṣādī himself claimed that some of his books were only developments or summaries of previously published works. It is important to note that this process, which was not unique to al-Qalaṣādī and which was already in evidence at the end of the fourteenth century both in the Maghreb and in Egypt, only reflects the continuation in the fifteenth century of the slow decline of scientific activity in the Islamic city. In this difficult context the scientific aptitude of al-Qalaṣādī was not really able to flourish fully, and it is greatly to his credit that he contributed to maintaining the level of scientific activity of that of the fourteenth century in the Andalus and the Maghreb.

See Also

▶ al-Idrīsī
▶ Ibn al-Bannāʾ

References

Djebbar, A. (1980). *Recherches et Enseignement Mathé matiques dans le Maghreb des XIII e -XIV e siècles* (pp. 41–54). Paris: Université de Paris-Sud, Publications Mathématiques d'Orsay.

Djebbar, A. (1988). Quelques aspects de l'algèbre dans la tradition mathématique arabe de L'Occident musulman. In *Actes du Premier Colloque maghrébin d'Alger sur l'Histoire des mathématiques arabes* (*Algeria, 1–3 Décembre 1986*) (pp. 99–123). Algeria, Algiers: Maison du Lívre.

Dozy, R., & De Geoje, M. J. (1968). *Edrisi, description de l'Afrique et de l'Espagne*. Leiden, The Netherlands: Brill.

Woepcke, F. (1854). Recherches sur l'histoire des sciences mathématiques chez les orientaux: Notice sur des notations algébriques employées par les Arabes. *Journal Asiatique, 4*, 348–384, 5th series.

Woepcke, F. (1859). *Traduction du traité d'arithmétique d'Abou Haçan Ali Ben Mohammed Alkalaçadi* (Recherches sur plusieurs ouvrages de Léonard de Pise). Rome: Imprimerie des Sciences mathématiques et physiques.

Al-Qūhī (or Al-Kūhī)

Yvonne Dold-Samplonius

Abū Sahl Wayjan ibn Rustam al-Qūhī (or al-Kūhī) probably originated from the village of Quh in the Iranian province of Tabaristan. He worked in Baghdad under the Buwayhid Caliphs ʿAḍud al-Dawla and his son and successor Sharaf al-Dawla. In 969/970 al-Qūhī assisted at the observations of the solstices in Shiraz. These observations, ordered by ʿAḍud al-Dawla, were directed by Abū'l-ḥusayn ʿAbd al-Raḥmān ibn ʿUmar ► al-Ṣūfī. In 988 al-Qūhī supervised astronomical observations in the garden of the palace of Sharaf al-Dawla in Baghdad in the company of several magistrates and respected scientists.

Some of al-Qūhī's contemporaries considered him to be the best geometer of his time; al-Khayyāmī held him in high esteem. In the geometrical writings known to us he mainly solved problems that would have led to equations of higher than the second degree. A note by al-Qūhī is added to Naṣīr al-Dīn al-Ṭūsī's redaction of Archimedes' *Sphere and Cylinder* in the Leiden manuscript, on how to construct a sphere segment equal in volume to a given sphere segment, and equal in surface area to a second sphere segment. This problem is similar to but more difficult than the constructions solved by Archimedes in *Sphere and Cylinder* II,6 and II,7. Al-Qūhī constructed the two unknowns, i.e., the radius of the sphere and the height of the segment, by intersecting an equilateral hyperbola with a parabola and rigorously discussed the conditions under which the problem is solvable.

Conic sections provided the tools for several problems, as in the classical problem of trisecting an angle. In the small treatise *Risāla fī qismat al-zāwiya* (On the Trisection of the Angle) al-Qūhī gave a purely Islamic solution by means of an orthogonal hyperbola. This solution was taken over by ► al-Sijzī. In *Risāla fī istikhrāj ḍil'al-musabba'al-mutasāwi'l-aḍlā*ʾ (On the Construction of the Regular Heptagon) the precise construction is more complete than the one attributed to Archimedes. Al-Qūhī's solution is based on finding a triangle with an angle ratio of 1:2:4. He constructed the ratio of the sides by intersecting a parabola and a hyperbola, with all parameters equal. Al-Sijzī, who claimed to follow the method of his contemporary Abū Sa'ied al-ʿAlā ► ibn Sahl, used the same principle. A second, different solution by al-Qūhī also exists. One of the most interesting examples of late tenth-century solutions is al-Qūhī's construction of an equilateral pentagon in a given square in *Risāla fī ʿamal mukhammas mutasāwi l-aḍlā*ʿ *fī murabba*ʿ*ma*ʿ*lūm* (On the Construction of an Equilateral Pentagon in a Known Square). This solution is based on Books I–VI of Euclid's *Elements*, Euclid's *Data*, and parts of Books I–III of Apollonius' ► Conics. The construction is remarkable, because it contains a proof of the focus-directrix property of a hyperbola with eccentricity $\varepsilon = 2$. It is reasonable to assume that al-Qūhī independently discovered and proved this property, thus going a step further than Apollonius.

In *Risāla fī istikhrāj misāḥat al-mujassam al-mukāfī* (On Measuring the Parabolic Body) al-Qūhī gave a somewhat simpler and clearer solution than Archimedes had done. He said that he knew only Thābit ibn Qurra's treatise on this subject, and in three propositions showed a shorter and more elegant method. Neither computed the paraboloids originating from the rotation of the parabola around an ordinate. That was first done by Ibn al-Haytham, who was inspired by Thābit's and al-Qūhī's writings. Although he found al-Qūhī's treatment incomplete, Ibn al-Haytham was nevertheless influenced by his thinking. Maybe the two met in Basra, where al-Qūhī wrote his correspondence to Abū Isḥaq al-ṣābī and four books on centers of gravity. Analyzing the equation $x^3 + a = cx^2$, al-Qūhī concluded that it had a (positive) root if $a \leq 4c^3/27$. This result, already known to Archimedes, was not known to al-Khayyāmī, whose analysis is less accurate.

Al-Qūhī was the first to describe the so-called perfect compass, a compass with one leg of variable length for drawing conic sections. In this clear and rather general work, *Risāla fī'l birkar al-tāmm* (On the Perfect Compass), he first described the method of constructing straight lines, circles, and conic sections with this compass and then treated the theory. He concluded that one could now easily construct astrolabes, sundials, and similar instruments. In his *Kitāb ṣan'at al-aṣṭurlāb* (On the Manufacture of the Astrolabe) al-Qūhī used an original method for drawing azimuth circles, based on an analemma, a procedure for reducing problems in three dimensions to two dimensions. A commentary on this work was written by Abū Sa'd al-ʿAlā ibn Sahl. Al-Qūhī's proofs for this construction were reproduced in an inferior form by Abū Naṣr Manṣūr ibn ʿIrāq, who highly esteemed al-Qūhī, in *Risāla fī dawā'ir as-sumūt fī al-aṣṭurlāb* (Azimuth Circles on the Astrolabe).

The correspondence between al-Qūhī and Abū Isḥaq al-ṣābī contains discussions of the possibility of curvilinear figures being equal to rectilinear figures, the meaning of "known ratio," and whether one can square a parabolic segment by exhausting it with triangles. The first letter especially gives impressive evidence for al-Qūhī's creativity in two theorems on centers of gravity of circular sectors and arcs. In the same correspondence he deducted a value of 28/9 for the ratio of the circumference of a circle to its diameter (π). This result was attacked by Abū Isḥaq and then, almost 150 years later, by Abū'l-Futūḥ Aḥmad ibn Muḥammad ibn al-Sarī. The latter thought that al-Qūhī got swept away by enthusiasm about his result. Also the 27 propositions in *Hādhā mā wujida min ziyādat Abī Sahl ʿalā al-maqālah al-thāniiyah min kitāb Uqlīdis fī al-uṣūl* (Abū Sahl's Additions to Book II of Euclid's Elements) are rather weak and not very clearly stated. Probably, however, those additions, if they were even written by al-Qūhī, were originally only marginal notes in his copy of Euclid's *Elements*.

See Also

- ▶ Abū'l-Wafāʾ
- ▶ Al-Ṣāghānī
- ▶ al-Ṣūfī
- ▶ Astrolabe
- ▶ Conics
- ▶ Ibn Al-Haytham (Alhazen)
- ▶ Ibn Sahl
- ▶ Naṣīr al-Dīn al-Ṭūsī
- ▶ Samūʾīl ibn ʿAbbās (Al-Maghribī)
- ▶ Thābit ibn Qurra
- ▶ Umar al-Khayyām

References

Abgrall, P. (1995). Les Circles Tangents d'al-Qūhī. *Arabic Sciences and Philosophy, 5*, 263–295.

Anbouba, A. (1978). Construction de l'Heptagone Régulier par les Arabes au 4e Siècle H. *Journal of the History of Arabic Science, 2*, 264–269.

Berggren, J. L. (1979). The barycentric theorems of Qūhī Sahl al-Qūhī. *Second International Symposium on the History of Arabic Science, Aleppo*.

Berggren, J. L. (1983). The correspondence of Abū Sahl al-Qūhī and Abū Isḥaq al-ṣābī: A translation with commentaries. *Journal of the History of Arabic Science, 7*, 39–124.
Berggren, J. L. (1991). Medieval Islamic methods for drawing azimuth circles on the astrolabe. *Centaurus, 34*, 309–344.
Berggren, J. L. (1994). Abū Sahl al-Kūhi's treatise on the construction of the astrolabe with proof: Text, translation and commentary. *Physis (NS), 31*, 141–252.
DeYoung, G. (1991–1992). Abū Sahl's additions to book II of Euclid's elements. *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften, 7*, 73–135.
Dold-Samplonius, Y. (1970). al-Qūhī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. XI, pp. 239–241). New York: Charles Scribner's Sons.
Hogendijk, J. P. (1982). Rearranging the Arabic mathematical and astronomical manuscript Bankipore 2468. *Journal of the History of Arabic Science, 6*, 133–159.
Hogendijk, J. P. (1984a). Al-Kūhī's construction of an equilateral pentagon in a given square. *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften, 1*, 101–144.
Hogendijk, J. P. (1984b). Greek and Arabic constructions of the regular heptagon. *Archive for History of the Exact Sciences, 30*, 197–330.
Hogendijk, J. P. (1984c). *Ibn al-Haytham's completion of the conics*. Berlin, Germany: Springer Verlag.
Knorr, W. (1989). *Textual studies in ancient and medieval geometry*. Boston: Birkhäuser.
Rashed, R. (1993). *Géométrie et dioptrique au Xe Siècle: Ibn Sahl, al-Qūhī et Ibn al-Haytham*. Paris: Les Belles Lettres.
Rashed, R. (2001). Al-Qūhī: From meteorology to astronomy. *Arabic Sciences and Philosophy, 11*, 157–204.
Sesiano, J. (1979). Note sur trois théorèmes de Mécanique d'al-Qūhī et leur conséquence. *Centaurus, 22*, 281–297.

Al-Rāzī

Albert Z. Iskandar

Abū Bakr Muḥammad Ibn Zakariyyā al Rāzī (Rhazes), the most original physician philosopher of his time, was born in al-Rayy (hence the name, al-Rāzī), now ruins near modern Teheran. Medieval historians wrote more on his copious bibliography than on his life.

▶ Al-Bīrūnī (d. AD 1048 or 1050) writes in his *Risāla fī Fihrist Kutub Muḥammad Ibn Zakariyyā al-Rāzī* (Missive on the Index of Books of Muḥammad Ibn Zakariyyā al-Rāzī) that he was asked by a learned man to compile a bibliography of al-Rāzī. To accomplish this task, he examined many manuscripts, and recorded only those works in which he found al-Rāzī's name mentioned as author in the text. Al-Bīrūnī's method of research undoubtedly resulted in his failure to record some of al-Rāzī's genuine works.

Al-Rāzī advised doctors to practice in densely populated cities, where they could benefit from the experience of many skillful physicians and have the chance to examine many patients. He himself moved from al-Rayy to Baghdad where, in his youth, he studied and practiced the art of healing at its hospital (*bīmāristān*). Later, he returned to al-Rayy, at the invitation of its ruler, Manṣūr ibn Isḥāq, to assume responsibility as Hospital Director. To this ruler, al-Rāzī dedicated two books, *al-Almnṣūrī fi'l ṭibb* (al-Manṣūrī on Medicine) and *al-ṭibb al-Rūiḧ ānī* (The Spiritual Physic). These were intended to unite the study of diseases of the body with those of the soul.

Having achieved fame in al-Rayy, al-Rāzī returned to Baghdad to become Head of its newly founded hospital, named after its founder the Abbasid caliph al-Muʿtaḍid (d. AD 902). The last years of his life were spent in al-Rayy, where he suffered from glaucoma (*al-māʾ al-azraq*), and died in AD 932 or 925.

Al-Rāzī's book *Fi'l Shukūk ʿalā Jālīnūs* (Doubts about Galen), so far unpublished, is devoted to the criticism of 28 of Galen's books, beginning with the *al-Burhān* (Demonstration) and ending with *Fi'l Nabḍ* (On the Pulse).

Before embarking on the criticism of Galen, he writes an apology in which he acknowledges his debt to his master, but says that "the art of physic is a philosophy which does not tolerate submission to any authority, nor does it accept any views, or yield to any dogmas without proper investigation." He says Galen himself supported this view. In the closing passage of his introduction, al-Rāzī affirms the validity of his book, saying that none of Galen's predecessors had escaped Galen's own scathing criticism.

To al-Rāzī, progress in scientific knowledge is inevitable. In his treatise *Fī Miḥnat al-ṭabīb wa Taʿyīnih*, he says "He who studies the works of the Ancients gains the experience of their labour as if he himself had lived thousands of years spent on investigation."

Al-Rāzī also mentions *al-Jāmiʿ al-Kabīr* four times in his book *al-Murshid aw al-Fuṣūl* (The Guide or Aphorisms), which was written to serve as an introduction to medicine. *Al-Jāmiʿ al-Kabī* consists of 12 sections (*aqsām*), of which only 2 have been recently discovered in manuscripts: *ṣaydalat al ṭibb* (Pharmacology in Medicine) and *Fī Istinbāṭ al-Asmāʾ wa'l-Awzān wa'l-Makāyīl* (On Finding the Meaning of Unfamiliar Terms, Weights, and Measures).

His medical prescriptions took into account the patients' social status. For the rich, princes, and rulers, the effective drugs had to be mixed with sweet vehicles, as explained in *al-ṭibb al-Mulūkī* (The Royal Medicine). For the poor, he wrote a book of recipes entitled *Man lā Yaḥḍuruh al-ṭabīb* (Who has no Physician to Attend Him) also known by the title *ṭibb al-Fuqarāʾ* (Medicine for the Poor).

Al-Rāzī argued that the medicinal properties attributed to various parts of animals, vegetables, and minerals should be recorded in books, which he did in his *Khawāṣṣ al-Ashyāʾ* (The Properties of Things). Such properties should neither be accepted nor discarded, unless experience (*al-tajriba*) proves them to be true or false. Physicians should not accept any property as authentic, unless it has been examined and tried.

In theory, al-Rāzī followed Galen, yet he found it necessary to correct him, and in practice, he revived the Hippocratic art of clinical observation. Having read the Hippocratic book *Abīdhīmyā* (Epidemics), he decided to write his own case histories, where he carefully recorded the name, age, sex, and profession of each patient. He also gave an early example of a clinical trial, when he divided his patients suffering from meningitis (*al-sirsām*) into two groups. He treated one group with bloodletting and intentionally, as a control, refrained from applying venesection to the other group.

All these detailed case histories are extant in his private notes which became known after al-Rāzī's death as the *al-ḥāwī fi'l ṭibb* (Continens on Medicine). It should be considered a private library of a well read and highly educated physician-philosopher, not a book meant for publication. It is interesting to remark that illnesses which affected al-Rāzī himself are recorded in *al-ḥāwī fi'l ṭibb*. In a note, preceded with "*Lī* (mine)," he mentions how he cured an inflammation of his own uvula by gargling with strong vinegar; in another, he jots down the fact that he recovered from a swelling in the right testicle by taking emetics (*muqayyiʾāt*) for a long time.

Al-Rāzī's medical works had great influence on medical education in the Latin West. *Al-ḥāwī fi'l ṭibb* was rendered into Latin (*Liber Continens*) by a Sicilian Jew, Faraj Ibn Sālim (Farrajut) in AD 1279. It was printed five times between AD 1488 and 1542. His *Liber ad almansorem*, consisting of ten books, and his *Liber Regius* were very popular among medieval European practitioners. The seventh book of *Liber ad Almansorem* (On Surgery) and the ninth entitled *Nonus Almansoris* (A General Book on Therapy) constituted a part of the medical curriculum in Western universities.

Al-Rāzī established an accurate differential diagnosis, based on clinical observations, between smallpox (*al-jadarī*) and measles (*al-ḥaṣba*). His book *Smallpox and Measles* was translated into Latin (*De variolis et morbillis*), and into other occidental languages and was printed about 40 times between AD 1498 and 1866.

The subject matter in this book is quite original. First, al-Rāzī asserts that Galen knew of smallpox, yet failed to indicate its etiology and to prescribe any satisfactory therapy. Secondly, he lays down his own differential diagnosis by his vivid description of the pustules of smallpox and the rash of measles. In his prognosis of the course of smallpox, he recommends close attention to the heart, the pulse, respiration, and excreta. He outlines his own method of protecting the patient's eyes and elaborates on how to avoid deep facial scarring.

References

Adler, R. E. (2004). *Medical firsts: From Hippocrates to the human genome*. Hoboken, NJ: Wiley.

Ahmed, V., & Ammatun-Noor. (1997). Abu Bakr Muhammad ibn Zakariya al-Razi: The Iranian. *Hamdard Medicus, 40*(4), 4–9.

Arberry, A. J. (1950). *The spiritual Physick of Rhazes, translated from the Arabic*. London: John Murray.

Channing, J. (1766). *Rhazes de variolis et morbillis. Arabice et Latine*. (Trans.). London: G. Bowyer.

Congourdeau, M.-H. (1996). Le traducteur grec du traité de Rhazès Sur la variole. *Storia e Ecdotica dei Testi Medici Greci*, 99–111.

Daghestani, A. N. (1997). Images in psychiatry: Al-Razi (Rhazes), 865–925. *American Journal of Psychiatry, 154*(11), 1602.

Druart, T. A. (1996). Al-Razi's conception of the soul: Psychological background to his ethics. *Medieval Philosophy and Theology, 5*, 245–263.

Greenhill, W. A. (1848). *A treatise on the small-pox and measles*. (Trans). London: Cambridge University Press.

Iskandar, A. Z. (1959). *A study of al-Rāzī's medical writings, with selected texts and english translations*. Ph.-D. Thesis, University of Oxford.

Iskandar, A. Z. (1960a). Taḥqīq fī Sinn al-Rāzī ʿind bidʾ Ishtighālih bi'l-Ṭibb. *al-Machriq, 54*, 168–177.

Iskandar, A. Z. (1960b). Kitāb Miḥnat al ṭabīb li'l Rāzī. *al-Machriq, 54*, 471–522.

Iskandar, A. Z. (1961). Rhazes' K. al-Murshid aw al-Fuṣūl (The guide or aphorisms), with texts selected from his medical writings. *Revue de l'Institut des Manuscrits Arabes, 7*(1), 1–125. 173–213.

Iskandar, A. Z. (1962). Al-Rāzī al-ṭabīb al-Iklīnīkī. *al-Machriq, 56*, 217–282.

Iskandar, A. Z. (1990). Al-Rāzī. In M. J. L. Young (Ed.), *The Cambridge history of Arabic literature: Religion, learning and science in the ʿAbbasid period* (pp. 370–377). Cambridge, UK: Cambridge University Press.

Kitābu'l-ḥāwī fi'ṭ-ṭibb (Continens of Rhazes), Encyclopaedia of Medicine by Abūl Bakr Muḥammad Ibn Zakariyyā ar-Rāzī (d. A.H. 313/A.D. 925). (1955–1971). 23 vols. Hyderabad-Deccan: Dāʾiratu'l-Maʿārif-l-Osmania.

Langermann, Y. T. (2002). Criticism of authority in the writings of Moses Maimonides and Fakhr al-Din al-Razi. *Early Science and Medicine, 7*(3), 255–275.

Mayerhof, M. (1955). Thirty-three clinical observations by Rhazes (*circa* 900 A.D.). *Isis, 23*, 321–356.

Müller, A. (1882–1884). *Ibn Abī Uṣaybiʿa. ʿUyun al-Anbāʾ fī ṭabaqāt al-Atibbāʾ*. 2 vols. Cairo, Egypt: Būlāq.

Nasser, A. (2002). Al-Razi book on smallpox and measles. *Journal of the International Society for the History of Islamic Medicine (ISHIM), 1*(1), 29–34.

Al-Ṣāghānī

Boris A. Rosenfeld
PA, USA

Abū ḥāmid Aḥmad ibn Muḥammad al-Ṣāghānī al-Asṭurlābī was an Arabic astronomer and mathematician. He was born in Chagaian (Central Asia) and worked in Baghdad.

His main work was the *Kitāb fī'l-tasṭīh al-tāmm* (Book of the Perfect Projection on to a Plane) which is extant in two manuscripts. The treatise is devoted to a generalization of the stereographic projection of a sphere onto a plane, usually used in the making of astrolabes. This concerns the projection from a pole of the sphere onto the equatorial plane or a plane parallel to it. Under this projection, circles on the sphere are imaged onto the plane as circles or straight lines. The "perfect projection" invented by al-Ṣāghānī is the projection of the sphere from any point of its axis onto a plane orthogonal to the axis. Under this projection, circles on the sphere are imaged on the plane as conic sections (ellipses, hyperbolas, and parabolas) or straight lines. These descriptions of methods for conics construction are important for geometry. In the treatise, al-Ṣāghānī considers the construction methods for images of different circles of the celestial sphere, such as the celestial equator and its parallels and the horizon and its almacantars, verticals, and one ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The contents of the treatise are explained in detail by al-Bīrūnī (973–1048) in his *Astrolabes*.

Al-Ṣāghānī was also the author of two mathematical treatises, on the construction of a regular heptagon inscribed in a circle and on the trisection of an angle. He also wrote three astronomical treatises. *Kitāb qawānīn ʿilm al-hay'a* (Book on Rules of the Science of Astronomy) is not extant, but al-Bīrūnī in his *Geodesy*

Boris A. Rosenfeld: deceased

mentioned measuring the value of the angle between the ecliptic and the celestial equator found by al-Ṣāghānī in Baghdad. The second, *Maqāla fī'l abʿād wa'l-ajrām* (Article on Distances and Volumes), dealt with the distances and volumes of planets and stars. The third work was *Fī'l sāʿāt al-maʿmūla ʿalā ṣafāʾiḥ al-asṭurlāb* (On Horary Lines Produced on the Tympanums of Astrolabes).

See Also

► Astrolabe

References

Frank, J. (1918). Zur Geschichte des Astrolabs. *Sitzungsberichte der Physikalisch-Medizinischen Sozietät zu Erlangen, 48–9*, 275–305.

Hogendijk, J. P. (2001). The contributions by Abu Nasr ibn Iraq and al-Saghani to the theory of seasonal hour lines on astrolabes and sundials. *Zeitschrift Fur Geschichte Der Arabisch Islamischen Wissenschaften*, 1–30.

Lorch, R. (1987). Al-Saghānī's treatise on projecting the sphere. *Annals of the New York Academy of Sciences, 500*, 237–252.

Matvievskaya, G. P., & Rosenfeld, B. A. (1983). *Mathematicians and astronomers of medieval Islam and their works (8th–17th C.)* (Vol. 2, pp. 162–163). Moscow: Nauka (in Russian).

Puig, R. (2014). Ṣāghānī: Abū Ḥāmid Aḥmad ibn Muḥammad al-Ṣāghānī al-Asṭurlābī. In *Biographical encyclopedia of astronomers* (pp. 1902–1903). Heidelberg: Springer.

Al-Samarqandī

Gregg De Young
The American University in Cairo, Cairo, Egypt

Shams al-Dīn al-Samarqandī, as his name implies, was from Samarqand, in what is now Uzbekistan. We know few of his biographical details with any certainty. He is believed to have been active during the second half of the seventh AH/AD thirteenth century, since he composed a star calendar for 675 AH/AD 1276–1277 to accompany his *Al-Tadhkira fī'l-Hay'a* (Synopsis of Mathematical Cosmography or Hay'a). A manuscript (Istanbul, Laleli Library, 2432), probably written by one of his pupils, reports that he died in 701 AH/AD 1302. Although Naṣīr al-Dīn al-Ṭūsī had gathered many leading intellectuals together at the Marāgha observatory, al-Samarqandī is never mentioned among their number.

Al-Samarqandī's earliest contributions were in the field of logic, but he is best known to historians of science for his brief tract, *Kitāb Ashkāl al-Ta'sīs* (*Book of Fundamental Theorems*), a collection of 35 propositions from Euclid's *Elements* (mostly from books I and II, although proposition VI, 1 was also included), with abbreviated demonstrations [De Young, 2001]. The title has often caused confusion because the theorems chosen for inclusion do not always seem to be fundamental in the sense of providing a mathematical underpinning for the *Elements*. But the term *shakl* (plural: *ashkāl*), which often is translated as "proposition," also has a wider meaning in philosophy and logic as "form" or "image." Moreover, the term *ta'sīs* may also carry wider connotations than merely something fundamental or basic. It can mean, in a more general context, an organization or foundation and hence could be interpreted to mean "that which exists." Read in this way, the title implies that the work is not just a collection of geometrical theorems but an investigation into the geometrical forms that formed the basis of and gave rise to the world of the existent, thus revealing an underlying Platonism that gives primacy to mathematics and especially geometry [Fazlıoğlu, 2008].

The treatise is very concise and is historically better known through the commentary composed by Qāḍīzāde al-Rūmī (died 840 AH/AD 1436). Of special interest has been the "proof" of Euclid's parallels postulate (the fifth postulate of book I) which al-Samarqandī included. The argument is more philosophical than mathematical: if two lines are not parallel – always equidistant from one another – then they must be approaching, getting closer together, on one side or the other. And if they are continually getting closer together, they must eventually meet one another. Most historical discussion of parallel lines in the *Ashkāl al-Ta'sīs* has focused on the "demonstration" quoted in the comments of Qāḍīzāde al-Rūmī but more correctly ascribed to Athīr al-Dīn al-Abharī (died 663 AH/AD 1265) [Dilgan, 1960; Souissi, 1982; Jouiche, 1986].

See Also

▶ Hay'a
▶ Qāḍīzāde al-Rūmī

References

De Young, G. (2001). *The Ashkāl al-Ta'sīs* of al-Samarqandī: A translation and study. *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften, 14*, 57–117.
Dilgan, H. (1960). Demonstration du Ve postulat d'Euclide par Shams-ed-din Samarkandi. *Revue d'histoire des sciences et leurs applications, 13*, 191–196.
Fazlioğlu, İ. (2008). The Samarqand mathematical-astronomical school: A basis for Ottoman philosophy and science. *Journal for the history of Arabic science, 14*, 3–68.
Jaouiche, K. (1986). *La théorie des parallèles en pays d'Islam*. Paris: Vrin.
Souissi, M. (1982). Le commentaire des 'Ashkāl al-Ta'sīs' de Samarqandî par Qadi Zade, et le preuve du Ve postulat d'Euclide. *Cahiers de Tunisie, 30*, 261–5.
Souissi, M. (1984). *Ashkāl al-Ta'sīs li-l-Samarqandī sharḥ Qāḍīzāde al-Rūmī*. Tunis: Dār al-Tūnisiyya li-l-Nashr.

Al-Shīrāzī

John Walbridge

Quṭb al-Dīn Maḥmūd ibn Masʿūd al-Shīrāzī (1236–1311) was a Persian scientist and philosopher. He was born into a medical family in Shiraz in central Iran. His father was a staff physician and ophthalmologist at the newly established MuẒaffarī hospital. As a child he was the apprentice of his father, who died when Shīrāzī was 14. Having assumed his father's position at the hospital, he continued his studies with several other local teachers of medicine and the rational and religious sciences. At this time he began the study of the first book, *al-Kullīyāt* (On General Principles) of Ibn Sīnā's *Qānūn fī 'l-ṭibb* (Canon of Medicine), the leading medical textbook of the Middle Ages. His father had also initiated him into the Suhrawardī order of Sufis (Islamic mystics).

By the time he reached adulthood, he was in need of advanced medical instruction that could not be provided by the teachers of a provincial city like Shiraz. It would have been normal for him to have gone off earlier to one of the major Islamic cities for advanced studies, but in 1253 the Mongols had invaded the Islamic lands of Central and Southwestern Asia, sacking Baghdad in 1258, so Shīrāzī was confined to his home city until peace was reestablished.

In 1259 Hulegu, the Mongol ruler of Iran, gave a large grant to the famous scientist ▶ Naṣīr al-Dīn al-Ṭūsī (1201–1274) to pay for the preparation of a new set of astronomical tables (▶ *zīj*) for use in astrological calculations. Ṭūsī established an observatory in the town of Marāgha, at that time the Mongol capital, and brought together a brilliant team of scientists and scholars. Shīrāzī came to the observatory as a student soon after it was founded. While he was disappointed by Ṭūsī's lack of knowledge about medical theory, he learned a great deal of mathematics, astronomy, and philosophy from him and his faculty, and he soon became the most important student at the observatory. Ṭūsī took him along on his travels and introduced him at court. Shīrāzī also apparently spent some time studying in Qazvīn, Khorasan, and Baghdad with various teachers.

Around 1270 he left the observatory and went to Konya in Anatolia, where he met the famous Sufi poet Rūmī and studied *ḥadīth* (the sayings of Muḥammad) with ṣadr al-Dīn Qūnawī, the leading disciple of the mystical philosopher Ibn

ʿArabī. Soon after he was appointed *qāḍī* (religious judge) of the Anatolian cities of Sivas and Malatya. This was evidently a sinecure to allow him to pursue his scientific work, for his first major work, *Nihāyat al-Idrāk fī Dirāyat al-Aflāk* (The Highest Attainment in the Knowledge of the Spheres), a technical work on mathematical astronomy, was published in Sivas in 1281 and was dedicated to the vizier of the Mongol ruler. Other works on astronomy and mathematics soon followed.

In 1282 he was appointed to a diplomatic mission to Egypt. Though the mission failed in its political objectives, Shīrāzī found three complete commentaries on the first book of Ibn Sīnā's *Qānūn*, along with glosses and other sources. With this new material in hand, he was finally able to achieve his youthful goal of mastering the intricacies of this work. Shortly after his return to Anatolia he published a large commentary on the *Qānūn*. He published second and third editions in 1294 and in 1310, a few months before his death.

Of his personality we are told that he had a sharp wit, and indeed he was a stock character in a certain genre of joke for several centuries thereafter. He was expert in chess and prestidigitation and was a lively conversationalist and lecturer. He was an authority on musical theory, which in the Middle Ages was considered a branch of mathematics, and was a fine player of the *ribāb*, a forerunner of the violin. He seems to have grown more concerned with religious matters as he grew older, although he was a Sufi all his life.

He eventually settled – interrupted by several exiles – in Tabriz, at that time the capital of Mongol Iran. He was an intimate of the court. The funds that supported his scientific work came from a series of viziers and petty rulers. In addition to his works on astronomy and medicine, he wrote on mathematics, philosophy, and the Islamic religious sciences. In his last years he spent less time on the rational sciences and more on religious subjects. He died in relative poverty, having given almost everything he had to charity and to his students and not yet having received the large payment promised for the third edition of his commentary on Ibn Sīnā's *Qānūn*. He was given a lavish funeral by a wealthy student.

Shīrāzī was typical in most respects of Islamic scientists. He was a polymath, interested not only in the corpus of science inherited from the Greeks but also in the religious sciences of Islam. Of the rational sciences it was astronomy and medicine that found the most ready market – astronomy as the handmaid of astrology or for timekeeping in the mosques. The other rational sciences, particularly mathematics, and philosophy, were supported by their more practical subordinate sciences. Sophisticated practitioners of the rational sciences generally drifted to the royal courts, the only reliable sources of funding for such subjects, and became involved in the life and politics of the court – and in its perils.

See Also

▶ Al-ʿUrḍī
▶ Astronomy
▶ Ibn Al-ʿArabī
▶ Ibn Sīnā (Avicenna)
▶ Marāgha
▶ Naṣīr al-Dīn al-Ṭūsī
▶ Optics in the Islamic World
▶ *Zīj*

References

Nasr, S. H. (1975). Quṭb al-Dīn Shīrāzī. In C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. IX, pp. 247–253). New York: Charles Scribner's Sons.

Saliba, G. (1994). *A history of Arabic astronomy: Planetary theories during the Golden Age of Islam*. New York: New York University Press.

Shīrāzī, Quṭb al-Dīn. (1895–1897). *Sharḥ ḥikmat al-Ishrāq*. Tehran.

Shīrāzī, Quṭb al-Dīn. (1938–1945) *Durrat al-Tāj li-Ghurrat al-Dubāj*. Tehran: Majlis.

Varjāvand, P. (1987). *Kāvush-i Raṣd-khāna-i Marāgha (excavation of the Marāgha observatory)*. Tehran, Iran: Amīr Kabīr.

Walbridge, J. (1992). *The science of mystic lights: Qutb al-Dīn Shīrāzī and the illuminationist tradition in Islamic philosophy*. Cambridge, MA: Harvard Center for Middle East Studies.

Al-Sijzī

Yvonne Dold-Samplonius

Al-Sijzī, Abū Sa'īd Aḥmad ibn Muḥammad ibn ʿAbd al-Jalīl, was born in Persia, ca. 945 and died ca. 1020. The name al-Sijzī indicates that he was a native of Sijistān in southeastern Iran and southwestern Afghanistan. This is confirmed, for example, when al-Sijzī refers in his *al-Mudkhal ilā ʿilm al-handasa* (Introduction to Geometry) to a planetarium which he had constructed in Sijistān. Al-Sijzī was already active in 963, when he copied a manuscript of Pappus' *Introduction to Mechanics* (Book VIII of the Collection), and still active in 998, when he completed a treatise on the proof of the plane transversal theorem.

Al-Sijzī's father, Abū'l-ḥusayn Muḥammad ibn Abd al-Jalīl, was also interested in geometry and astronomy, and al-Sijzī addressed some of his works to him, e.g., *Risālat f ī Khawāṣṣ al-qubba az-zā'ida wa-l-mukāfiya* (On Parabolic and Hyperbolic Cupolas), completed in 972. Around 969 al-Sijzī spent some time at the Buwayhid court in Shirāz and assisted in 969/970 at the observations of the solstices conducted by Abd al-Raḥmān ibn ʿUmar al-ṣūfi. There he met a number of important geometers and astronomers, including Abū'l Wafā', Abū Sahl al-Qūhī, and NaẒif ibn Yumn (d. ca. 990).

Al-Sijzī was active in astrology and had a vast knowledge of the literature. He usually compiled and tabulated, adding his own critical commentary, as with three works by ▶ Abū Maʿshar and the second of the five books ascribed to Zoroaster. He used Sassanid material and sources from the time of Hārūn al-Rashīd and from the late Umayyad period for a book on general astrology and its history. In his work on horoscopes he gives tables based on Hermes, Ptolemy, Dorotheus, and "the Moderns." Al-Sijzī's tables, together with those of Ptolemy, are quoted by Iḥtiyāzu' l-Dīn Muḥammad in his *Judicial Astrology*. The treatise *Kitāb fī Qawānīn mizājāt al-asṭurlāb al-shimālī maʿa l-janūbī* (On the Astrolabe) deals with the different kinds of astrolabe retes (a circular plate with many holes used on the astrolabe to indicate the positions of the principal fixed stars) with which al-Sijzī was familiar. This treatise is used by ▶ al-Bīrūnī in his *Istī ʿab al-wujūh al-mumkina f ī ṣan ʿat al-asṭurlāb* (Book on the Possible Methods for Constructing the Astrolabe).

Al-Sijzī wrote at least 45 geometrical treatises, of which some 35 are extant, and about 14 astronomical treatises. He was well-read and had many contacts with his contemporaries. A number of his works are therefore of unusual historical interest. In *Risālat f ī Qismat az-zāwiya al-mustaqīmat al-khaṭṭain bi-ṭalāṭat aqsām mutasāwiya* (On the Division of the Angle into Three Equal Parts) al-Sijzī describes a number of problems, to which various other writers had reduced the problem of the trisection of the angle. The method of "the Ancients" by means of a neusis was not considered a legitimate construction by al-Sijzī. His own construction, by intersecting a circle and a hyperbola, is a variation of the solution by al-Qūhī. The treatise ends with five problems of al-Bīrūnī. Regarding al-Sijzī's construction of the heptagon, this is, according to Jan Hogendijk, to a great extent the history of a dispute between two young geometers, al-Sijzī and Abū'l-Jūd, who were both engaged in plagiarism. In the meantime al-Qūhī solved the problem in an elegant manner.

For the *Geometrical Annotations* (*Kitāb fi l-masā'ili l-mukhṭārati llatī jarat baynahu wa-bayna muhandisī Shīrāz wa-Khurāsān wa-taʿlīqātihi*, Book on the Selected Problems Which Were Currently Being Discussed by Him and the Geometers of Shirāz and Khorāsān, and His (Own) Annotations) al-Sijzī had the example of Ibrāhīm ibn Sinān's *al-Masā'il al-mukhṭāra* (Selected Problems) in mind. A number of the problems and solutions are clearly influenced by or adapted from the *Selected Problems*, but al-Sijzī's treatise is on the whole on a lower level.

The *Misāḥat al-ukar bi-l-ukar* (Book of the Measurement of Spheres by Spheres) is about a surrounding sphere which contains in its interior up to three mutually tangent spheres. Al-Sijzī determines the volume of the solid which results when one deletes from the surrounding sphere all points that belong to the spheres in its interior. He expresses this volume as the volume of a new sphere, and he determines the radius of this new sphere in terms of the radii of the spheres used in the definition of the solid. Al-Sijzī's proofs are trivial consequences of identities for line segments, proved geometrically. The treatise contains 12 propositions, of which proposition 11 and its proof are false for (three-dimensional) spheres. The proposition holds in dimension four. Perhaps al-Sijzī had four-dimensional spheres in mind, although he does not use them elsewhere in the treatise; perhaps he made a mistake.

His small treatise *Risālat f ī Kaif īyat taṣauwur al-khaṭṭain alladhain yaqrubān wa-lā yaltaqiyān* (On the Asymptote, or How to Conceive Two Lines Which Approach Each Other But Do Not Meet, If One Extends Them All the Way to Infinity) is devoted to Apollonius II,14. Some cases, he says, can be solved as explained in his *Kitāb f ī tashīl as-subul li-stikhrāj al-ashkāl al-handasīya* (On Facilitating the Roads to the Geometrical Propositions); for others a philosophical method is needed, as Proclus has shown in the definitions of his *Elements of Physics*. The treatise ends with the case where the two asymptotes are two hyperbolas. In *Risālat f ī anna ʻl-ashkāl kullahā min al-dā ʻira* (On [the Fact] that All Figures Are Derived from the Circle), a treatise until recently attributed to Naṣir ibn ʿAbdallāh, al-Sijzī describes one of the few instruments that finds the *qibla* (the direction of Mecca) geometrically. He also wrote an original treatise on the construction of a conic compass.

In the introduction to *Risālat f ī'l-shakl al-qaṭṭāʿ* (The Transversal Figure), written before 969, al-Sijzī says that he wrote the work having seen neither Thābit ibn Qurra's *Kitāb f ī'l-shakl al-mulaqqab bi-l-qaṭṭāʿ* (Book of the Transversal) nor any other work on the topic, except Ptolemy's *Almagest*. The treatise begins with enunciations and proofs of two lemmas, which also appear, in different terms, in the *Almagest*. Following the two lemmas al-Sijzī enunciates and proves his 12 propositions. Aware of the astronomical applications of the theorem he evidently saw the need to provide a complete mathematical basis for these uses. The details of the proofs of all 12 theorems are carried out according to a uniform procedure. This makes the treatise a step toward recognizing the mathematical discipline of trigonometry.

See Also

- ▶ Abū Maʿshar
- ▶ *Almagest*: Its Reception and Transmission in the Islamic World
- ▶ Al-Qūhī (or Al-Kūhī)
- ▶ Astrolabe
- ▶ Astrology in Islam
- ▶ Ibrāhīm ibn Sinān
- ▶ *Qibla* and Islamic Prayer Times

References

Al-Sijzī, Abū Sa'īd Aḥmad ibn Muḥammad ibn ʿAbd al-Jalīl. (1996). *Al-Sijzī's treatise on geometrical problem solving*. Teheran, Iran: Fatemi.

Anbouba, A. (1978). Construction de l'Heptagone Régulier par les Arabes au 4e Siècle H. *Journal of History of Arabic Science, 2*, 264–269.

Berggren, J. L. (1981). Al-Sijzī on the transversal figure. *Journal of the History of Arabic Science, 5*, 23–36.

Crozet, P. (1993). L'Idée de Dimension Chez al-Sijzī. *Arabic Sciences and Philosophy, 3*, 251–286.

Dold-Samplonius, Y. (1975). al-Sijzī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 12, pp. 431–432). New York: Charles Scribner's Sons.

Hogendijk, J. P. (1981). How trisections of the angle were transmitted from Greek to Islamic geometry. *Historia Mathematica, 8*, 417–438.

Hogendijk, J. P. (1984). Greek and Arabic constructions of the regular heptagon. *Archive for History of Exact Sciences, 30*, 197–330.

Hogendijk, J. P. (1989). *New findings of Greek geometrical fragments in the Arabic tradition* (Symposium Graeco-Arabicum II, pp. 22–23). Amsterdam: B. R. Grüner.

Knorr, W. R. (1989). *Textual studies in ancient and medieval geometry*. Boston, MA: Birkhauser.

Rashed, R. (1987). Al-Sijzī et Maomonide: Commentaire Mathématique et Philosophique de la Proposition II-14 des Coniques d'Apollonius. *Archives Internationales d'Histoire des Sciences, 37*, 263–296.

Rosenfeld, B. A., Safarov, R. S., & Slavutin, E. I. (1985). The geometric Algebra of as-Sijzī. *Istoriko-Matematicheskie Issledovaniia, 29*, 321–325. 349 (in Russian).

Saidan, A. S. (1983). *Rāsaʾil Ibn Sinān* (The works of Ibrāhīm ibn Sinān, with two more tracts: (1) by Thābit ibn Qurra, (2) by Al-Sijzī [i.e., on facilitating the roads to the geometrical propositions]). Kuwait: Qism al-Turāth al-ʿArabī, (in Arabic).

Al-Ṣūfī

Paul Kunitzsch
University of Munich, Munich, Germany

Al-Ṣūfī, Abu'l-ḥusayn ʿAbd al-Raḥmān ibn ʿUmar, was born in 903 in Rayy, near modern Tehran, and died in 986.

Al-Ṣūfī was an astronomer in the Arabic-Islamic area. He was of Persian origin, but wrote in Arabic, the language of all science in that time. He was best renowned, and became most influential, through his *Kitāb ṣuwar al-kawākib al-thābita* (Book on the Constellations), written around 964. Knowledge of the fixed stars in Greek-based Arabic-Islamic astronomy was mainly derived from Ptolemy's catalog of 1,025 stars arranged in 48 constellations contained in his *Almagest* (ca. AD 150). Al-Ṣūfī reexamined Ptolemy's values of the star coordinates and magnitudes. In his book, he described all the stars catalogued by Ptolemy, adding his criticism in each individual case. However, in the tables added to his book he nevertheless faithfully rendered Ptolemy's traditional values, adding a constant of 12°42′, for precession, to Ptolemy's longitudes. Only the magnitudes were given according to al-Ṣūfī's own observation. For each constellation he added two drawings, one showing the figure as seen in the sky, the other as seen on the celestial globe. His book and his drawings served as models for work on the fixed stars in the Arabic-Islamic world for many centuries, and became known even in medieval Europe, where his constellation drawings were imitated in a series of Latin astronomical manuscripts (though no veritable Latin translation of his book was made). Apart from this book, al-Ṣūfī left treatises on the use of the astrolabe and the celestial globe, an introduction to astrology, and a short geometrical treatise. His name lives on, Latinized as Azophi, as a name for a crater on the Moon.

References

Kunitzsch, P. (1976). Al-Ṣūfī. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 13, pp. 149–150). New York: Scribners.

Kunitzsch, P. (1982). ʿAbd-al-Raḥmān b. ʿOmar Ṣūfī. In E. Yarshater (Ed.), *Encyclopaedia Iranica, I* (pp. 148–149, Fasc. 2). London: Routledge & Kegan Paul.

Kunitzsch, P. (1986a). *Peter Apian und Azophi: Arabische Sternbilder in Ingolstadt im frühen 16. Jahrhundert*. Munich, Germany: Beck.

Kunitzsch, P. (1986b). The astronomer Abu'l-ḥusayn al-Ṣūfī and his book on the constellations. *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 3, 56–81. Rpt. in Kunitzsch, P. *The Arabs and the Stars*. Northampton, UK: Variorum Reprints, 1989 (item XI).

Schjellerup, H. C. F. C. (trans.). (1986). *Description des é toiles fixes par Abd-al-Rahman al-Sûfi*. St.-Pétersbourg, Russia: Commissionaires de l'Académie Impériale des sciences, 1874. Rpt. Frankfurt am Main, Germany: Institut für Geschichte der Arabisch-Islamischen Wissenschaften.

Al-Suyūṭī

Anton M. Heinen

Al-Suyūṭī (1445–1505) wrote on just about every discipline that had been recognized, in his time, as having its own method and subject matter. What is most noteworthy is that *hay'a* (cosmology, cosmography, but also astronomy) was among them. The author was in his own estimation an authority in the traditional Arabic and Islamic sciences (*al-ʿulūm al-ʿnaqliyyah*, transmitted sciences), especially in grammar, jurisprudence, and in tradition (*ḥadīth*, the

Sayings of the Prophet), but in no way in those “Sciences of the Ancients” (*al-ʿulūm al-ʿaqliyyah*), which had entered the libraries of Islamic culture through numerous translations from Greek, Syriac, Middle Persian, etc. He even expressed his special hatred for philosophy and logic. The title of his treatise, *al-Hayʾa al-sanīya fī l-hayʾa al-sunnīya*, already reveals the challenge he had in mind: his was to be *the* Islamic cosmology, based on authentic Islamic traditions, the *Sunna*, which so conveniently rhymed with *sanīya* (brilliant, magnificent, glorious). The choice of the technical term *al-hay'a* in the title implies that the author is offering an alternative to those cosmologies based on the principles and methods of pre-Islamic astronomers. As such it is a parallel of his book *al-ṭibb al-nabawī* (Prophetic Medicine). As the author says himself, it was his goal “that those with intelligence might rejoice, and those with eyes take heed.” Actually, the great number of extant manuscripts in our libraries proves that as-Suyūṭī's *Hay'a* attracted more attention than most other contemporary books on the cosmos.

This work is a collection of fragmentary descriptions and explanations of such natural phenomena as the sun, moon, and stars in their celestial spheres, lands and seas, winds and clouds, etc. The distinctive feature is, however, that all these fragments are authenticated in the traditional manner with chains of trustworthy authorities which connect them with Quranic revelation or Prophetic wisdom. As a result, some of the earliest theories about cosmological entities and natural phenomena have been preserved that may elucidate the worldviews prevalent among the young Muslim community before they were developed under the impact of the translations from pre-Islamic cultures. It remains doubtful whether even in the Middle Ages a mythical theory about the winds, because of the traditional authorities, would have been accepted with the same truth claim as a modern one. But the fact that the authorities were already interested in the phenomena of nature and cosmos may have opened rather than closed the eyes of the student.

See Also

▶ *Hay'a*

References

Goldziher, I. (1871). Zur Charakteristik Jelāl ud-dīn us-Sujūṭī's und seiner literarischen Thätigkeit. *Sitzungsberichte der Koeniglichen Akademie der Wissenschaften, Philosophisch-historische Klasse, 69*, 17.

Heinen, A. M. (1982). *Islamic cosmology. A study of as-Suyūṭī's al-Hayʾa as-saniya fī l-Haʾya as-sunnīya with critical edition, translation, and commentary*. Beirut, Lebanon: In Kommission bei Franz Steiner Verlag Wiesbaden.

Sartain, E. M. (1975). *Jalāl al-Dīn al-Suyūṭī* (2 vols.). Cambridge, UK: Cambridge University Press.

Al-Ṭabarī

Sami K. Hamarneh

Abū'l-ḥasan ʿAlī ▶ ibn Sahl Rabbān al-Ṭabarī was born in the environs of the city of Marw, in the province of Khurasān in Persia (presently Mary, in Turkmenistan), about AD 783, before the reign of the Abbasid Caliph Hārūn al-Rashīd (786–809). His father Sahl was a prominent citizen of great learning and a highly placed state official. As a religious leader in the Syriac-speaking community, he was reverently called *Rabbān* (from the Aramaic for teacher), and had far-reaching knowledge in theology, philosophy, and medicine.

Sahl took a special interest in his son's upbringing, providing him with the best available educational opportunities. ʿAli read the best Syriac books and excelled in learning. When he was 14, he turned to medicine. He concentrated there, because he realized he could help the sick and the needy.

From the Marw region, he moved to Tabaristān (Māzandarān, south of the Caspian Sea). Thus he became known as al-Ṭabarī. He was appointed counselor-secretary-scribe to the

Prince-Sultan Māzyār ibn Qārin. When the latter rebelled against the Abbasid's authority in open revolt, Caliph al-Muʿtaṣim sent a powerful army that crushed the mutiny and killed Māzyār in AD 839.

Al-Ṭabarī spoke of it later on as "a tragic episode" which left deep scars that remained until late in his life. Meanwhile, he was summoned to the Caliph's court at the new capital, Sāmarrāʾ. Under the Caliph's influence, al-Ṭabarī renounced his Christian faith and embraced Islam. He continued as a physician during the remaining part of al-Muʿtāsim's life, and remained there under his successor, his brother al-Wāthiq (843–847).

His good fortune came with the rise of Caliph al-Mutawakkil (AD 847–861). He was promoted to the position of physician-in-ordinary, and also became the Caliph's counselor and trusted companion (*nadīm*). In appreciation, al-Ṭabarī dedicated his best and largest medical compendium, *Firdaws al-ḥikmah* (Paradise of Wisdom) to his patron in AD 850. This was the first and most comprehensive medical encyclopedia of its kind in Islam. It took him 20 years to complete. In the introduction, the author stated that the work was to be useful to his medical students as well as to practitioners. He listed five points concerning the importance of the art of medicine:

1. It brings relief and healing to the sick, and consolation to the weary.
2. It successfully diagnoses and skillfully treats ailments, even unseen diseases not easy to discover or observe.
3. It is needed by all, regardless of age, gender, or wealth.
4. It is among the noblest of all callings.
5. The words *ṭibb*, *ṭibābah*, *mu'āssāh*, and *usāt* all relate to medicine and its healing processes.

Al-Ṭabarī then mentioned four virtues that all physicians had to possess in order to be successful and esteemed: *al-rifq* (leniency and kindness), *raḥmah* (mercy and compassion), *qanāʿah* (contentedness and gratification), and *ʿafāf* (chastity with simplicity).

Firdaws was divided into 7 sections in 30 treatises, composed of 360 chapters in all. They ranged from cosmogony, the nature of man, embryology, and anatomy, to materia medica, psychotherapy, pathology, and surgery. Other topics included theoretical and practical medicine in the Greek and Indian traditions, and rules of conduct with insistence on strict adherence to the highest ethical standards.

Another noteworthy literary contribution was his book *al-Dīn wā'l-Dawlah* (Religion and the State). It represents a defense as well as an exposition of the religion of Islam, the Holy Qurʾān, and the Holy Prophet Muḥammad. It seems temperate, rational, and objective in style and tone, and appears free from misgivings or barren argumentation. It also abounds with quotations from the Bible (in the Syriac version).

In these two works, al-Ṭabarī shed much light on the development and progress of the religious, philosophical, and medical advancements during the first two quarters of the ninth century AD. He died in Sāmarrā ca. 858.

The Kitāb al-Dīn was soon eclipsed during the Islamic Middle Ages, because of a lack of interest in such studies as comparative religion. Only in the twentieth century was the book edited more than once. *Firdaws*, however, has continued to enjoy a good reputation, with a wide circulation throughout the Islamic world. Both works can now be considered classical literary works.

References

Al-Ṭabarī. (1928). In M. Z. Siddīqī (Ed.), *Firdaws al-ḥikmah*. Berlin, Germany: Sonne. and Karachi: Hamdard Press, 1981.

Arnaldez, R. (1997). Le Paradis de la Sagesse du Médecin ʻAli b. Rabban Al-Tabari. In *Documenti e Studi Sulla Tradizione Filosofica Medievale* (pp. 389–402).

Bouyges, M. ʿAlī al-Ṭabarī. (1949–1950). *Mélanges de l'Univérsité St Joseph 28*, 69–114.

Brockelmann, C. (1932). *Firdaws al-ḥikmah* of ʿAlī al-Ṭabarī. *Zeitschrift für Semitistik und verwandte Gebiete, 8*, 270–276.

Browne, E. G. (1921). *Arabian medicine*. Cambridge: Cambridge University Press.

Leclerc, L. (1980). *Histoire de la Médecine Arabe*. Paris: Leroux. 1876; and Rabat, Morocco: Ministry of Islamic Affairs.

Meyerhof, M. (1931). ʿAlī al-Ṭabarī's "Paradise of Wisdom": One of the oldest Arabic compendiums of medicine. *Isis, 16*, 6–54.
Mingana, A. (Ed.). (1923). *Kitāb al-Din wā'l-Dawlah*. Manchester, UK: Manchester University Press. 1923; and Cairo: al-Muqtaṭaf Press.
Schmucker, W. (1969). *Die Materia Medica im Firdaws al-ḥikmah des Tabari*. Bonn, Germany: University of Bonn.
Siggel, A. (1941). Gynäkologie und Embryologie aus dem Parad der Weisheit des al-Ṭabarī. *Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin, 8*(1/2), 216–272.

Altars in China

Lei Gao[1] and Jan Woudstra[2]
[1]Department of Landscape Architecture and Spatial Planning, Norwegian University of Life Sciences, Ås, Norway
[2]Department of Landscape, University of Sheffield, Sheffield, UK

Altar: A Definition

An altar, or *tán* (坛) in Chinese, is "a sacrificing place" as defined by *Shuowen jiezi*, the oldest surviving Chinese dictionary dating to 100 AD. The main structure of an altar is a round or rectangular mound (known as the sacrificial platform, or the altar itself) made by rammed earth and sometimes covered with a layer of white plaster, bricks, or stones (Fig. 1). The sacrificial platform is often encircled by one or more circles of walls and accompanied by a group of buildings and constructions (Fig. 2).

There are different types of sacrificing places in ancient China, among which altars and temples are most common. Altars and temples are different in form and content. Generally speaking, temples are roofed, while altars are open to the sky. Besides Buddhist and Taoist temples, temples are also for deified humans such as ancestors, sages, and heroes, while altars are for natural gods, or, in rare cases, for legendary human figures (Liu, 2000, pp. 3–5).

Altar and Confucian Rituals

The ancient Chinese believed that gods (or spirits) had exclusive power to control nature and human fates. Until the early twentieth century, such beliefs were only rarely questioned. There are two sources of gods. One is derived from natural elements (such as Heaven, Earth, the sun, the moon, stars, mountains, and rivers) and phenomena (such as thunder, droughts, or floods). The other comes from humans (such as ancestors, historical, or legendary figures). The worship of nature and ancestors has a history almost as long as Chinese civilization. The earliest material evidence for ritualistic practice in China can be traced back to the period between 7000 and 5700 BC, when Neolithic humans at the lower region of the Yellow River were already able to produce wine, music, and scripts for ritual purposes (Zhang et al., 1999, p. 368).

During Confucius' life (551–479 BC), his ideology encouraged development of elaborate theories and practices on rituals. Confucius regulated and interpreted ancient rituals. After his death, his thoughts were collected and recorded by his disciples in the *Liji* (Book of Rites), a collection of Confucius' discourses on the rules of propriety or ritual ceremonies. In the *Liji*, rituals were divided into five categories, known as the rituals of sacrifice, wedding, funeral, archery, and visiting. Among them the most important rituals are the imperial sacrifices to the Gods of Heaven, Earth, Land, and Grain. These sacrifices must be held not in temples, but at altars, because "the Son of Heaven (that is, the emperor) was open to receive the hoarfrost, dew, wind, and rain, and thus to fully experience the influences of Heaven and Earth" (Legge, 1885, p. 425).

From the Han dynasty (206 BC–220 AD), Confucianism was authorized as the state ideology and remained largely dominant until the Qing dynasty (1644–1911 AD). It was especially after the twelfth century that Neo-Confucianism, a form of Confucianism that adopted ideas from Daoism and Buddhism, became the dominant philosophy influencing everything from the

Altars in China, Fig. 1 A bird's-eye view of the archaeological excavation of the main part of the Round Altar (Altar of Heaven) in Chang'an (former name of Xi'an) dates back to Sui and Tang times (581–907 AD). The height of the round mound is about 8 m and the diameter 53 m. It has four layers of platforms and 12 sets of stairways, indicating four seasons of the year and 12 divisions (each division is 2 h) of the day (An et al., 2000)

Altars in China, Fig. 2 The aerial view of the Altar of Heaven in Beijing, built in Ming and Qing times (1368–1911 AD) (Luo, 2002, p. 258)

culture of politics to daily social etiquette. In Neo-Confucianism, the abstract concept of the "Law of Heaven" (*tianli* 天理) is seen as the starting principle; all beings on Earth are bound to follow this law. It denotes balance (i.e., *yin* and *yang*) and movement (i.e., following the natural sequence). Therefore, all beings are connected and reflect each other. Rituals provide the practical guidelines and direction with which the law should be followed.

There is a distinct hierarchy of sacrifice. Different people practice different rituals. Sacrifice to Heaven, Earth, the Sun, and the Moon can only be carried out by emperors, while the sacrifice to Soil and Grain (symbolizing territory and food, which are thought to be two of the most important issues for a government) is practiced by people within different social levels, each of whom has respective altars for sacrifice (Chen, 1985, pp. 23–24; Legge, 1885, pp. 207–209).

The emperor pays his sacrifices at the imperial Altar of Soil and Grain, the local governmental officials at local Altars of Soil and Grain, while additionally every 100 homes have their own Altar of Soil and Grain. The Altar of the God of Agriculture, traditionally used solely by emperors, is also sanctified to receive sacrifice from various levels of society. This serves to teach local officials the importance of husbandry.

Altar sacrifice is the most important of the five types of rituals, and sacrifice to Heaven and Earth by the emperor is considered the most supreme. By practicing this ritual, the emperor sets an example to the state and thus his subjects follow suit. Within this context altar sacrifice represents the core values of Chinese culture. By sacrificing to Heaven, the emperor presents himself to the whole nation as the model of observance and reverence to his ruler – the God of Heaven. As a consequence, all his subjects learned to be observant and reverent to the emperor (Legge, 1885, p. 367). Apart from the purpose of regulating government, imperial sacrifice served as the means to beg for a good harvest, which is vital to agriculture and therefore the nation. The gains from agriculture largely depended on climate, particularly on water and sun, so praying for good weather to various Nature gods was always seen as essential. This is another responsibility for the sovereign who had to pay great reverence to the deities. For example, in order to pray for rain during droughts, the emperor was to fast for three days followed by walking to the Altar of Rain (located at the Altar of Heaven compound) himself, rather than being carried there.

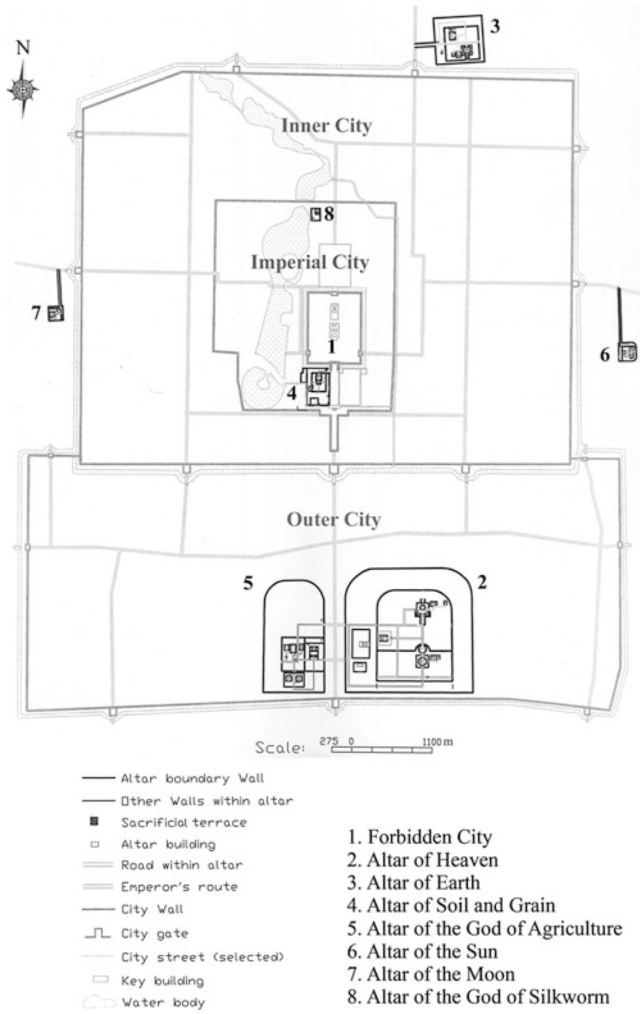
Imperial Altars in Beijing

In 1420, the Ming emperor Yongle (1360–1424, r. 1403–1424) built three altars in Beijing when he moved the capital from Nanjing to Beijing, namely, the Altar of Soil and Grain, the Altar of Heaven and Earth, and the Altar of Mountain and River. In 1530, considering contemporary altars not "authentic," the Ming emperor Jiajing (1507–1567, r. 1522–1566) claimed to restore the ancient ritual system and altered the imperial altars. The number of altars increased to seven, with the Altar of Heaven and Earth being separated into two altars, the Altar of Heaven and the Altar of Earth, and three altars were added: the Altar of the Sun, the Altar of the Moon, and the Altar of the God of Silkworms. The Altar of Mountain and River was incorporated into the Altar of the God of Agriculture. This arrangement was retained afterwards and accepted by subsequent Ming and Qing emperors.

The altars were incorporated within the formal layout of Beijing, the center of which was formed by the Forbidden City. This was surrounded by the Imperial City Wall, which was then encircled by the Inner City Wall and the Outer City Wall (which, though only half finished, was connected to the southern side of the Inner City Wall). A straight north–south axis through the Forbidden City divided the city and its walls symmetrically into two. The emperor's administration hall and hall of residence were located in the middle, with a straight avenue emerging from it, connecting the Forbidden City with the southern gate of the Outer City Wall. The Altar of Heaven and the Altar of the God of Agriculture were located on either side to east and west of the southern gate. The Altar of Soil and Grain, located immediately south of the Forbidden City, was on the west side of this axis. The Altars of the Sun and the Moon were outside the Inner City to the east and west on a cross axis. The Altar of the God of Silkworms was centrally to the north inside the Imperial City, with the Altar of Earth to the north of the Inner City (Figs. 3 and 4).

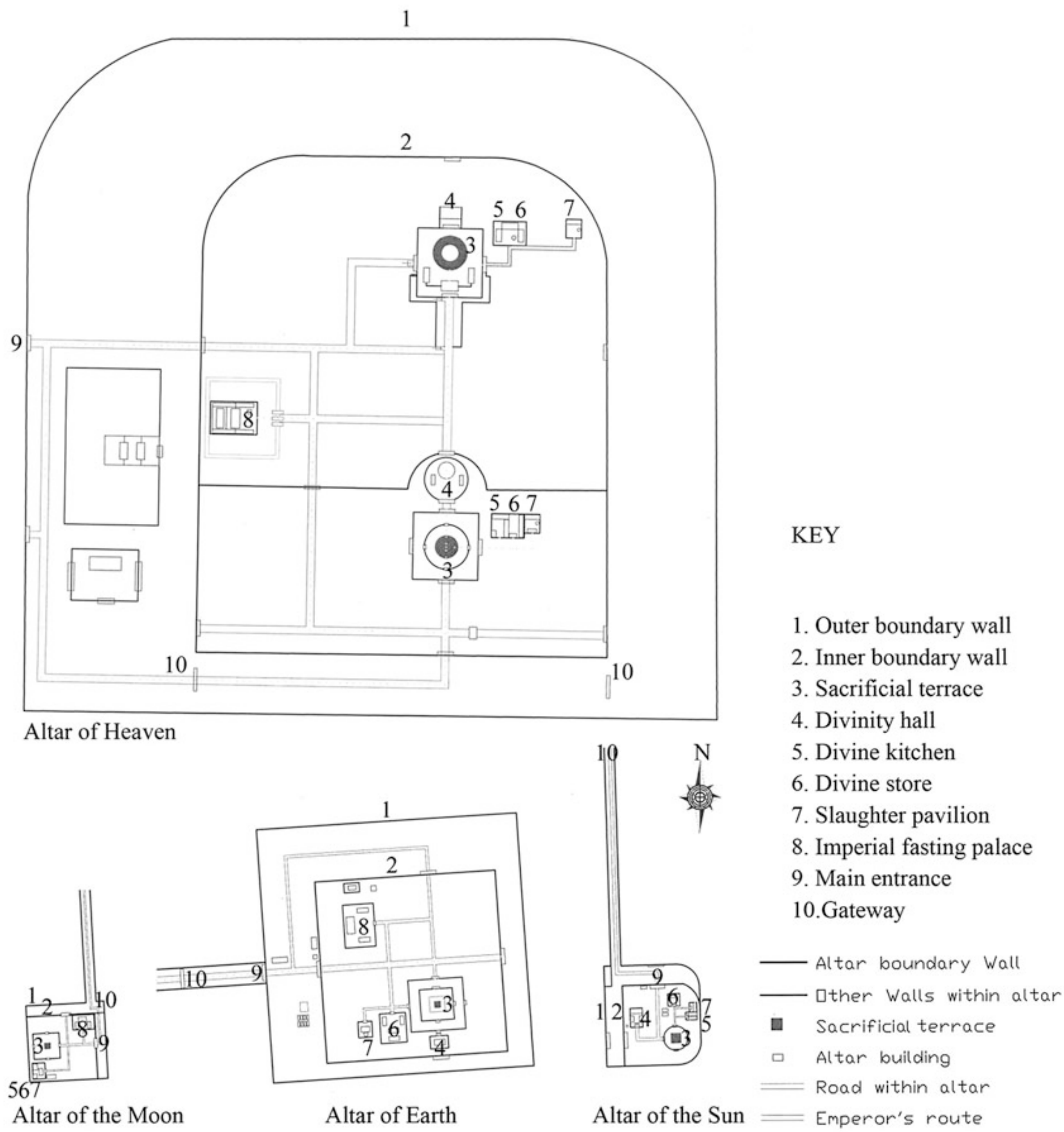
The location and orientation of these altars, as well as the individual layout and designs of structures, were all determined by Confucian rituals, thus reflecting a worldview which integrated human society and Nature gods. The layout of the altars was formal. Walls and pavements were arranged orthogonally, buildings and terraces were connected to each other, and evergreen trees were planted in regular delineations. All these characteristics provided an air of solemnity, while the fact that they were only open to the emperor and his entourage provided an element of mystique.

Altars in China, Fig. 3 Location of imperial altars in Qing dynasty City of Beijing (Gao & Woudtra 2011)



Despite the fact that the layouts were originally defined by rituals, the altars were changed over time in response to the needs and ideas of various emperors. Originally, the Book of Rites regulated both the Altar of Heaven and the Altar of Earth, when they were two separate altars, located at either side of the city. But in the Ming dynasty, the emperor Yongle thought it improper to separate the Gods of Heaven and Earth, since "the God of Heaven and the God of Earth, like father and mother, should stay together." As a result in 1420, he ordered the Altar of Heaven and Earth to be built and decreed this arrangement to remain forever (Editorial Board of Beijing Chronicles, 2006, pp. 2–3). However, in 1530, Emperor Jiajing believed this order distorted the authorized rituals and needed to be rectified. Therefore, he built the Altar of Earth to the north of the city and renamed the Altar of Heaven and Earth to the Altar of Heaven. In accommodating this to its sole purpose, a new sacrificial terrace was added to the south dedicated to the God of Heaven. The existing rectangular-shaped Divine Hall was demolished and rebuilt in a circular shape to represent Heaven (the Chinese believed Heaven to be round and the Earth square). A decade later, the Altar of Heaven was expanded towards the west and an extra boundary wall added, which provided the arrangement which can still be appreciated today (Fig. 5).

The Altars of Heaven, Earth, the Sun, and the Moon were places for sacrificing to Nature gods on specific days of the year. On the day of the

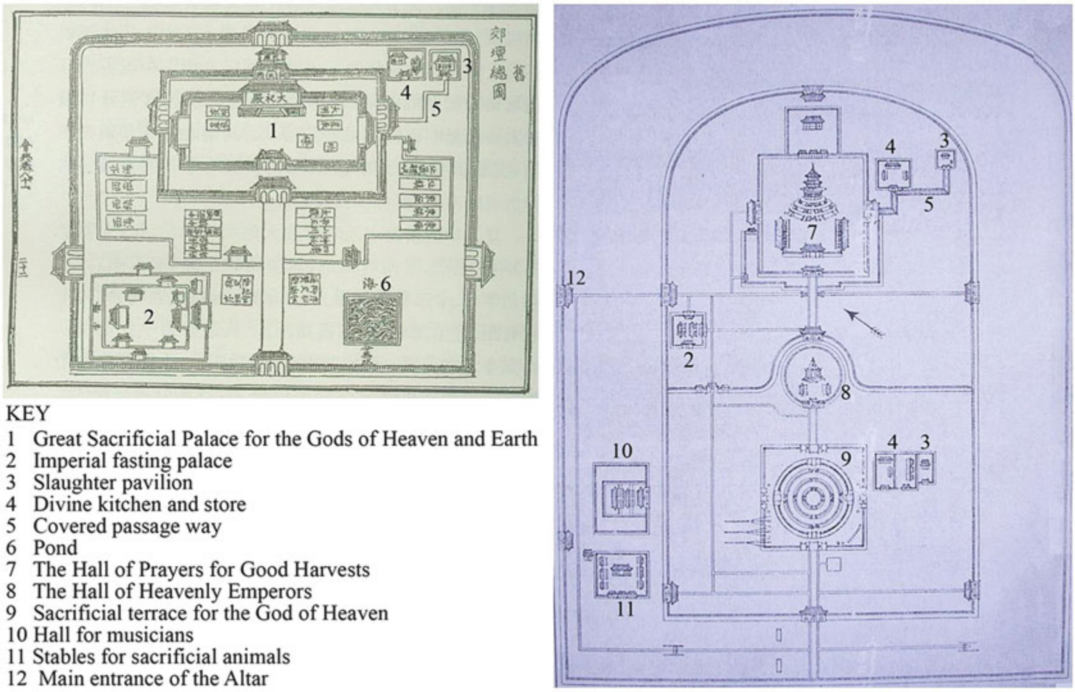


Altars in China, Fig. 4 Plans of four imperial altars in Beijing, drawn to the same scale and orientation, reveal a similarity in physical arrangement including positioning of altar features and symbolism. The variation in size reflects the relative significance of the respective gods to whom they are dedicated (Gao & Woudtra 2011)

winter solstices, the sacrifice to Heaven was held at the Altar of Heaven. And the sacrifice to Earth was held on the day of the summer solstices at the Altar of Earth. The sacrifice to the sun is held on the spring equinox and the sacrifice to the moon on the autumnal equinox.

In the Book of Rites, it is said that the temple for ancestors should be located to the east of the king's palace and the Altar of Soil and Grain to the west. This rule has been kept with few questions. The Altar of Soil and Grain in Beijing is located next to the Forbidden City, at the its west front.

The Altar of the God of Agriculture and the Altar of the God of Silkworms were for agricultural ancestors (as well as for legendary gods). Emperors took responsibility for agriculture and empresses for feeding silkworms and making



Altars in China, Fig. 5 Historical situation of the Altar of Heaven during the Ming dynasty (*left*) and Qing dynasty (*right*). While the plan on the left does not represent the correct proportions, and neither of these plans are at the correct scale, they show the general shape of individual buildings and features, as well as their relationships. The major changes from the earlier period include the new construction of the Hall of Prayers for Good Harvest (*right plan*) on the site of the Great Sacrificial Palace for the Gods of Heaven and Earth (*left plan*) and the addition of the Sacrificial Terrace for the God of Heaven (*right plan*) to the south requiring further amendments to the original site (Casson, 1955, p. 400; Fu, 2004, p. 342)

clothes, making their respective sacrifices. In consideration of the *yin–yang* theory and practical considerations, the Altar of the God of Agriculture was arranged to face south mirroring the Altar of Heaven on the other side of the central north–south axis, thus providing a balanced composition. Before becoming the Altar of the God of Agriculture, it was referred to as the Altar of Mountains and Rivers. After the revision of sacrificial tradition in 1530, the Mountain and River gods were moved to the Altar of Earth as associated gods. The Altar of the God of Silkworms, located outside the city wall during the sixteenth century, was relocated inside the imperial "Western Gardens," immediately alongside the Forbidden City. In this way the empress and her attendants could pay sacrifice without having to face the public – something much frowned upon at this time.

Due to the very complicated rules and processes and extreme significance of the imperial sacrifices, a special branch of government known as the Ministry of Rites was set up to administer ritual issues, including selecting sites, constructing altars and temples, inviting people to attend, as well as approaches to sacrifices. The most significant event was the annual sacrifice to the God of Heaven, which took place at the winter solstice. The second most significant was the sacrifice to the God of Earth on the summer solstice; the spring and autumn equinoxes were for the God of the Sun and the God of the Moon, respectively. The sacrifice to the God of Soil and Grain was taken on a special day of each spring and autumn (known as the day of Soil), and the first day of the spring plowing was the time for sacrificing to the God of Agriculture. It was the same for the empress sacrificing to the God of

Silkworms. Such arrangements were considered as following the order of nature.

Ritual ceremonies at imperial altars played a significant role in consolidating spiritual beliefs, but they also served as a reminder of political control, therefore being consolidated by various imperial dynasties. Qing emperors, although not Han Chinese in origin, took ritual ceremonies more seriously than previous Ming emperors, who sometimes sent princes or ministers to perform the rituals. With the exception of the sacrifices to the Sun and Moon gods, which ceased in 1813, the imperial sacrifices at the other altars continued until the end of the Empire in 1911. The practice of ritual ceremonies at imperial altars had dual meanings. On the one hand, it instilled a sense of fear in the emperors' and officials' minds and reminded them of their subordinate status towards a world beyond their dominance; on the other hand, by performing at imperial altars, the emperor sanctified his ruling status and stabilized the hierarchy of society. The imperial altars served as a stage for such ceremonial performances, which reinforced the meanings and values of these physical landscapes.

References

An, J., Li, C., et al. (2000). 陕西西安唐长安城圜丘遗址的发掘 (Archaeological excavation of the round altar of Tang Chang'an in Xi'an, Shanxi Province). *考古 (Acta Archaeologica Sinica), 2000*(7), 29–47.

Casson, H. (1955). The temple of heaven, Peking. *Architectural Review, 118*, 400–401.

Chen, C. (2004). *先秦祭坛及相关问题研究 (A study on altars of pre-qin times and related issues)*. Unpublished Master's thesis, Wuhan University, Wuhan.

Chen, H. (Annotator) (1322/1985). 礼记集说 (A collection on the remarks of the Book of Rites). 四书五经中册 (*Four books and five classics, middle volume*). Beijing, China: Zhonguo Shudian.

Editorial Board of Beijing Chronicles. (2006). *天坛志 (Chronicle of the altar of heaven)*. Beijing, China: Beijing Press.

Fu, X. (2004). *中国古代建筑十论 (Ten treatises on Chinese ancient architecture)*. Shanghai, China: Fudan University Press.

Gao, L., & Woudtra, J. (2011). From landscape of gods to landscape of man: Imperial altars in Beijing. *Studies in the History of Gardens & Designed Landscapes, 31*(4), 231–268.

Legge, J. (Trans.). (1885). The sacred books of the east. In F. M. Muller (Ed.). *The Li Ki, books I-X* (Vol. 28). Oxford, UK: Clarendon Press.

Liu, Z. (2000). *北京的坛庙文化 (The altar and temple culture in Beijing)*. Beijing, China: Beijing Press.

Luo, Z. (2002). *中国帝王苑囿 (Imperial parks and gardens in China)*. Beijing, China: Patent Press.

Zhang, J., Harbottle, G., Wang, C., & Kong, Z. (1999). Oldest playable musical instruments found at Jiahu early Neolithic site in China. *Nature, 401*, 366–368.

Al-Uqlīdisī

Jacques Sesiano

Al-Uqlīdisī, Abū'l-ḥasan Aḥmad ibn Ibrāhīm, wrote an Arithmetic (*Kitāb al-Fuṣūl fī'l-ḥisāb al-hindī*) in Damascus in 952–953. This is a sizable compendium and remarkable as the earliest arithmetic extant in Arabic.

The first part explains the place-value system, the four arithmetical operations (addition, subtraction, multiplication, division), and the extraction of square roots for integers and fractions, both common and sexagesimal. Numerous examples are given. This part is supposed to be accessible to a large audience. The second part develops the earlier topics and adds curiosities or different methods. The third part would seem to be the result of the author's experience in teaching; it consists of explanations and questions with their answers concerning some difficulties the reader might have met in the first two parts. The fourth part contains some digressions about the changes Indian arithmetic undergoes when one uses ink and paper (since Indian computations were made on the dust abacus). In this part al-Uqlīdisī also explains (according to him, better than his predecessors) how to extract cube roots.

Al-Uqlīdisī was concerned with the applicability of arithmetic. How original his work was we do not know. He often claims originality or at least superiority of his teaching, but so do his contemporaries. He does not claim originality, however, for the most important feature of his *Arithmetic*, the first occurrence of decimal fractions (besides the usual common and sexagesimal ones). He uses a mark placed over the last integral unit in order to indicate the separation from the subsequent, decimal part.

References

Saidan, A. (1966). The earliest extant Arabic arithmetic. *Isis, 57*, 475–490.

Saidan, A. S. (1973). *Al-fuṣūl f ʻl-ḥisāb al-hindī*. Amman, Jordan: al-Lajnah al-Urdunnīyah lil-Taʿrīb wa'l-Nashr wa'l-Tarjaman. Arabic text.

Saidan, A. S. (1978). *The arithmetic of al-Uqlīdisī*. Dordrecht, Netherlands: Reidel (English Translation).

Al-ʿUrḍī

Boris A. Rosenfeld
PA, USA

Muʾayyad al-Dīn ibn Barmak al-ʿUrḍī al-Dimashqī (thirteenth century) was an astronomer, architect, and engineer. He was born in Damascus and first worked in Syria. He did some hydraulic engineering in Damascus and constructed an astronomical instrument for the ruler of Hims (Emessa), al-Manṣūr Ibrāhīm (1239–1245). He also taught *handasa* (architecture or geometry).

In or soon after 1259, he was in Maragha, the capital of the Mongol conqueror Hulagu Khan, the grandson of Genghis Khan. He was one of the four astronomers who worked with Naṣīr al-Dīn al-ṭūsi, the founder of the Maragha observatory. He participated in the organization, building, and construction of the instruments of this observatory and in the building of a mosque and a palace in Maragha.

The best known al-ʿUrdī's work is *Risāla fī kayfiyya al-arṣād wa mā yukhtāj ilā ʿilmihi wa ʿamalihi min al-ṭuruq al-muwaddiya ilā maʿrifa ʿawdāt al-kawākib* (Modes of Astronomical Observations and the Theoretical and Practical Knowledge Needed to Make Them, and the Methods Leading to Understanding the Regularities of the Stars). Manuscripts of this treatise are extant in Istanbul, Paris, and Teheran. The treatise contains the description of 11 of the most important astronomical instruments of the Maragha observatory which he himself mainly constructed: (1) mural quadrant, (2) armillary sphere, (3) solstitial armilla, (4) equinoctial armilla, (5) Hipparchus' diopter (alidade), (6) instrument with two quadrants, (7) instrument with two limbs, (8) instruments to determine sines and azimuths, (9) instruments to determine sines and versed sines, (10) "the perfect instrument" built by him in Syria, and (11) parallactic ruler (after Ptolemy).

Al-ʿUrḍī was also the author of three astronomical treatises: *Kitāb al-hayaposa* (Book on Astronomy) on the motion of planets, *Risāla fī ʿamal al-kura al-kāmila* (Treatise on Construction of the Perfect Sphere), and *Risāla fī'l-taʿrīf al-buʿd bayna markaz al-shams wa'l-awj* (Treatise on the Determination of the Distance between the Center of the Sun and the Apogee).

Al-ʿUrḍī's sons Shams al-Dīn and Muḥammad also worked in the Maragha observatory. Muḥammad (ca. 1280) constructed a celestial globe 150 mm in diameter, which is extant in the Mathematical Salon in Dresden.

See Also

▶ Marāgha
▶ Naṣīr al-Dīn al-Ṭūsī
▶ Observatories in the Islamic World

References

Bezza, G. (2007). çUṭārid: çUṭārid ibn Muḥammad al-Ḥāsib. In *The biographical encyclopedia of astronomers* (pp. 1163–1164). New York: Springer.

Carey, M. (2009). The gold and silver lining: Shams Al-Din Muhammad b. Mu'ayyad al-'Urdi's Inlaid

Boris A. Rosenfeld: deceased

Celestial Globe (c. AD 1288) from the Ilkhanid Observatory at Maragha. *Iran*, 97–108.
Dallal, A. S. (1997). Travaux récents en histoire de l'astronomie arabe. *Arabic Sciences and Philosophy: A Historical Journal, 7*, 283–297.
Jourdain, A. (1810). *Mémoire sur l'Observatoire de Méragha et les Instruments Employées pour y Observer*. Paris: Joubert.
Matvievskaya, G. P., & Rosenfeld, B. A. (1983). *Mathematicians and astronomers of medieval Islam and their works (8th–17th c.)* (Vol. 2, pp. 414–415). Moscow: Nauka (in Russian).
Saliba, G. (2002). Greek astronomy and the medieval Arabic tradition the medieval Islamic astronomers were not merely translators. They may also have played a key role in the Copernican revolution. *American scientist*, 360–367.
Sarton, G. (1931). *Introduction to the history of science* (Vol. 2, pp. 1013–1014). Baltimore, MD: Williams & Wilkins.
Sayılı, A. (1960). *The observatory in Islam*. Istanbul: Turk Tarih Kurumu.
Zaimeche, S. (2002). Islam and science. *Foundation for Science, Technology and Civilization Journal*.

Anatomy in Ancient India

Lakshmi Rajgopal

In India I found a race of mortals living upon the earth but not adhering to it; inhabiting cities but not being fixed to them; possessing everything yet possessed by nothing.
Apollonius Tyanaeus (Greek thinker and traveller, first century AD).

The history of India is both fascinating and daunting. The geographical terrain of Bharat (Hindustan), as India was known then, extended far beyond the boundaries of India as they exist now. It is this region that cradled a civilisation in the Indus valley about 5,000 years ago, evidence of which is amply found in Harappa, Mohenjo-daro, Lothal (Gujarat) and other places. There is evidence that ancient Hindus practiced science, especially medical science; they were adept in practical anatomy and knew how to apply anatomical knowledge to the practice of surgery.

Prehistoric Period

The history of medicine in India can be divided into two broad periods. The prehistoric period ranges from the Stone Age to the beginning of written history. This period can again be subdivided into the early prehistoric period (40000–2500 BCE) and the protohistoric period (2500–1500 BCE). Prehistoric people were wanderers, hunters and worshippers of supernatural phenomena (Subba Reddy, 1971). Any anatomical knowledge these men might have possessed was only to use it for hunting and not as a basis for diagnosis and surgical treatment of diseases. There is evidence, in the form of cave paintings (Fig. 1a, b) discovered in Bhimbetaka, near Bhopal in Central India, that superficial anatomical knowledge was used to hunt animals.

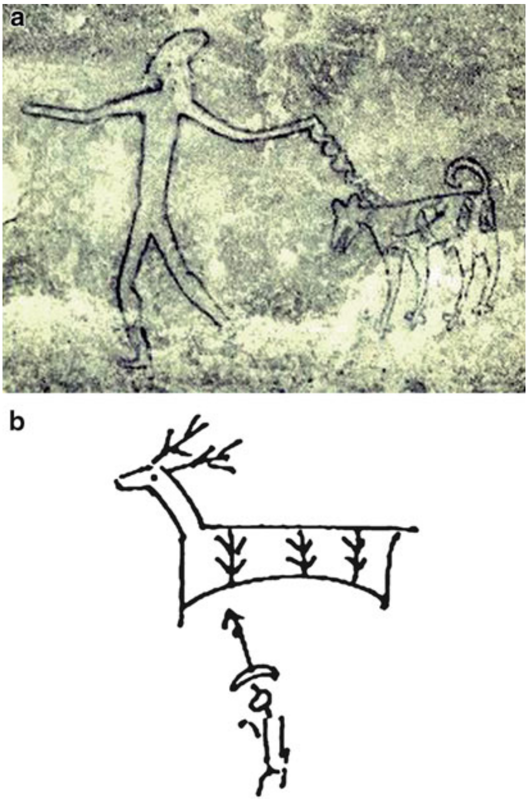
These are similar to the Pindal elephant pierced by arrows near its heart and the Niaux bison portrayed with weapons directed at its vital centres; they show that prehistoric man had some knowledge of gross anatomy (Gordon, 1949).

Protohistoric Period

The Protohistoric period is the time when the Indus Valley civilisation flourished in northwest India. The people of this civilisation were architects and built planned cities. They were also public health experts, as is evidenced by the wells and bathrooms in the houses and a closed system of drains that have been excavated in Harappa, Mohenjo-daro and other sites. They were also healers, although the practice of healing was more magico-religious, based on rites and rituals (Kutumbiah, 1962).

Historic Period

The historic period of ancient Hindu medicine started with the invasion of the Indus valley by Indo-European tribes such as the Aryans around 1500 BCE. The Vedic period extended from 1500 to 800 BCE. This was followed by the Brahmanic period or the Buddhic period, from 800 BCE to



Anatomy in Ancient India, Fig. 1 (**a**, **b**) Cave paintings at Bhimbetaka (Reproduced from K. L. Kamath. Prehistoric Paintings, URL: http://www.kamat.com/kalranga/rockpain/betaka.htm accessed on 23 Sept. 05)

1000 AD. This was followed by the Mongol period or the Moghul period from 1000 AD onwards (Major, 1954).

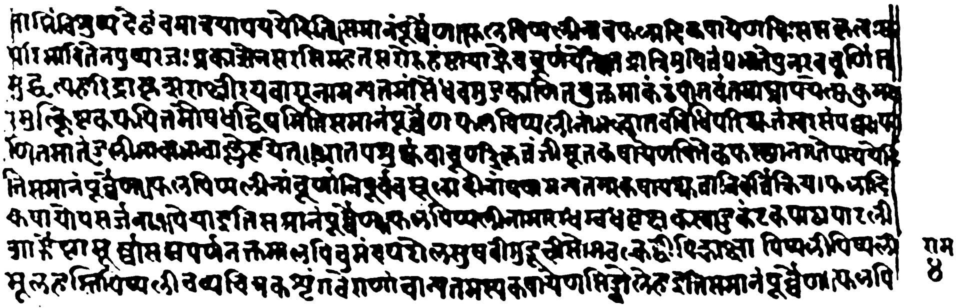
Vedic Period

The word "Veda" means knowledge – *ṛgveda* is knowledge of hymns of praise; *Yajurveda* is knowledge of sacrificial formulae; *Sāmaveda* is knowledge of melodies and *Atharvaveda* is knowledge of magic formulae (Major, 1954). The Vedas speak about the structure of the body. In the *ṛgvedic* hymns mention is made of the lungs, the heart, the stomach, the intestines, the kidneys and other viscera (Kutumbiah, 1962). Atharvavedic medicine is an amalgam of magico-religious elements consisting of chants and charms and empirico-rational elements which used drugs to cure disease. The *Atharvaveda* gives an impression of the coarser anatomy of the body. There is a hymn in the tenth book which mentions the creation of man describing the articulation of bones (Lanman, 1905). *Atharvaveda* also refers to the heart as a "lotus with nine gates". The comparison of the heart with a lotus is very common in Sanskrit literature. When we compare it with present day knowledge, we see that there are indeed three venous openings in the right atrium, four pulmonary veins opening in the left atrium and the pulmonary artery and the aorta leaving the right and the left ventricles, making nine openings in all. The heart, if held upside down, does resemble a lotus bud (Rajgopal, Hoskeri, Bhuiyan, & Shyamkishore, 2002). *Atharvaveda* also describes childbirth in some detail.

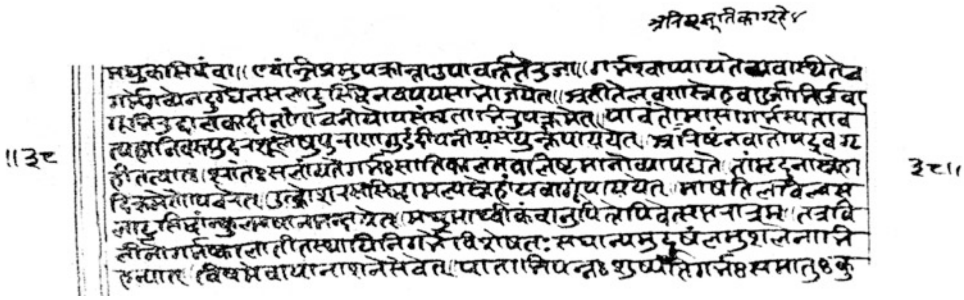
Brahmanic Period

Vedic books such as *saṃhitās* contained hymns. It was difficult for common people to follow them. So the post-Vedic period saw a lot of literary work which described the Vedic work in simpler language. Thus were born the *Brāhmaṇas* which described and explained the Vedic rites and stories. These were followed by *Aranyakas* which were the continuation of the *Brāhmaṇas* but were meant for people who have entered the third ashram of *Vanaprasta* in life. *Aranyaka* is derived from *arni* meaning wooden sticks, the rubbing of which results in the production of the sacrificial fire. The fire thus produced was used by the Vanaprastis for their day-to-day living (Bodas, 1908). Aranyakas were followed by *Upaniṣads*. In fact *Upaniṣads* are part of Aranyakas which treat the higher doctrine of the soul (Upaniṣad = secret knowledge/esoteric lore). Upanishadic knowledge is obtained by the disciples by sitting around a teacher and listening to him in the 'Guru-Shishya' tradition (Udwadia, 2000).

Hindu scriptures had a peculiar way of comparing the structure of human body with things that are metaphysical. In *Satapatha Brāhmaṇa*, Yajnavalkya, who flourished in the court of King Janaka, mentions that the total number of bones in the body is 360 and compares it to 360 days of the year (Hoernle, 1907). It is during this period



Anatomy in Ancient India, Fig. 2 A leaf from *Suśrutasaṃhitā* (Reproduced from Indian System of Medicine by O. P. Jaggi. New Delhi: Atmaram & Sons)



Anatomy in Ancient India, Fig. 3 A leaf from *Carakasaṃhitā* (Reproduced from Indian System of Medicine by O. P. Jaggi. New Delhi: Atmaram & Sons)

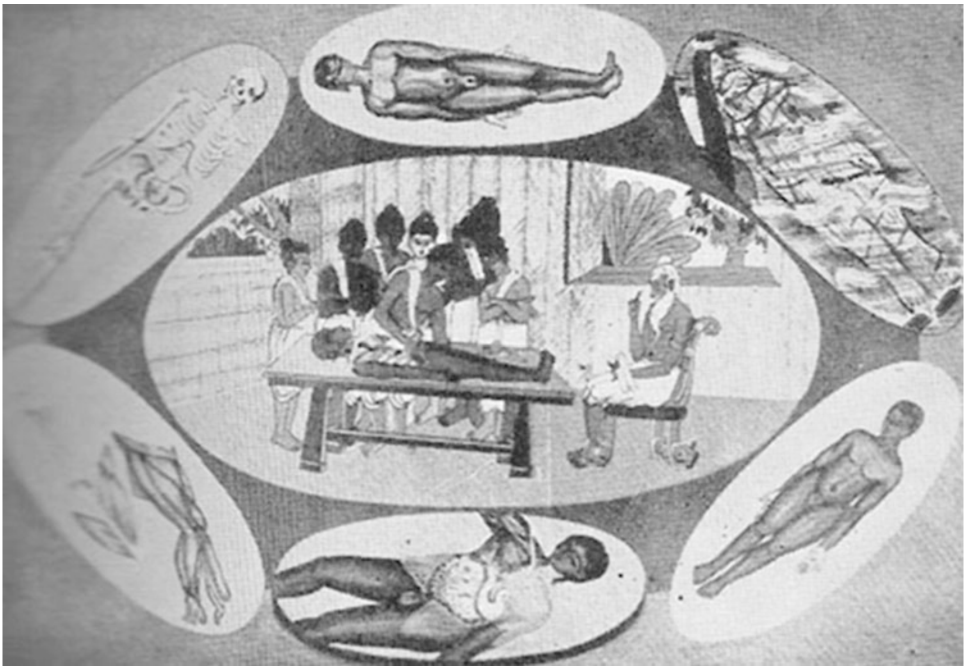
that the science of "Āyurveda" came into being, roughly between 800 and 600 BCE. Āyurveda, or the science of life, was expounded by Brahma and given to the Ashwinikumars; they then taught Indra, who transmitted his knowledge to other priests (Jaggi, 1972). This period was the "Golden Period" in the history of Indian medicine.

The Golden Period

According to the Indian medical tradition, the knowledge of medicine had two origins. On the one hand, it was delivered by the God Indra to the sage Bharadwaja and the latter then handed it over to Punarvasu ► Ātreya. On the other hand, it descended from Indra to Dhanvantri (also called Divodasa or Kasiraja) and from him to ► Suśruta. This tradition gives medicine a mythical origin and when traced further leads to historical facts. In the age of Buddha, two great universities existed in India where all forms of science including medical science were taught. They were Benares or Kasi in the East and Takshila or Taxila in the West on the river Jhelum (Hoernle, 1907). The leading professor of Medicine in Takshila was Ātreya and the famous teacher of surgery at Benares was Suśruta. They were two stalwarts of Āyurveda and their teachings were compiled in the form of texts. Suśruta's teachings were compiled as *Suśrutasaṃhitā* (Fig. 2).

Ātreya had Agniveśa as one of his disciples, and ► Caraka was in turn his student. Caraka revised *Agniveśatantra* and it came to be known as *Carakasaṃhitā*. Caraka was the court physician of the celebrated Indo-Scythian king Kanishka and that puts the period of Caraka as 125–150 AD (Bhandarkar, 1906) (Fig. 3).

Suśrutasaṃhitā is a great storehouse of Aryan surgery. Though Garrison claims that Indian medicine was weak in anatomy which he attributes to fanciful enumerations (Garrison, 1924),



Anatomy in Ancient India, Fig. 4 Preparation of a dead body for dissection (Reproduced from the museum guide of the Institute of History of Medicine, Hyderabad)

it is a fact that to practise the art of surgical healing, one must have sound knowledge of anatomy. Suśruta could not have achieved such mastery over surgery without a thorough knowledge of anatomy. It is precisely for this reason Suśruta insisted that his disciples practice dissection, even though their religion prohibited it. Suśruta had devised his own method of overcoming religious cutting open the dead body prohibition by placing the dead body in a cage covered with hemp and then keeping it in a secluded spot in the riverbed which would allow the body to decompose slowly in water. Later the observer gently scraped off the layers of the skin using *kusa* grass and could see both the external and internal aspects (Clendening, 1942; Dampier, 1942; Jaggi, 1972; Kutumbiah, 1962) (Fig. 4).

Both Suśruta and Caraka devoted an entire chapter to anatomy, *Sarira Sthana*, in their *Saṃhitās*. Osteology (the study of bones), myology (the study of muscles) and splanchnology (study of the viscera and its organs) are some divisions of anatomy in which these ancient authors excelled. Suśruta noted 300 bones and 210 joints in the body. He also classified joints into eight different types, e.g. *kora* (hinge joint) at the ankles and elbows, and *samudga* or *ulukhala* (ball and socket joint) as in the hip and shoulder. Caraka's anatomy is mainly that of external observation. Caraka described 360 bones and 200 joints. The reason for the discrepancy is that many cartilages, nails and protuberances were counted as separate bones. ► Suśruta gave the total number of muscles as 500 and specified their distribution as 400 in 4 extremities, 66 in the trunk and 34 in the head and neck regions. Caraka's description of muscles is quite rudimentary. Besides muscles, both Suśruta and Caraka described 900 *snayus* (ligaments; Kutumbiah, 1962).

Suśruta had more thorough and critical knowledge of the internal viscera as is evidenced by his description of the heart and the vessels. He referred to the heart as a lotus bud hanging with its apex downward and also

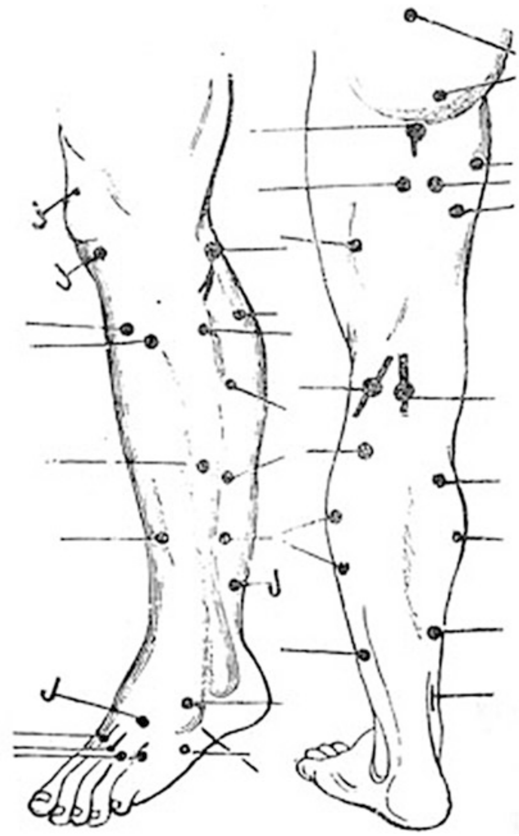
Anatomy in Ancient India, Fig. 5 Preparation of clay models by students of anatomy (Reproduced from the museum guide of the Institute of History of Medicine, Hyderabad)

noted 24 *dhamanis*, 700 *siras* and 22 *srotas*. Dhamanis are thick-walled tubes and siras are thin-walled tubes equivalent to present-day arteries and veins. Srotas probably referred to lymphatics. Suśruta observed that all the dhamanis and siras arose from the umbilicus and there were 40 important ducts in the body. Caraka said that the heart was the root of ten dhamanis which run to different parts of the body. Nerves were also classified as ducts and included in the count of vessels.

Suśruta does not state anything of importance concerning the brain but considers the head as the centre of all senses. Both Suśruta and Caraka mention various viscera in the abdomen. The stomach is referred to as *amasaya*; the intestine is called *pakvasaya* and the rectum *gudam*. The uterus is known as *garbhasaya* and the gallbladder as *pitthasaya* (Kutumbiah, 1962).

According to Suśruta, apart from dissecting, a student of anatomy should learn the subject and obtain mastery over it by preparing clay models (Fig. 5). Suśruta implored his students of surgery to be careful about 107 vital spots or *marmas* in the body. Marmas are the meeting place of any two or more of the five elements of the body: vessels, muscles, ligaments, bones and joints. The marmas are then classified into five groups (1) *Mamsa* marmas (fleshy); (2) *Sira* marmas (of the vessels); (3) *Snayu* marmas (of the ligaments); (4) *Asthi* marmas (of the bones) and (5) *Sandhi* marmas (of the joints). According to Suśruta, some of them when injured will result in instantaneous death and some others when injured will cause pain and paralysis (Bhishagratna, 1991; Clendening, 1942; Dampier, 1942; Jaggi, 1972) (Figs. 6 and 7).

Apart from gross anatomical findings, embryology, the study of the development of the foetus, also achieved a high level in ancient India. Structures such as amniotic membranes are mentioned in the Bhagavad Gītā (Needham, 1934). Indian anatomists were of the opinion that union



Anatomy in Ancient India, Fig. 6 Vital spots or *marmas* in the limbs according to Suśruta (Reproduced from The *Suśruta Saṃhitā* – English translation by K. K. Bhishagratna. Varanasi: B. Chowkhamba Sanskrit Series Office)

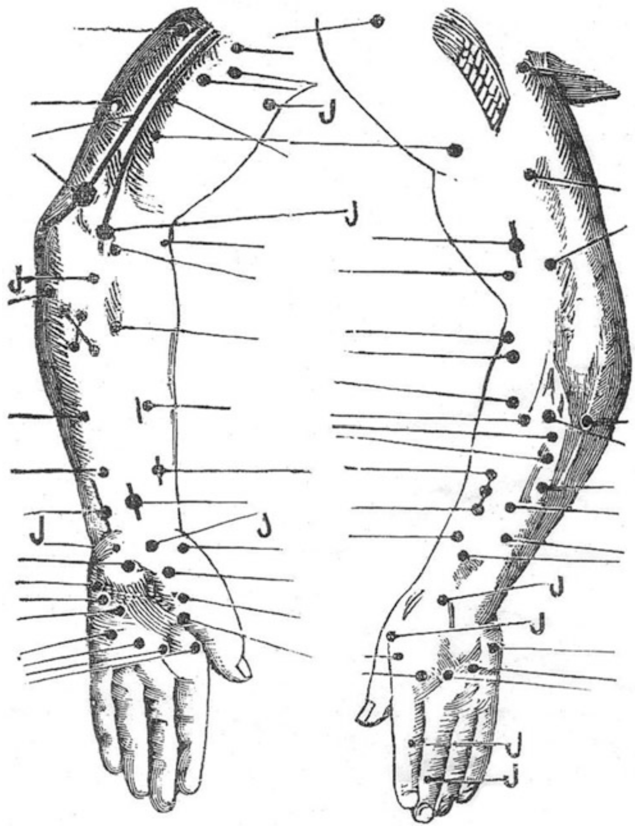
of the blood of the mother, called *sonita* and the semen of the father, called *sukra* was responsible for the production of the foetus. They were aware that the mechanism of sex determination took place at the time of fertilisation (Kutumbiah, 1962). Moore and Persaud (1999) quote *Garbhoniṣad* (sixth century BCE) which describes the stages of development of the foetus. A 1-day-old embryo is jelly-like and called *kalala*. After seven nights, it becomes vesicular (*Budbuda*) which indeed is the case, as we know now. We call this a blastocyst. After a month it becomes a firm mass and the head is formed after 2 months.

In the third month legs and arms appear distinctively. In the sixth month hair, nail, bones and veins develop. In the eighth month there is drawing of the vital force (*ojas*) from the mother. Indian anatomists believed that the growth of the embryo occurs by a process of layering where at least seven strata are superimposed one upon the other. The seven layers are *avabhasini*, *lohita*, *sveta*, *tamra*, *vedini*, *rohini* and *mamsadhara* (Kutumbiah, 1962). They also believed that softer parts of the foetus, such as skin, blood, flesh, fat, navel, heart, lungs, liver and marrow, are derived from the mother and the harder parts, such as the head, nails, teeth, bones and nerves, are derived from the father (Jaggi, 1972; Zimmer, 1948). The formation of the embryo is also compared with the formation of creamy layers of milk; this similar comparison to the clotting of milk to form cheese has also been used by Aristotle (Needham, 1934).

It is possible that Indian thought influenced the schools of Asia Minor and through them those of Greece (Dampier, 1942). There is evidence that Indian medical practices spread all over Asia including Indonesia, Tibet and Japan. The translation of Ayurvedic literature into Arabic and Persian in the eighth to eleventh century AD led to its further spread (Lyon & Petrucelli, 1987). *Carakasaṃhitā* was translated from Sanskrit into Arabic in the eighth century AD and *Sharaka indianus* appears in the Latin translation of Avicenna, Rhazes and Serapion. *Suśrutasaṃhitā* was translated into Arabic before the end of the eighth century AD as 'Kitab-i-shawshoon–Al-Hindì' and also mentioned as 'Kitab-i-Susrud' by Ibn Abillsaibal. Rhazes often quotes 'Sarad' as an authority in Surgery (Mukhopadhyaya, 1913).

The ancient Indian medical doctors can be credited with the inquisitiveness to learn about the structure of the human body and a systematic study of the same. They practised human dissection despite religious restrictions. They also had an appreciation of the relation of anatomy to the practice of medicine. Even if the enumerative method of various parts of the body may minimise their significance, what cannot be denied is that they used their knowledge of anatomy to master surgery and practised medicine in a more scientific way.

Anatomy in Ancient India, Fig. 7 Vital spots or *marmas* in the limbs according to Suśruta (Reproduced from The *Suś ruta Saṃhitā* – English translation by K. K. Bhishagratna. Varanasi: B. Chowkhamba Sanskrit Series Office)



See Also

► Surgery in Ancient India

References

Bhandarkar, D. B. (1906). Early history of India. *The Journal of Bombay Branch of Royal Asiatic Society, 20*, 269.

Bhishagratna, K. K. (1991). *The Suśrutasaṃhitā*. (K. K. Bhishagratna, Trans.). Varanasi, India: B. Chowkhamba Sanskrit Series Office.

Bodas, M. A. (1908). A brief survey of Upanishads. *The Journal of Bombay Branch of Royal Asiatic Society, 22*, 67–80.

Clendening, L. (1942). *Sourcebook of medical history*. New York: Paul B. Heuber.

Dampier, W. C. (1942). *Science in the ancient world* (A History of Science and Its Relations with Philosophy and Religion 3rd ed.). London: Cambridge University Press.

Garrison, F. H. (1924). *Sumerian and oriental medicine* (An Introduction to the History of Medicine 3rd ed.). Philadelphia: WB Saunders.

Gordon, B. L. (1949). *Medicine through antiquity*. Philadelphia: F. A. Davis.

Hoernle, A. F. R. (1907). *Studies in the medicine of ancient India. Part I* (Osteology or The Bones of the Human Body). Oxford, UK: Clarendon.

Jaggi, O. P. (1972). *Indian system of medicine* (History of Science and Technology in India. Part IV). New Delhi, India: Atma Ram and Sons.

Kutumbiah, P. (1962). *Ancient Indian anatomy* (Ancient Indian Medicine). Madras, India: Orient Longmans Limited.

Lanman, C. R. (Ed.). (1905). *Whitney's translation and commentary of Atharva Veda Samhita*. Massachusetts, USA: Cambridge Press.

Lyon, A. S., & Petrucelli, R. J. (1987). *Medicine – an illustrated history*. New York: Harry N. Abrams.

Major, R. H. (1954). *The dawn of medicine* (A History of Medicine, Vol. I). Chicago: Charles C. Thomas.

Moore, K. L., & Persaud, T. V. N. (1999). *Introduction to the developing human – historical gleanings* (The developing human – clinically oriented embryology 6th ed.). New Delhi, India: Harcourt Asia.

Mukhopadhyaya, G. (1913). *Ancient medical authors and their works* (The Surgical Instruments of the Hindus Ith ed.). Calcutta, India: Calcutta University.

Needham, J. (1934). *Embryology in antiquity* (A History of Embryology). Cambridge, UK: Cambridge University Press.

Rajgopal, L., Hoskeri, G. N., Bhuiyan, P. S., & Shyamkishore, K. (2002). History of anatomy in India. *Journal of Postgraduate Medicine, 48*, 243–245.

Subba Reddy, D. V. S. (1971). *Medicine in India: Pre-historic period* (Institute of History of Medicine – Museum Guide – Part II). Hyderabad, India: The Central Council for Research in Indian Medicine & Homeopathy.

Udwadia, F. E. (2000). *Ancient Indian medicine* (Man and Medicine – A History). New Delhi, India: Oxford University Press.

Zimmer, H. R. (1948). *Hindu medicine*. Baltimore, MD: Institute of the History of Medicine, The Johns Hopkins University.

Ancient Egypt

J. Worth Estes

Humanity was concerned with sickness and death long before the Egyptians appeared along the banks of the Nile. But only from the beginning of pharaonic civilization, about 2900 BCE, do we have evidence of how sickness and trauma were treated in the ancient world. It comes primarily from several monographs, or collations of sections of earlier monographs, written on papyrus. The major medical papyri are, in their probable chronological order:

- *Veterinary Papyrus of Kahun*, ca. 1900 BCE, on the treatment of animals
- *Gynecological Papyrus of Kahun*, ca. 1900 BCE, a fragment of a monograph on the diseases of women
- *Papyrus Edwin Smith*, ca. 1550 BCE, part of a monograph on wounds that also includes a fragment of a work on the heart and vessels called the *Secret Book of the Physician* that was probably composed ca. 3000 BCE
- *Papyrus Ebers*, ca. 1550 BCE, a collection of remedies for several kinds of ailments that contains a longer version of the *Secret Book*
- *Papyrus Hearst*, ca. 1550 BCE, a less systematically organized collection of remedies that duplicates many of those in the Ebers Papyrus
- *Papyrus Berlin 3038*, ca. 1350–1200 BCE, another collection of drug recipes, with another version of the *Secret Book*
- *Papyrus Chester Beatty*, ca. 1250–1150 BCE, a fragment of an earlier monograph on diseases of the anus
- *Magical Papyrus of London and Leiden*, ca. third century AD, containing many examples of spells used in healing rites

From the beginning, magic dominated Egyptian concepts of illness and its treatment. Empiric observations eventually entered therapeutic thinking, but magic was seldom far removed from it. The Egyptians attributed healing powers to a number of their local gods, while Thoth, scribe of the major gods and inventor of the arts and sciences, became a part-time god of medicine. Not until he was deified sometime after 525 BCE did Imhotep, who had been the chief minister of the pharaoh Zoser (reigned 2630–2611 BCE), and the inventor of the pyramid, assume the role of chief god of Egyptian medicine.

Throughout most of the three millennia of pharaonic history, three kinds of healers treated the sick. Two of them, magicians and priests, relied chiefly on magical or religious rituals. The third group, the lay physicians called *swnw* (pronounced something like "sounou"), relied chiefly on surgery and drugs, techniques that were also used by healing priests. How they learned their professional skills is not known, but most probably they learned from their fathers, and all were literate. Interestingly, not all were men: an inscription from the Old Kingdom period (2575–2134 BCE) describes a woman named Peseshet as the Lady Director of the Lady Physicians.

*Swnw*s usually accompanied armies into the field, and were employed at public works sites such as temples, pyramids, and quarries. The oldest known doctor's bill lists payments to a *swnw* who worked at the village of the workmen who built the tombs and temples of Thebes, in about 1165 BCE. Although physicians were paid only about a third as much as construction workers, *swnw*s sometimes achieved very high rank at court, and were rewarded accordingly.

The average age at marriage was 12–13 for women, and 15–20 for men. The fertility rate, at east among the few queens for whom we have data, was lower than might have been expected, about 3.5 births per woman, in part because children were not weaned until they were 3-years old. The average life expectancy at birth was probably about 30 years in the early Old Kingdom, and might have increased to as much as 36 years over the next 2,500 years. Evidence of very old age is scarce among mummies simply because most Egyptians died in their 30s, before the diseases that are typical of old age could have developed. A few kings and priests lived into their 90s, but fewer than 10 % of Egyptians lived longer than 40 years. By contrast, about 94 % of modern Americans die after age 40, and their life expectancy is about 76. As in most preindustrial cultures, both the population and the average life expectancy rose (and the death rate fell) when the food supply increased, as farmers increased their ability to exploit the Nile with improved irrigation systems.

Egyptians well understood the biological relationships among the testes, penis, semen, and pregnancy. However, because much of their anatomical knowledge came from cattle, they thought that semen was produced in the bone marrow, even if they also knew that removing the testes – castration – prevented any possibility of fatherhood. On the other hand, they knew nothing about the ovaries, and thought that women's role in reproduction was simply to nourish the fully formed seed that the father planted in the fertile uterus. Although the *swnw* did not attend births, he did treat women's medical problems. He attributed menstrual abnormalities to malpositions of the uterus, which meant that many "gynecological" treatments were designed to restore it to its proper position.

It has been difficult to learn much about the actual causes of death in ancient Egypt, despite the hundreds of mummies in the world's museums. Several have been studied nondestructively, using X-rays and CAT scans. Such noninvasive techniques can easily reveal diagnoses such as fractures, dislocations, calcified arteries, and gall stones, but such conditions need not be fatal per se. X-rays of 26 royal mummies from the New Kingdom (1550–1070 BCE) period have revealed more about their age at death, their teeth, and about mummification techniques, than about their illnesses, and even less about the causes of their deaths. The few mummies that have been dissected have provided surprisingly little specific pathological information, partly because most Egyptians probably died of infections that left few anatomical traces, and partly because mummification usually destroyed potentially diagnostic tissues. On the other hand, Egyptians may have been so thinly scattered along the river that many infectious diseases could not easily have propagated themselves. Nevertheless, in some places at least, the population may have finally become sufficiently dense over the centuries to facilitate the spread of such diseases.

Not all evidence of illness in ancient Egypt has come from human remains. A few statuettes show spinal distortions characteristic of tuberculosis of the spine, as do several mummies. Similarly, both a funeral monument and a mummified leg show the dropped foot deformity typical of poliomyelitis (although it could also have been a club foot). Identifiable illnesses are not found in the detailed pictures of everyday life that adorn tombs, since sickness had no useful role in the next life.

In addition to tuberculosis, Egyptians had many of the diseases we have, although in different proportions of the population, plus several protozoal and worm infestations that are still found along the banks of the Nile, such as trachoma and schistosomiasis. Most of the nontraumatic illnesses that occurred in ancient Egypt have not been identified in modern terms, but the Ebers Papyrus shows that the *swnw* classified them by their anatomic location, such as the skin, hair, abdomen, limbs, genitalia, and so on.

The Edwin Smith Surgical Papyrus contains several "firsts" in the history of medicine, including the first written descriptions of any surgical procedures, and the earliest examples of inductive scientific reasoning. The 48 cases described in the monograph are organized anatomically, from the top of the head down through the neck to the upper arm and chest; the scribe stopped transcribing the text when he reached the section on the upper spine. Because many injuries described in the Smith Papyrus were probably battle wounds, its prognostic predictions can also be taken as early examples of systematic battlefield triage.

The original author of this surgical text classified injuries by their extent and severity, and by their localization in bone or flesh, and established a systematic procedure for dealing with each kind of problem. Each chapter is devoted to a different injury, beginning with clinically important phenomena that could be seen or palpated, followed by a diagnosis based on facts elicited during the examination, and concluding with a prognosis. The prognoses are in three standard forms: injuries that are treatable, those of uncertain outcome that the *swnw* will try to treat anyway, and those that are unlikely to respond to any treatment, such as depressed skull fractures and compound fractures. The latter prognosis usually leads to the recommendation that nature be allowed to take its course.

Ancient Egyptian surgery provided simple, practical solutions to a number of self-evident problems. Today, most of it would be called "minor surgery," such as incising and draining abscesses, removing superficial wens, tumors, and so on. Circumcision was practiced on adolescent boys, but by priests, not physicians. The *swnw* did not perform major operations such as amputations, although he did try to reduce simple fractures and dislocations. Penetrating wounds were drained and cleaned. The *swnw* used adhesive plasters, not sutures, to hold wound edges together.

He differentiated between "diseased," or infected, wounds, and "nondiseased" wounds, which we would call "clean." The Smith Papyrus recommends daily inspections so that dressings can be changed when necessary. Many wound ointments were made with honey or the green copper ore malachite. Recent experiments have shown that both substances could have been effective against the kinds of bacteria most often found in contaminated wounds, permitting them to begin healing of their own accord.

When it came to what we now call internal medicine, magicians and healing priests relied largely on spells and incantations to cure their patients, and on amulets, written spells, and repulsive materials like animal feces to drive away or prevent illness. Sometimes they relied on healing statues standing in sacred ponds, so that patients who bathed in the same water would be cured by the god to whom the statue was dedicated. Late in pharaonic history, a patient might be instructed to sleep in a temple, expecting that its god would send him a dream that would reveal his cure, a procedure called "incubation."

The *swnw* might not have understood the underlying pathology of nonsurgical illness, but he had a logical, even if speculative, theory of disease. According to the medical historian Henry Sigerist, "Physiology began when man tried to correlate the action of food, air, and blood." The Egyptians saw the heart as the focal point of that correlation. It was the body's most important organ, and the seat of intelligence and emotion.

The *swnw*, who knew that air is vital to life, thought that it passed through the trachea to both the heart and the lungs. From the heart it traveled, in blood and along with other fluids, to other organs in primary afferent ducts called *metu*. From those organs a series of secondary *metu*, or efferent ducts, led to the surface of the body. The body's secretions and excretions, including phlegm, tears, semen, urine, and even a little blood, escaped through that second set of *metu*. This concept permitted the *swnw* to exploit a fairly plausible theory of disease. He could accept the *metu* as fact chiefly because Egyptians could not differentiate arteries, veins, nerves, and tendons anatomically. They thought that all of them were hollow *metu* that transported disease, in the form of a foul substance called *ukhedu*, to various organs, depending on how many *metu*, and which ones, were involved.

Because decay and foul odor characterize both normal feces and death, the potentially fatal *ukhedu* was thought to originate in the feces as the residue of incompletely digested food. Indeed, postmortem putrefaction is most noticeable in the intestines. Thus, if any *ukhedu* were allowed to accumulate to overflowing within the intestines, the excess would overflow up into the *metu* that normally carry blood from the heart to the intestines, so that the excess traveled backward to the heart. From there it could then enter other primary or secondary *metu* and be carried to other organs. Once it had entered a given *metu*, the *ukhedu* in that vessel could destroy the blood in it, producing pus. When it reached other organs, the pus would settle in and produce disease in them. Thus, the appearance of pus on the surface of a wound was a favorable prognostic sign, inasmuch as it signified that it was escaping and not accumulating within the body. Many treatments were designed to help *ukhedu* escape from the body. For instance, because boils were obviously filled with pus, they were opened so that the dangerous *ukhedu* could escape. Similarly, the standard wound ointments made with malachite or honey would counteract *ukhedu* that surfaced in a wound.

Egyptian drugs included many animal parts. Almost no clinical selectivity was associated with any of them, although ostrich eggs were used somewhat selectively in diarrhea remedies. Most of the animal products used in drugs, such as fat and grease, were used principally as emollients in wound ointments. In addition, the blood of several species was thought to be modestly selective for hair problems and eye trauma. But most animal parts used in drugs were included chiefly because of their magical associations. For instance, since ravens are black, their blood was used to treat the Egyptians' black hair; stallion semen was used to restore sexual drive; and fish skulls appear in headache remedies.

By contrast, the majority of drugs recommended in the Ebers Papyrus was aimed at disorders of the gastrointestinal tract, followed by remedies for the eyes, limbs, and skin. The *swnw* classified accumulations of *ukhedu* in the *metu*-ducts as gastrointestinal disorders, because the *ukhedu* originated in the alimentary canal. Thus, cathartics were usually prescribed to help flush *ukhedu* out of the rectum before it could accumulate to dangerous levels. Although some remedies for disturbances within the *metu* or the intestines do promote bowel movements, many laxative or cathartic drugs were used to treat nonintestinal symptoms. For instance, the mild laxative aloe was sometimes prescribed for eye disease, and the strong laxative colocynth for respiratory ailments. Thus, it seems likely that the *swnw* thought that all cathartics were at least somewhat selective for removing *ukhedu* from both the rectum and the *metu* which distributed it in the body.

Constipation implied that accumulated *ukhedu* could not escape by its usual route through the anus. Indeed, an Egyptian might take strong laxatives 3 days a month just to prevent *ukhedu* from filling up, and overflowing from, his rectum into his *metu*, whence it might reach his heart. Although diarrhea was a frequent complaint, sometimes it was not treated at all, because plentiful stools implied that the bowels were being adequately emptied of the dangerous *ukhedu*.

Honey, the most popular of all drug ingredients mentioned in the papyri, was used not only in wound ointments, but also in both laxatives and antidiarrheals, and in many other remedies. Since it was not used for any one kind of clinical problem more often than another, we can infer that honey was not used very selectively for symptoms associated with any particular organ system. Honey was probably regarded as selective for the *ukhedu*, especially when it appeared in wounds as pus.

The next most frequently used drug was called *djaret*. The word has not yet been convincingly translated, but it was clearly a plant product. Because it appears in about half of all prescriptions for diarrhea, *djaret* was probably thought to have some selectivity for that problem. In addition, it was included in a third of the prescriptions for eye diseases, and may have been thought to be at least modestly selective for them. However, whatever it was, *djaret* was also prescribed for many other disorders, so it must have been regarded as a multipurpose drug, even if as not as a panacea. Frankincense, too, was often prescribed for many illnesses, but it was aimed most selectively at pains of the head and limbs, and less often at intestinal problems. Like the mysterious *djaret*, an antimony ore was applied to eye problems.

The next most frequently used ingredients were applied fairly nonselectively, although some were often used in both laxative and antidiarrheal mixtures. The pulp of the colocynth gourd is a very powerful cathartic that was also used for the latter purpose. Figs were used for abdominal pains and urinary disorders. Malachite was aimed at eye problems; it could not be taken internally because copper salts cause vomiting. It probably first entered medical usage as a topical ointment after long usage as an eye cosmetic. The author of the Ebers Papyrus knew about the laxative property of castor oil, but he included it in only a very few recipes for cathartics; he thought it was better suited for making women's hair grow. Like many other Egyptian remedies, it, too, survived in Western medical usage until well into this century, but as a cathartic, not as a hair restorer. However, most of the 328 different drug ingredients mentioned in the Ebers Papyrus were used for almost any illness.

Although Egyptian physicians prescribed a wide variety of remedies, they appear merely to have dispensed predetermined remedies to patients with similar ailments; the *swnw* seems not to have treated each patient as an individual. That concept would not be introduced until Greek medicine began to flourish in the fifth century BCE. There is no evidence that any of the *swnw*'s remedies, save for malachite and honey, when applied topically, had any truly beneficial effect on the outcome of ancient patients' illnesses, nor is there any modern reason to think so. Although they may not have known it, ancient physicians were able to rely on their drugs, and even on their magical spells, because of the body's impressive ability to use mechanisms such as the immune and inflammatory responses to heal itself of most ordinary ailments. By contrast, Egyptian surgery probably did provide reasonably effective treatments for many traumatic injuries.

References

Bardinet, T. (1997). Les médecins dans la société égyptienne à l'époque des pharaons: mythe et réalité. *Medicina nei Secoli, 9*(2), 177–188.

Breasted, J. H. (1930). *The Edwin Smith surgical papyrus* (2 vols.). Chicago: University of Chicago Press.

Cuenca-Estrella, M., & Martín, R. B. (2004). *La Medicina En El Antiguo Egipto*. Madrid, Spain: Alderabán Ediciones.

Daglio, C. (1998). *La Medicina Dei Faraoni: Malattie, Ricette e Superstizioni Dalla Farmacopea Egizia*. Torino, Italy: Ananke.

Ebbell, B. (Ed.). (1937). *The papyrus ebers*. London: Oxford University Press.

Estes, J. W. (1993). *The medical skills of ancient egypt* (Rev. ed.). Canton, MA: Science History Publications.

Győry, H. (2002). Medicina Theroretica Aegyptiorum. *Orvostörténeti közlemények, 178*, 45–73.

Halioua, B., & Ziskind, B. (2005). *Medicine in the days of the Pharaohs*. Cambridge, MA: Belknap Press of Harvard University Press.

Harris, J. E., & Wente, E. F. (Eds.). (1980). *An x-ray atlas of the royal mummies*. Chicago: University of Chicago Press.

Leake, C. D. (1952). *The old Egyptian medical papyri*. Lawrence, KS: University of Kansas Press.

Leca, A.-. P. (1971). *La Médecine Egyptienne au Temps des Pharaons*. Paris: Éditions Roger Dacosta.

Leospo, E. (2000). Medicina e Magia Nell'Antico Egitto. *Il Bene e Il Bello*, 13–8.

Lippi, D. (1996). Les Papyrus médicaux de l'Egypte Pharaonique. *Medicina nei Secoli, 8*(1), 145–147.

Littman, R. J. (1996). Medicine in Alexandria. In W. Haase (Ed.), *Aufsteig und Niedergang der römischen Welt* (Teil II, Band 37, pp. 2678–2708). Berlin, Germany: de Gruyter.

Majno, G. (1992). *The healing hand: Man and wound in the ancient world* (2nd ed., pp. 69–140). Cambridge, MA: Harvard University Press.

Marganne, M.-H. (2002). L'"école médicale" d'Alexandrie et son Influence sur la médecine de l'égypte Gréco-Romaine. *Medicina nei secoli, 14*(2), 359–382.

Russell, T. G., & Russell, T. M. (2003). Medicine in Egypt at the time of Napoleon Bonaparte. *British Medical Journal (General practice ed.), 327*(7429), 1461–1464.

Selin, H., et al. (2003). *Medicine across cultures: History and practice of medicine in non-Western cultures*. Dordrecht, Netherlands: Kluwer.

Sigerist, H. E. (1991). *A history of medicine. Vol. 1. Primitive and archaic medicine* (pp. 217–373). New York: Oxford University Press.

Ancient Indian Square Roots

David H. Bailey[1] and Jonathan M. Borwein[2]
[1]University of California, Davis, Department of Computer Science, Davis, CA, USA
[2]CARMA Priority Research Centre, University of Newcastle, Callaghan, NSW, Australia

Introduction

Our modern system of positional decimal notation with zero, together with efficient algorithms for computation, which were discovered in India some time prior to 500 CE, certainly must rank among the most significant achievements of all time. And it was not easy. As Pierre-Simon Laplace (1923) explained, “the difficulty of inventing it will be better appreciated if we consider that it escaped the genius of Archimedes and Apollonius, two of the greatest men of antiquity” (pp. 222–223).

The Mayans came close, with a system that featured positional notation with zero. However, in their system successive positions represented the mixed sequence (1, 20, 360, 7,200, 144,000, . . .), rather than the purely base-20 sequence (1, 20, 400, 8,000, 160,000, . . .), which precluded any possibility that their numerals could be used as part of a highly efficient arithmetic system (Ifrah, 2000, p. 311).

What is more, mathematicians in ancient India developed remarkably advanced schemes, at a very early era, for computing square roots. This entry summarizes these schemes. It is based on an earlier study by the present authors, to which readers are referred for additional details (2012).

The Discovery of Positional Arithmetic

The original discovery of positional decimal arithmetic is, sadly, unknown. The earliest known physical evidence, using single-character Brahmi numerals (which are the ancestors of our modern digits), is an inscription of the date 346 on a copper plate, which corresponds to 595 CE (Chrisomalis, 2010, p. 196). But there are numerous passages of more ancient texts that suggest that both the concept and the practice of positional decimal numeration were known much earlier (Plofker, 2009, p. 122).

For example, a fifth-century text includes the passage “Just as a line in the hundreds place [means] a hundred, in the tens place ten, and one in the ones place, so one and the same woman is called mother, daughter, and sister [by different people]” (Plofker, 2009, p. 46). Similarly, in 499 CE the Indian mathematician Ārayabhaṭa wrote, “The numbers one, ten, hundred, thousand, ten thousand, hundred thousand, million, ten million, hundred million, and billion are from place to place each ten times the preceding” (Clark, 1930, p. 21).

These early texts did not use Brahmi numerals, but instead used the Sanskrit words for the digits one through nine and zero, or, when needed to match the meter of the verse, used one of a set of literary words (known as “word-symbols”) associated with digits. For example, the medieval Indian manuscript *Sūryasiddhānta* included the verse, “The apsids of the moon in a cosmic cycle are: fire; vacuum; horsemen; vast; serpent; ocean.” Here the last six words are word-symbols for 3, 0, 2, 8, 8, 4, respectively (meaning the decimal number 488,203, since the order is reversed) (Ifrah, 2000, p. 411).

The most ancient Indian documents are more recent copies, so that we cannot be absolutely certain of their ancient authenticity. But one manuscript whose ancient authenticity cannot be denied is the *Lokavibhāga* (“Parts of the Universe”). This has numerous large numbers in positional decimal notation (using Sanskrit names or word-symbols for the digits) and detailed calculations (Siddhanta-Shastri, 1962, pp. 70, 79, 131). Near the end of the *Lokavibhāga*, the author provides some astronomical observations that enable modern scholars to determine, in two independent ways, that this text was written on 25 August 458 CE (Julian calendar). The text also mentions that it was written in the 22nd year of the reign of Simhavarman, which also confirms the 458 CE date (Ifrah, 2000, p. 417).

One even earlier source of positional word-symbols is the mid-third-century CE text *Yavanajātaka*, whose final verse reads, "There was a wise king named Sphujidhvaja who made this [work] with four thousand [verses] in the Indravajra meter, appearing in the year Visnu; hook-sign; moon." The three word-symbols, "Visnu," "hook sign," and "moon," mean 1, 9, and 1, signifying year 191 of the Saka era, which corresponds to 270 CE (Plofker, 2009, p. 47).

The earliest record of zero may be in the *Chandahsūtra*, dated to the second or third century BCE. Here we see the solution to a mathematical problem relating to the set of all possible meters for multi-syllable verse, which involves the expression of integers using a form of binary notation (Plofker, 2009, p. 55). The very earliest origin of the notion of positional decimal notation and arithmetic, however, is still obscure; it may be connected to the ancient Chinese "rod calculus" (Plofker, p. 48).

Ārayabhaṭa's Square Root and Cube Root

One person who deserves at least some credit for the proliferation of decimal arithmetic calculation is the Indian mathematician Ārayabhaṭa, mentioned above (see Fig. 1). He devised ingenious digit-by-digit algorithms for computing square roots and cube roots, as given (tersely) in his 499 CE work *Āryabhaṭīya* (Clark, 1930, pp. 24–26). These schemes were used, with only minor variations, by Indian mathematicians such as Siddhasena Gani (~550 CE), Bhāskara I (~600 CE), Śrīdhara (~750 CE), and Bhāskara II (~1,150 CE), as well as by numerous later Arabic and European mathematicians (Datta & Singh, 1962, I, pp. 170–175).

Ancient Indian Square Roots, Fig. 1 Statue of Ārayabhaṭa on the grounds of IUCAA, Pune, India (no one knows what Ārayabhaṭa actually looked like) (Courtesy of Wikimedia)

The Bakhshālī Manuscript

Another ancient source that clearly exhibits considerable familiarity with decimal arithmetic in general and square roots in particular is the Bakhshālī manuscript. This ancient mathematical treatise was found in 1881 in the village of Bakhshālī, approximately 80 km northeast of Peshawar. Among the topics covered in this document, at least in the fragments that have been recovered, are solutions of systems of linear equations, indeterminate (Diophantine) equations of the second degree, arithmetic progressions of various types, and rational approximations of square roots. The manuscript appears to be a commentary on an even earlier work (Hayashi, 1995, pp. 86, 148).

Ever since its discovery in 1881, scholars have debated its age. Some, like British scholar G. R. Kaye, assigned the manuscript to the twelfth century, in part because he believed that its mathematical content was derivative from Greek sources. Others, such as Rudolf Hoernle, assigned the underlying manuscript to the "3rd or 4th century CE" (Hoernle, 1887, p. 9). In the most recent analysis, Takao Hayashi assigned the commentary to the seventh century, with the underlying original not much older (1995, p. 149).

The Bakhshālī Square Root

One particularly intriguing item in the Bakhshālī manuscript is the following algorithm for computing square roots:

> [1:] In the case of a non-square [number], subtract the nearest square number; divide the remainder by twice [the root of that number]. [2:] Half the square of that [that is, the fraction just obtained] is divided by the sum of the root and the fraction and subtract [from the sum]. [3:] [The non-square number is] less [than the square of the approximation] by the square [of the last term]. (Translation is due to Datta (1929), except last sentence is due to Hayashi (1995, p. 431).)

The Bakhshālī Square Root in Modern Notation

In modern notation, this algorithm is as follows. To obtain the square root of a number q, start with an approximation x_0 and then calculate, for $n \geq 0$:

$$a_n = \frac{q - x_n^2}{2x_n} \qquad \text{(sentence \#1 above)}$$

$$x_{n+1} = x_n + a_n - \frac{a_n^2}{2(x_n + a_n)} \qquad \text{(sentence \#2 above)}$$

$$q = x_{n+1}^2 - \left[\frac{a_n^2}{2(x_n + a_n)}\right]^2. \qquad \text{(sentence \#3 above)}$$

The last line is merely a check; it is not an essential part of the calculation. In the examples presented in the Bakhshālī manuscript, this algorithm is used to obtain rational approximations to square roots only for integer arguments q, only for integer-valued starting values x_0, and is only applied once in each case (i.e., it is not iterated). But from a modern perspective, the scheme clearly can be repeated and in fact converges very rapidly to $\sqrt{q}$, as we shall see in the next section.

Here is one application in the Bakhshālī manuscript (Hayashi, 1995, pp. 232–233).

Problem 1 *Find an accurate rational approximation to the solution of*

$$3x^2/4 + 3x/4 = 7{,}000 \tag{1}$$

(*which arises from the manuscript's analysis of some additive series*).

Answer $x = \left(\sqrt{336{,}009} - 3\right)/6$. To calculate an accurate value for $\sqrt{336{,}009}$, start with the approximation $x_0 = 579$. Note that $q = 336{,}009 = 579^2 + 768$. Then calculate as follows (using modern notation):

$$\begin{aligned} a_0 &= \frac{q - x_0^2}{2x_0} = \frac{768}{1{,}158}, \\ x_0 + a_0 &= 579 + \frac{768}{1{,}158}, \\ \frac{a_0^2}{2(x_0 + a_0)} &= \frac{294{,}912}{777{,}307{,}500}. \end{aligned} \tag{2}$$

Thus, we obtain the refined root

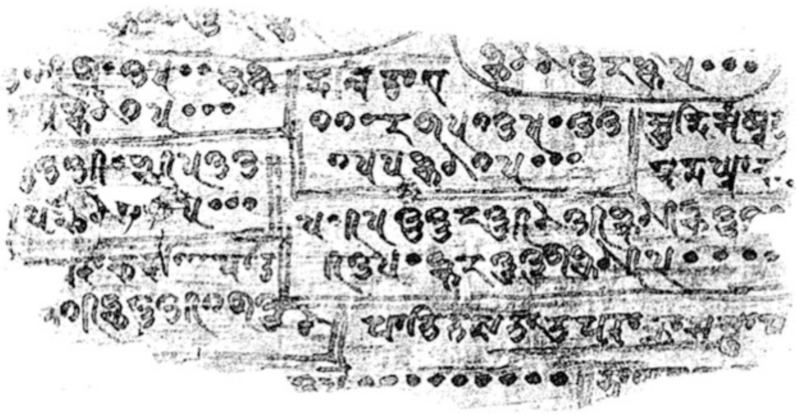
$$\begin{aligned} x_1 &= x_0 + a_0 - \frac{a_0^2}{2(x_0 + a_0)} \\ &= 579 + \frac{515{,}225{,}088}{777{,}307{,}500} \\ &= \frac{450{,}576{,}267{,}588}{777{,}307{,}500} \end{aligned} \tag{3}$$

(Note: This is 579.66283303325903841..., which agrees with $\sqrt{336{,}009}$ = 579.66283303313487498... to 12-significant-digit accuracy). The manuscript then performs a calculation to check that the original quadratic equation is satisfied. It obtains, for the left-hand side of Eq. 1,

$$\frac{50{,}753{,}383{,}762{,}746{,}743{,}271{,}936}{7{,}250{,}483{,}394{,}675{,}000{,}000}, \tag{4}$$

which, after subtracting the correction

$$\frac{21{,}743{,}271{,}936}{7{,}250{,}483{,}394{,}675{,}000{,}000}, \tag{5}$$



Ancient Indian Square Roots, Fig. 2 Fragment of Bakhshālī manuscript with a portion of the square root calculation mentioned in Problem 1. For example, the large right-middle section corresponds to the fraction $\frac{50,753,383,762,746,743,271,936}{7,250,483,394,675,000,000}$ in Formula (4) (Graphic from Hayashi, 1995, p. 574)

gives,

$$\frac{50,753,383,762,725,000,000,000}{7,250,483,394,675,000,000} = 7,000. \tag{6}$$

Each of the integers and fractions shown in the above calculation (except the denominator of Eq. 5, which is implied) actually appears in the Bakhshālī manuscript, although some of the individual digits are missing at the edges – see Fig. 2. The digits are written left to right, and fractions are written as one integer directly over another (although there is no division bar). Zeroes are denoted by large dots. Other digits may be recognized by those familiar with ancient Indian languages.

Convergence of the Bakhshālī Square Root

Note, in the above example, that starting with the 3-digit approximation 579, one obtains, after a single application of the algorithm, a value for $\sqrt{336,009}$ that is correct to 12 significant digits. From a modern perspective, this happens because the Bakhshālī square root algorithm is *quartically convergent* – each iteration approximately quadruples the number of correct digits in the result, provided that sufficiently accurate arithmetic is used (although there is no indication of the algorithm being iterated more than once in the manuscript itself) (Bailey & Borwein, 2012).

An Even More Ancient Square Root

There are instances of highly accurate square roots in Indian sources that are even more ancient than the Bakhshālī manuscript. For example, Srinivasiengar noted that the ancient Jain work *Jambūdvīpa-prajñapti* (~300 BCE), after erroneously assuming that $\pi = \sqrt{10}$, asserts that the "circumference" of a circle of diameter 100,000 *yōjana* is 316,227 *yōjana* + 3 *gavyūti* + 128 *dhanu* + 13½ angula, "and a little over" (1967, pp. 21–22). Datta added that this statement is also seen in the *Jībāhigama-sūtra* (~200 BCE) (1929, p. 43), while Joseph noted that it seen in the *Anuyoga-dvāra-sūtra* (~0 CE) and the *Trilokosara* (~0 CE) (2010, p. 356).

According to one commonly used ancient convention, these units are 1 *yōjana* = 14 km (approximately); 4 *gavyūti* = 1 *yōjana*; 2000 *dhanu* = 1 *gavyūti*; and 96 *angula* = 1 *dhanu* (Joseph, 2010, p. 356). Converting these units to *yōjana*, we conclude that the "circumference" is $316227.766017578125\ldots$*yōjana*. This agrees with $100,000\sqrt{10} = 316227.766016837933\ldots$ to 12-significant-digit accuracy!

What algorithm did these ancient scholars employ to compute square roots? The present authors conclude, based on a detailed analysis, that the most reasonable conclusion is that the Indian mathematician(s) who published the above did some preliminary computation to obtain the approximation 316,227; then used one Heron iteration (i. e., $x_{n+1} = (x_n + q/x_n)/2$), which was known in ancient times in Greece and elsewhere to compute an approximate fractional value; and then converted the final result to the length units above (2012). Evidently the Bakhshālī formula had not yet been developed.

Note that just to perform one Heron iteration, with starting value 316,227, one would need to perform at least the following rather demanding calculation:

$$\begin{aligned} x_1 &= \frac{1}{2}\left(x_0 + \frac{q}{x_0}\right) \\ &= \frac{1}{2}\left(316,227 + \frac{100,000,000,000}{316,227}\right) \\ &= \frac{1}{2}\left(\frac{316,227^2 + 100,000,000,000}{316,227}\right) \\ &= \frac{99,999,515,529 + 100,000,000,000}{2 \times 316,227} \\ &= \frac{199,999,515,529}{632,454} \\ &= 316,227 + \frac{484,471}{632,454}, \end{aligned} \tag{7}$$

followed by several additional steps to convert the result to the given units. By any reasonable standard, this is a rather impressive computation for such an ancient vintage (200–300 BCE). Numerous other examples of prodigious computations in various ancient Indian sources are mentioned by Datta and Singh (1962), Joseph (2010), Plofker (2009), and Srinivasiengar (1967). Although some impressive calculations are also seen in ancient Mesopotamia, Greece, and China, as far as we are aware, there are more of these prodigious calculations in ancient Indian literature than in other ancient sources.

In any event, it is clear that ancient Indian mathematicians, roughly contemporaneous with Greeks such as Euclid and Archimedes, had command of a rather powerful system of arithmetic, possibly some variation of the Chinese "rod calculus" or perhaps even some primitive version of decimal arithmetic.

Controversies

In spite of these discoveries, we should caution that there is a tendency among some ethnomathematicians to optimistically ascribe independent or prior discovery to various Indian sources, such as the Vedas (a collection pre-Christian-Era texts) and the Kerala school (a group of mathematicians writing from the fourteenth to sixteenth centuries). For example, while Kerala mathematicians appear to have found the Gregory series for the arctangent and computed π to 12-digit accuracy, nonetheless they did not formulate any systematic theory of calculus, nor is there any evidence that they transmitted their findings outside the school (Plofker, 2009, p. 253).

Conclusion

The discovery of positional decimal arithmetic with zero, together with efficient algorithms for computation, by unknown Indian mathematicians, certainly by 500 CE and probably several centuries earlier, is a mathematical development of the first magnitude. And the schemes they developed for computing square roots are also quite remarkable for this era.

It should be noted that these ancient Indian mathematicians missed some key points. For one thing, the notion of decimal fraction notation eluded them and everyone else until the tenth century, when a rudimentary form was seen in the writings of the Arabic mathematician al-Uqlidisi, and in the twelfth century, when al-Samaw'al illustrated its use in division and root extraction (Joseph, 2010, p. 468). Also, as mentioned above, there is no indication that Indian mathematicians iterated algorithms for finding roots.

Aside from historical interest, does any of this matter? As historian Kim Plofker notes, in ancient Indian mathematics, "True perception, reasoning, and authority were expected to harmonize with one another, and each had a part in supporting the truth of mathematics" (Plofker, 2009, p. 12). As she neatly puts it, mathematics was not "an epistemologically privileged subject." Similarly, mathematical historian George G. Joseph writes, "A Eurocentric approach to the history of mathematics is intimately connected with the dominant view of mathematics … as a deductive system." In contrast, as Joseph continues, "[s]ome of the most impressive work in Indian and Chinese mathematics … involve computations and visual demonstrations that were not formulated with reference to any formal deductive system" (Joseph, 2010, p. xiii).

In short, the Greek heritage that underlies much of Western mathematics may have unduly predisposed many of us against experimental approaches that are now facilitated by the availability of powerful computer technology. Thus, a renewed exposure to non-Western traditions may lead to new insights and results and may clarify the age-old issue of the relationship between mathematics as a language of science and technology and mathematics as a supreme human intellectual discipline.

References

Bailey, D. H., & Borwein, J. M. (2012). Ancient Indian square roots: An exercise in forensic paleo-mathematics. *American Mathematical Monthly, 119*, 646–657.

Chrisomalis, S. (2010). *Numerical notation: A comparative history*. Cambridge, UK: Cambridge University Press.

Clark, W. C. (1930). *The Āryabhaṭīya of Āryabhaṭa: An Ancient Indian work on mathematics and astronomy* (Translation and commentary). Chicago: University of Chicago Press.

Datta, B. (1929). The Bakhshālī mathematics. *Bulletin of the Calcutta Mathematical Society, 21*, 1–60.

Datta, B., & Singh, A. N. (1962). *History of Hindu mathematics* (Vols. I–II). Delhi, India: Bharatiya Kala Prakashan. (Reprinted 2004)

Hayashi, T. (1995). *The Bakhshālī manuscript: An ancient Indian mathematical treatise*. Amsterdam: John Benjamins.

Hoernle, R. (1887). *On the Bakhshālī manuscript*. Vienna: Alfred Holder.

Ifrah, G. (2000). *The Universal history of numbers: From prehistory to the invention of the computer* (D. Bellos, Harding, E. F., Wood S., & Monk, I., Trans.). New York: Wiley.

Joseph, G. G. (2010). *The crest of the peacock: Non-European roots of mathematics*. Princeton, NJ: Princeton University Press.

Laplace, P. S. (1923). *The system of the World* (Vol. 2; H. H. Harte, Trans.). Charleston, SC: Nabu Press. (Reprinted 2010)

Plofker, K. (2009). *Mathematics in India*. Princeton, NJ: Princeton University Press.

Siddhanta-Shastri, B. (1962). *Lokavibhāga* (Translation to Hindi and commentary). Sholapur, India: Gulabchand Hirachand Doshi.

Srinivasiengar, C. N. (1967). *The history of Ancient Indian mathematics*. Calcutta, India: World Press.

Ancient Jewelry in Turkey

Thomas Zimmermann
Department of Archaeology, Bilkent University, Ankara, Turkey

Early Evidence (ca. 40,000–10,000 BCE)

The skillful manufacture of jewelry items using a huge variety of different materials has a long and eventful history in Ancient Turkey, making it a fascinating arena for studying ancient craftsmanship at large. Shell beads dated as early as the beginning of the Upper Paleolithic (ca. 40,000 BP) are reported from the Üçağızlı Cave (Kuhn, Stiner, Reese, & Erksin, 2001, p. 7641); marine shell beads used as ornaments are likewise known from funeral contexts at the Epipaleolithic site of Pınarbaşı in Central Anatolia (Baird, 2012; Fig. 1). The presence of maritime shell specimens in inland sites further testifies to trade and exchange contacts established with communities residing along the Mediterranean littoral (Baysal, 2013).

Neolithic Advances (ca. 10,000–5,000 BCE)

With the beginning of the Holocene about 12,000 years ago, the first sedentary communities

Ancient Jewelry in Turkey, Fig. 1 Dentalia and shell beads from Pınarbaşı, Central Turkey (After Baird, 2012)

appear, struggling to succeed in this radical new lifestyle and the risky demands of agriculture and animal husbandry. The southeast of Turkey as the northern extent of the Fertile Crescent becomes a dynamic catchment for the versatile application of different raw materials and jewelry-making techniques: stone, bone, shell, and malachite beads are proficiently manufactured in huge numbers and a considerable variety of shapes in the Aceramic Neolithic (tenth to eighth millennium BCE) (Erim-Özdoğan, 2011; Fig. 2). Of particular importance is the combination of different working materials, such as Mediterranean shells with traces of inlayed Malachite from the Pre-pottery Neolithic levels of Çayönü, and more especially the utilization of cold-hammered and annealed (heated, but not smelted) copper as a new working material for bead and pendant making (Fig. 3). Larger jewelry objects include rather coarse limestone fragments allegedly used as rings or bracelets (e.g., from Akarçay Tepe, Şanlıurfa, and Southeast Turkey) (Özbaşaran & Duru, 2011, p. 176; Fig. 4) but also beautifully polished, flawlessly shaped marble bracelets from Cafer Höyük (Malatya, Southeast Turkey) (Cauvin, Aurenche, Cauvin, & Balkan-Atlı, 2011, p. 12; Fig. 5).

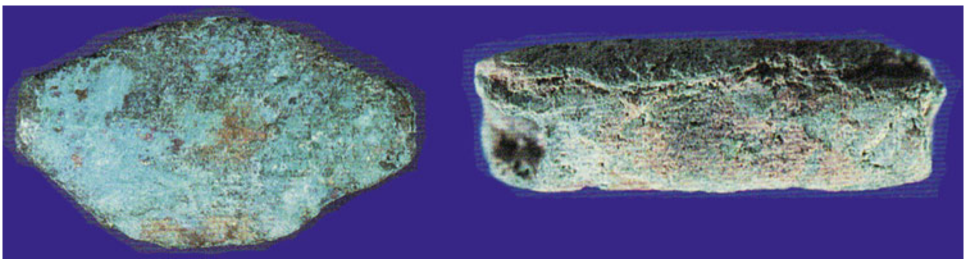
The pioneering use of cold- and hot-worked copper can also be observed at the Central Anatolian Aceramic site of Aşıklı Höyük (ca. 8,500–7,400 BCE): several tubular and biconical copper beads, predominantly retrieved from intramural burials, were not necessarily exclusive funeral gifts but rather personal ornaments of individuals (Fig. 6). Noteworthy in terms of applied working techniques are two different ways of making copper jewelry at the site: beads were either made from thin sheets of copper, which was rolled or twisted to finalize the desired shape, or hammered from a lump of solid copper and then pierced with a hot awl-type instrument (Özbaşaran, 2012, p. 142). Copper aside, red limestone and different types of chalcedony count among the most prominent raw materials for jewelry making (Fig. 7).

Unabated creativity and further specialization in shaping and combining different working materials such as stone, bone, and copper for making beads and pendants are plainly visible also in the succeeding centuries, when pottery started to be produced on a regular scale. Excavations at the internationally famous site of Çatalhöyük in the Konya plain (Southern Central Anatolia) have produced a huge variety in ornaments produced and consumed there (recently Bains (2012)). More exciting in this regard is Köşk Höyük (Niğde, Central Anatolia, ca. 6,500–5,500 BCE) from whence comes the inventory of a jewelry workshop with beads in different shapes and sizes and various bone tools for scraping, cutting, and drilling (Öztan, 2012, pp. 34–35; Fig. 8).

Technological Breakthroughs (Chalcolithic and Early Bronze Age, ca. 5,000–2,000 BCE)

An epoch-making technological breakthrough that occurred about 5,000 BCE (Middle Chalcolithic) in Ancient Turkey finally paved

Ancient Jewelry in Turkey, Fig. 2 Stone beads from Çayönü, Southeast Turkey (After Erim-Özdoğan, 2011)



Ancient Jewelry in Turkey, Fig. 3 Copper beads from Çayönü, Southeast Turkey (After Erim-Özdoğan, 2011)

Ancient Jewelry in Turkey, Fig. 4 Fragments of probably limestone bracelets from Akarçay Tepe, Southeast Turkey (After Özbaşaran & Duru, 2011). Photo by T. Ülgür

the way for a new chapter in ancient craftsmanship. Extractive metallurgy, smelting copper from the ore, first successfully performed at the site of Mersin-Yumuktepe, allows for an entirely new treatment of copper and other metals, which can now be liquefied, poured, cast and recycled, reshaped, and redesigned. This technological leap impacts on jewelry making at large, since raw copper (and later also other non-precious and precious metals) is no longer worked like stone (i.e., simply hammered and sometimes heated to shape it more easily), but as a material with different physical qualities. With the advent of real metalworking, previously unseen groups of jewelry objects, first and foremost pins as dress fasteners now occur in the relevant archaeological assemblages (Fig. 9).

However, a real boost in metal production and consumption on a larger scale does not occur in Ancient Turkey before the end of the fourth millennium BCE. The rich inventory of a cist grave found in Arslantepe, Malatya (Eastern Turkey) contained beneath weapons and metal vessels and also pins, bracelets, and a large diadem with hallmarked wavy line decoration. The rather exotic alloy of evenly balanced copper and silver used for some of the items might testify to a new

Ancient Jewelry in Turkey, Fig. 5 Marble bracelets from Cafer Höyük, Southeast Turkey (After Cauvin et al., 2011)

Ancient Jewelry in Turkey, Fig. 6 Copper beads and pierced deer teeth from burial context at Aşıklı Höyük, Central Turkey (After Özbaşaran, 2012)

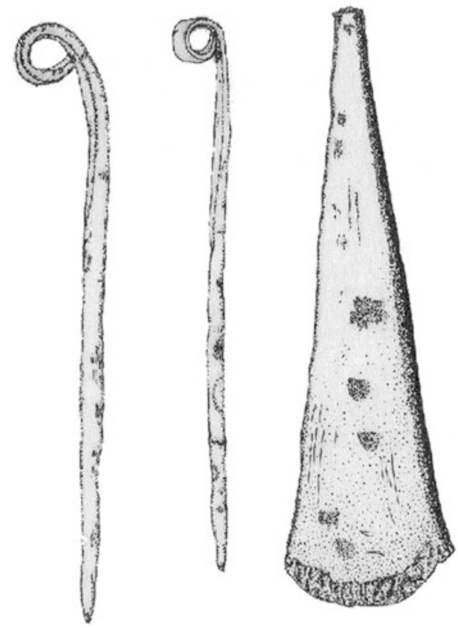
(Trans)caucasian jigsaw piece within the cultural mosaic of Late Chalcolithic (Eastern) Anatolia (Frangipane, 2001) (Fig. 10).

The next apogee in crafting ornaments occurs towards the mid-third millennium BCE (Early Bronze Age II–III). This is also the time when early jewelry making had one of its finest periods – best reflected in the prominent treasure finds from the Troia citadel (Çanakkale, NW Turkey). These treasure complexes – the largest one coined "Priam's treasure" in a pseudo-historic fashion by Heinrich Schliemann – are, despite their obscure and much debated history of retrieval, considered genuine by most archaeologists (Easton, 1984; Easton, 1994; Sazcı, 2007; *contra* Traill, 1984, 2000). These assemblages, some of them probably unnoticed grave gifts, are composed of a breathtaking variety of objects and materials, ranging from lapis lazuli axes and large bronze omphalos plates to tiny beads, chain links, and metalsmith's equipment, including magnifying lenses and prefabricated gold ingots (Fig. 11). Outstanding are especially the earrings and head ornaments that combine different advanced gold-working techniques, for example, granulation and loop-in-loop fabrication of chains (Fig. 12), a group of material well known and perpetualized by the iconic image of Schliemann's second wife Sophia Engastromenos, wearing Troian jewelry with a weary facial expression (Fig. 13). Since no potential forerunners for such exquisite jewelry are attested in the region, the hypothesis of highly skilled itinerant artisans, presumably trained in Mesopotamia and hired by the thriving local elites, has gained widespread academic consensus (Tolstikov & Trejster, 1996; Treister, 2002; Figs. 14 and 15). Equally skillfully crafted jewelry is also known from other early centers as at Alaca Höyük (as burial gifts) (Fig. 16) and Eskiyapar (as one of the very few secure hoards in pre-Classical Anatolia) (Fig. 17). However, smaller rural settlements have also produced evidence for beautifully manufactured ornaments and where even the custom of combining silver

Ancient Jewelry in Turkey, Fig. 7 Chalcedony and red limestone beads from Aşıklı Höyük, Central Turkey (After Özbaşaran, 2012)

Ancient Jewelry in Turkey, Fig. 8 Stone beads and stonework tools from jewelry workshop at Köşk Höyük, Central Anatolia (After Öztan, 2012)

and copper attested much earlier at the end of the fourth/beginning of the third millennium BCE (cf. supra) resounds in selected inventories (Fig. 18).



Ancient Jewelry in Turkey, Fig. 9 Earliest cast metal items (flat ax or chisel and pin) from Mersin-Yumuktepe, Southeast Turkey, layer 16 (ca. 5,000 BCE) (After Yalçın, 2008)

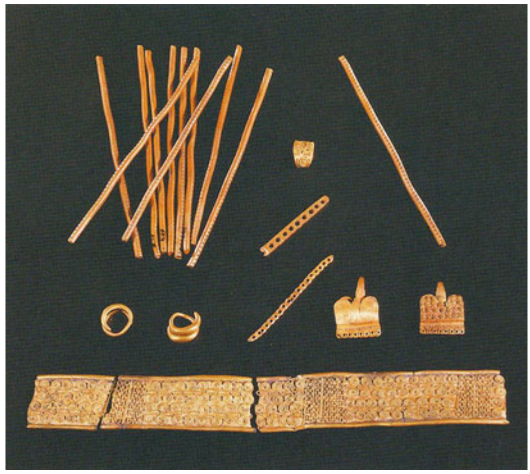
The Historical Periods (Middle Bronze to Iron Age, ca. 2,000/1,950–547 BCE)

The beginning of the second millennium BCE marks the advent of history in Ancient Turkey. Assyrian merchants, traversing the Taurus mountain ridge to establish trading posts (*karums*) in Anatolia, bring not only clothing and other much demanded luxury goods but also literacy with them. Many thousands of cuneiform tablets, most of them retrieved from the major Assyrian trade center known as the Karum Kanesh at Kültepe/Nesha (Kayseri, Central Anatolia), give an unprecedented idea of a flourishing economy, based on the trade of metals and garments, being of mutual benefit for the Old Assyrian traders and

Ancient Jewelry in Turkey, Fig. 10 Copper-silver bracelets, rings, and quadruple spiral headed pins from Arslantepe, Eastern Turkey (After Frangipane, 2001). Photos by R. Ceccaci, Arslantepe Archive, Sapienza University of Rome

the indigenous Anatolian populations alike. The production and consumption of exquisite jewelry, now also mentioned in written texts to complement the sparse archaeological evidence, was most certainly enough an indispensable facet of Middle Bronze Age life in Anatolian towns, villages, and trade hubs. Known from both philological and archaeological contexts are traditional dress fasteners such as pins with varying head shapes but also a great variety of elaborate golden jewelry items, for example, granulated earrings with lapis lazuli or carnelian decoration (Özgüç, 2004, pp. 222–233; Dercksen, 2011, p. 113; Fig. 19).

From 1,650 BCE onward, the Hittites, once merely one of the many Anatolian ethnicities the Assyrians did business with, become the new masters of Anatolia, forging together an ever-growing, tightly organized empire, a politically powerful and equal rival to the Assyrian, Egyptian, and Mycenaean realms. However, much of the magnificent artwork of Hittite times,



Ancient Jewelry in Turkey, Fig. 11 Treasure "F" from Troia, Northwest Turkey, with prefabricated gold rods (possibly ingots) (After Sazcı, 2007)

including jewelry, is frequently represented not by stratified examples from regular excavations, but as finds without proper context from private or museum collections (exceptions like the pendant published in Bell (1986) or the lotus flower ornament from Ortaköy/Shapinuwa (Süel & Süel, 2008, p. 185) confirm the rule). On the other hand, cuneiform inventory lists occasionally shed some further light on Hittite types of jewelry and the materials used (Maxwell-Hyslop, 1980; Siegelova, 2008). Here it is important to note that iron was regularly used not only for weapons and tools but also jewelry production and was probably valued very highly as a material that was difficult to retrieve and even more difficult to work with. The known range of jewelry, worn by men and women alike, comprises earrings, pendants, and bracelets but also larger items as with diadems or pendants (Fig. 20).

The collapse and disintegration of the Hittite empire towards the end of the second millennium BCE in the wake of the Mediterranean and Near Eastern crisis years around 1,200 BCE followed a phase of political restructuring that reshaped Anatolia for the centuries to come. In the East, the Urartians became the new masters of the Eastern Anatolian highlands, while the Phrygians reigned in Central Anatolia, with the Lydian kingdom controlling larger parts of what is

Ancient Jewelry in Turkey, Fig. 12 Golden headdress from Troia, Northwest Turkey, Treasure "A", showing loop-in-loop fabrication of chains (After Tolstikov & Trejster, 1996)

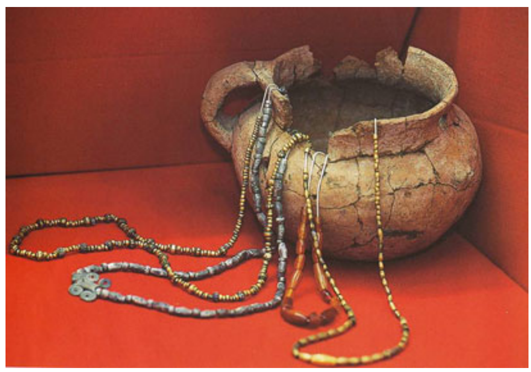
Ancient Jewelry in Turkey, Fig. 13 Schliemann's wife Sophia Engastromenos wearing Troian jewelry (After Tolstikov & Trejster, 1996)

Ancient Jewelry in Turkey, Fig. 14 Examples for Troian goldwork from Treasure "A" (After Tolstikov & Trejster, 1996)

nowadays Western Turkey. But as with the corpus of Hittite metalwork, much of the jewelry produced by these three major ruling entities of first millennium Iron Age Anatolia is known in the form of looted material on display in international museum collections, lacking any proper archaeological context. Urartian metal jewelry objects, however, betray another supreme level in crafting jewelry objects: brass as an alloy of copper and zinc is now manufactured also on a regular basis, as is iron for larger jewelry items (Figs. 21 and 22). Further to the west, with Sardis as its capital, the Lydian kingdom marks not only an influential political center for Post-Bronze Age Anatolia but also another focus of excellence in using silver-rich gold (electrum) washed out of the river Pactolus (modern Sart Çayı). This is best illustrated with the so-called Lydian treasure, a huge assemblage of goldwork and silverwork dug

Ancient Jewelry in Turkey, Fig. 15 Pins and earrings from Troia, Treasures “A” and “O” (After Tolstikov & Trejster, 1996)

Ancient Jewelry in Turkey, Fig. 16 Selected jewelry from the Alaca Höyük, Central Turkey “royal” burials (Museum of Anatolian Civilizations, Ankara)



Ancient Jewelry in Turkey, Fig. 17 Jewelry from the Eskiyapar hoard, Northeastern Central Turkey (Museum of Anatolian Civilizations, Ankara)

up illegally from several sites and trafficked abroad, which could be studied and published in detail only after its retrieval and return to Turkey (Özgen & Öztürk, 1996). Some of the masterfully executed jewelry pieces might testify to an amalgamation of Persian/Achaemenid and Eastern Greek styles, but the majority retains a genuine Lydian fashion which then became so utterly influential in Greek art (Fig. 23). As for Central Anatolia, this was under Phrygian rule, with Gordion as its capital. The so-called Midas tumulus (probably the burial place of his father Gordios) contained a splendidly furnished burial chamber, equipped with wooden furniture, banqueting equipment and especially large numbers of the characteristic bronze Phrygian fibulae, the diagnostic dress fastener of the Iron Age (Fig. 24).

Ancient Jewelry in Turkey, Fig. 18 Silver-copper-gold ring from an Early Bronze Age burial at Resuloğlu, Çorum, Central Turkey (After Zimmermann, Yıldırım, Özen, & Zararsız, 2009)

Ancient Jewelry in Turkey, Fig. 19 Gold rings with lapis lazuli and obsidian inlays from Kültepe-Karum layer Ib, Central Turkey (After Özgüç, 2004)

Ancient Jewelry in Turkey, Fig. 20 Lotus flower ornament from the Hittite city of Shapinuwa/Ortaköy, Central Turkey (After Süel & Süel, 2008)

The Persian conquest of Anatolia, with the capture of Sardis in 547 BCE, brought an end to the political rule of the indigenous Western Asiatic cultures and was in turn replaced by

Ancient Jewelry in Turkey, Fig. 21 Pins and beads from the Early Iron Age cemetery at Karagündüz, Eastern Turkey (After Sevin & Kavaklı, 1996)

Ancient Jewelry in Turkey, Fig. 22 Iron bracelets from the Early Iron Age cemetery at Karagündüz, Eastern Turkey (After Sevin & Kavaklı, 1996)

Hellenistic rule after the fourth century BCE, before gradually coming under Roman domination, a process that started in 129 BC. When these Western empires culturally superseded Ancient Turkey and made Anatolia part of the

Ancient Jewelry in Turkey, Fig. 23 Gold necklace and bracelet with glass inlays from the "Lydian treasure" complex, Western Turkey (After Özgen & Öztürk, 1996)

Ancient Jewelry in Turkey, Fig. 24 Selection of typical Phrygian bronze fibulae from Central Turkey (After Caner, 1983)

Greek-speaking world, they could draw from a deep well of marvelous technological accomplishments and excellence in workmanship, accumulated and made perfect over many millennia.

References

Bains, R. K. (2012). *The social significance of Neolithic stone bead technologies at Çatalhöyük*. Unpublished doctoral thesis, University College London, London.

Baird, D. (2012). Pınarbaşı: From Epi-paleolithic campsite to sedentarising village in Central Anatolia. In N. Başgelen (Ed.), *The Neolithic in Turkey. New excavations and new research. Central Turkey* (pp. 181–218). Istanbul, Turkey: Archaeology & Art Publications.

Baysal, E. (2013). Epipalaeolithic marine shell beads at Pınarbaşı. Central Anatolia from an Eastern Mediterranean perspective. *Anatolica, 39*, 261–276.

Bell, M. R. (1986). A Hittite pendant from Amarna. *American Journal of Archaeology, 90*, 145–151.

Caner, E. (1983). *Fibeln in Anatolien I* (Prähistorische Bronzefunde Abteilung XIV, Vol. 8). Munich, Germany: C. H. Beck.

Cauvin, J., Aurenche, O., Cauvin, M.-C., & Balkan-Atlı, N. (2011). The pre-pottery site of Cafer Höyük. In N. Başgelen (Ed.), *The Neolithic in Turkey. New excavations and new research. The Euphrates basin* (pp. 1–40). Istanbul, Turkey: Archaeology & Art Publications.

Dercksen, J. G. (2011). From ore to artefact: Metals in Kanesh. In F. Kulakoğlu & S. Kangal (Eds.), *Anatolia's prologue. Kültepe Kanesh Karum* (pp. 110–115). Istanbul, Turkey: Kayseri Metropolitan Municipality.

Easton, D. F. (1984). Priam's treasure. *Anatolian Studies, 34*, 141–169.

Easton, D. F. (1994). Priam's gold. The full story. *Anatolian Studies, 44*, 221–243.

Erim-Özdoğan, A. (2011). Çayönü. In N. Başgelen (Ed.), *The Neolithic in Turkey. New excavations and new research. The Tigris basin* (pp. 185–269). Istanbul, Turkey: Archaeology & Art Publications.

Frangipane, M. (2001). The Transition Between Two Opposing Forms of Power at Arslantepe (Malatya) at the Beginning of the 3rd Millenium. TüBA-AR, 4, 1–24.

Kuhn, S. L., Stiner, M. C., Reese, D. S., & Erksin, G. (2001). Ornaments of the earliest Upper Paleolithic. New insights from the Levant. *PNAS, 98*, 7641–7646.

Lehner, J. W., & Yener, A. (2014). Organization and specialization of early mining and metal technologies in Anatolia. In B. W. Roberts & C. P. Thornton (Eds.), *Archaeometallurgy in global perspective* (pp. 529–557). New York: Springer.

Maxwell-Hyslop, K. R. (1971). *Western Asiatic jewellery*. London: Methuen.

Maxwell-Hyslop, K. R. (1980). A note on the jewellery listed in the inventory of Manninni (CTH 504). *Anatolian Studies, 30*, 85–90.
Özbaşaran, M. (2012). Aşıklı. In N. Başgelen (Ed.), *The Neolithic in Turkey. New excavations and new research. Central Turkey* (pp. 135–158). Istanbul, Turkey: Archaeology & Art Publications.
Özbaşaran, M., & Duru, G. (2011). Akarçay Tepe. A PPNB and PN settlement in Middle Euphrates – Urfa. In N. Başgelen (Ed.), *The Neolithic in Turkey. New excavations and new research. The Euphrates basin* (pp. 165–202). Istanbul: Archaeology & Art Publications.
Özgen, I., & Öztürk, J. (1996). *The Lydian treasure. Heritage recovered*. Istanbul: Uğur Okman.
Özgüç, T. (2004). *Kültepe. Kaniš/Neša*. Istanbul: Yapı Kredi Yayınları.
Oztan, A. (2012). Köşk Höyük. A Neolithic settlement in Niğde-Bor plateau. In N. Başgelen (Ed.), *The Neolithic in Turkey. New excavations and new research. Central Turkey* (pp. 31–70). Istanbul, Turkey: Archaeology & Art Publications.
Sazcı, G. (2007). *Troia Hazineleri*. Istanbul, Turkey: Aygaz.
Sevin, V., & Kavaklı, E. (1996). *Van/ Karagündüz. An early Iron Age cemetery*. Istanbul, Turkey: Arkeoloji ve Sanat Yayınları.
Siegelova, J. (2008). Metals in Hittite records. In Ü. Yalçın, H. Özbal, & A. G. Paşamehmetoğlu (Eds.), *Ancient mining in Turkey and The Eastern Mediterranean* (pp. 43–56). Ankara, Turkey: Atilim University.
Süel, A., & Süel, M. (2008). Shapinuwa. A capital of the Hittite state. In J. Aruz, K. Benzel, & J. M. Evans (Eds.), *Beyond Babylon. Art, trade, and diplomacy in the second millennium B.C.* (pp. 184–185). New York: Yale University Press.
Tolstikov, W. P., & Trejster, M. J. (1996). *Der Schatz aus Troia. Schliemann und der Mythos des Priamos-Goldes*. Stuttgart, Germany: Belser Verlag.
Traill, D. (1984). Schliemann's discovery of Priam's treasure. A re-examination of the evidence. *Journal of Hellenic Studies, 104*, 96–115.
Traill, D. (2000). "Priam's Treasure": Clearly a composite. *Anatolian Studies, 50*, 17–35.
Treister, M. (2002). The relative and absolute chronology of the Trojan treasures. In R. Aslan, S. Blum, G. Kastl, F. Schweizer, & D. Thumm (Eds.), *Mauerschau. Festschrift für Manfred Korfmann* (pp. 245–258). Remshalden, Germany: Verlag B. Greiner.
Yalçın, Ü. (2008). Ancient metallurgy in Anatolia. In Ü. Yalçın, H. Özbal, & A. G. Paşamehmetoğlu (Eds.), *Ancient mining in Turkey and The Eastern Mediterranean* (pp. 15–40). Ankara, Turkey: Atilim University.
Zimmermann, T., Yıldırım, T., Özen, L., & Zararsız, A. (2009). "All that glitters is not gold, nor all that sparkles silver" – fresh archaeometrical data for Central Anatolian Early Bronze Age metalwork. *Antiquity Project Gallery, 83 No. 321*. http://www.antiquity.ac.uk/antiquityNew/projgall/zimmerman321/index.html

Ancient Urban Water System Construction of China

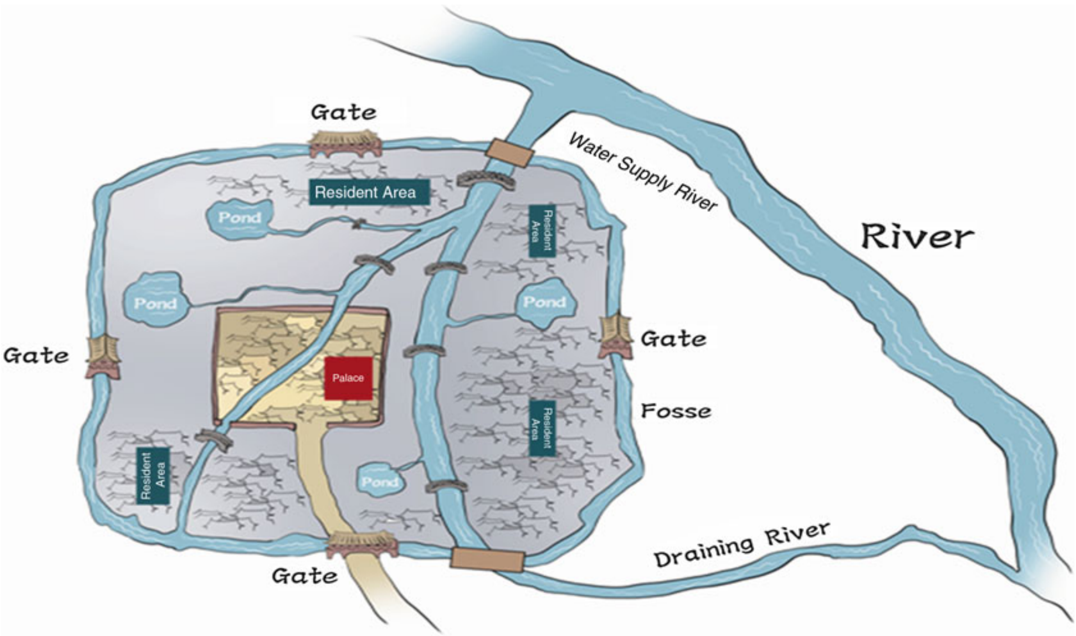
Xaio Yun Zheng
Yunnan Academy of Social Sciences, Peking, China

Introduction

China is an agricultural-based country, but the documented urban history was dated back to more 4,000 years. The early civilizations began in the middle and lower basin of Yellow River (Cai, 2012). Accordingly, in the early age of the Chinese cities, the major river nearby places were strongly considered as the site for building the city, especially rivers like Yellow River basin and Yangtze River basin. However, all the influential ancient cities in China were built close to the major rivers. They include a series of the most influential ancient capital cities such as Anyang, Chang'an, Luoyang, Kaifeng, Nanjing, Hangzhou, Beijing, etc. For example, Anyang, the oldest capital city of China, was built crossed the riversides of the old Heng Shui (洹水) river. Chang'an, today's Xi'an City, was built close to eight rivers likes Wei(渭), Jin(泾), Lao(涝), Feng(沣), etc and became the capital city for 1,700 years by 13 dynasties. Kaifeng City was located between the Yellow River and Huai River. Nanjing city was located at the south riverside of Yangtze River (Jin, 2005). Being situated near rivers, the city had convenient water supply and irrigation system, which later also made transportation convenient. At the same time, it also faced high flooding risk from the rivers; accordingly, the ancient founders and governors of the cities always paid strongly attention to combat urban flood. Even later, many cities were built near the major canals, for example, the Grand Canal Jinghan. However, the situation did not change (Tang, Wang, Li, & Deng, 2012).

Basically, the early Chinese civilization was developed in the Yellow River basin. Accordingly, the major cities also developed in the

A



Ancient Urban Water System Construction of China, Fig. 1 The urban water system of ancient China in general

Yellow River basin before Nan-Bai Dynasties (420—589 AD), but after Nan-Bai Dynasties, the major cities along the Yangtze River were developed. This outnumbered the Yellow River basin hundreds of years later, along with the economic development of the basin (Dong, 2004). Accordingly, the design and construction of urban water system of ancient Chinese cities were based on the condition of the urban site which mainly located near the rivers, after a model of urban water system was formed at the Han dynasty; not just major cities but also smaller cities also followed the model to design and construct their urban water system in subsequent years (Zheng, 2014).

The Urban Water System Design

Although the ancient cities had a complex design to adapt to the local water environment especially the rivers, the tracks of regular pattern of urban water system can still be followed. Usually, the model of water system in ancient Chinese city was usually combined with (1) water supply river, (2) urban rivers, (3) Internal Draining System, (4) ponds and lakes, (5) city moats (fosse), and (6) draining river (Fig. 1). However, these parts formed an urban water system in a city. Usually, each part performs its function, but they are connected to each other to perform the integrated functions in a city.

The Water Supply System

The water supply system is a canal or river that directs water into the city for water supply. According to the regulation of city site, a major city is usually located close to the river. However, if the river was not suitable to be used for water supply directly due to unexpected food risk by the river drop, the city founders have to build a canal to lead water into the city. But the fact is that many cities were built very close or crossed the river to make the river as the urban water supply source. For instance, the East Capital of North Song Dynasty (A.D. 960—1127), today's Kaifeng City, was built near the Yellow River. Hence, there were four rivers, Bian river (汴河), Jingshui river (金水河), Cai river (蔡河), and Wuzhang river (五丈河), which crossed flow the city and perform the functions of water supply and transportation. Also, many cities were built close to the Grand Canal Jinghan. The canal and its branch rivers usually cross the urban areas of the city and became the water supply rivers directly due to lower flood risk. Also, if the flood risk was not high, the city built close to the river in the urban area would always be in a favourable situation.

The Urban River

The urban river is the rivers or canals that flow inside the city as a water-cycling system. During the ancient ages, the urban rivers were very important to perform the functions of water use and drainage. Sometimes, they include the natural rivers inside the city when the city was built. Other times, canals were built as the urban river. For example, in Shuzhou City, there are many rivers inside the city. Consequently, there are seven major rivers flow in the city, but at same time, many other smaller rivers flow inside the city. For example, in every one street in some district, one river flows through. In the Han Chang'an City, not just the natural rivers in the city were present, but some canals were also built; for example, a very famous canal "The Open Ditch" was built to introduce water into the palaces. Urban river performs the functions of water supply, drainage and transportation, waterscape, etc. Furthermore, the residents especially use water from the rivers (Chinese usually did not drink from river, but from wells especially in major cities) according to the Chinese tradition. Thus, urban rivers were convenient for residents to get daily water, wash foods and clothes, etc. Urban river is also a function of the urban drainage, and most rainwater and wastewater were drained by the urban rivers. In another way, urban river also plays an important role in transportation, especially in many cities in Yangtze River basin. Along with the Grand Canal Jinghan, river transportation is not just busy inside the city, but is also important for the trade outside, for example, the cities of Jaingsu province like Suzhou, Yangzhou, Huaiyin, etc.

Ponds and Lakes

Ponds and lakes are usually natural or are built in a city. Thus, it is very popular to find ponds and lakes inside the old cities. Ponds and lakes are very important part of the city's natural water system, but many of them were built for multipurpose use, e.g., for storage and sluice of water and also as the city waterscapes. For example, in the ancient Chang'an City, 10 big ponds were built for rainwater sluice and water storage in summer, but water supply in winter. At same time, many cities also included the natural lakes inside the city. The ponds and lakes were usually linked with the urban rivers during the dry season and were used for water storage. Also, this ponds and lakes were important for sluice of rainstorm water during summer. At same time, the waterscape made the city more beautiful.

The Draining System

The drainage system for rainwater and wastewater was strongly considered during the construction of a city. Usually, it was designed and built with a city's original construction plan. The archeological discovery showed that early sewer in China was dated back to 4,000 years ago (Zheng, 2013). In major cities, the network of draining channel was built in palace and residential areas. However, some were underground channel, while some were surface channel for draining waste water and rainwater into the urban rivers and, later, into the drainage rivers. The draining system usually constitutes of four parts. They include: (1) The small sewers from the houses. (2) The street sewers and channels receive water from the house sewers. In many cities, there were open ditches or underground sewers along the street, which is a very popular way of building sewer along the streets, which is then covered with flagstones. (3) The urban rivers receive water from the street sewers. (4) The draining river to drain water to the outside the city. In addition, an urban draining system also includes other parts of the water system such as ponds, lakes, and moat.

Moat (Fosse)

The ancient city was usually built with the town walls. Also, a canal was built outside the walls which surrounded the town. Basically, the moats were built for the urban defense, but it was also linked with the city's water system for drainage. When the city meets rainstorm, it will perform the function of sluice from the town to reduce the risk of flood. Accordingly, the function of moat was often used for drainage purpose than its original purpose, which is for defense.

Draining River

Draining river is the river or canal that passed the city which leads water into the lower basin of the river or to other places.

The Logic of the Urban Water System Design

The rivers nearby were strongly considered in the building of cities by Chinese ancestor due to its convenient water supply. Accordingly, most Chinese early cities were built along the major rivers basins, especially the Yellow River basin and Yangtze River basin. Nevertheless, there are high flood risks when a city is built near a river for the purpose of convenient water supply. Therefore, it had a major impact on the cities at any period because flood was the major disaster to ancient cities. Consequently, the logic of design and construction of the urban water system was to build a water-cycling system in the city and ensure water cycling which flows in and out of the city. Hence, a perfect situation was the seasonal balance of water storage and drainage in the city. Therefore, when a city was built with water supply through river or canal, the drainage river and sluice system inside the city will be built simultaneously. After water was introduced into the city and cycled inside the city for use, it will be channeled out of the city into that same river source or other rivers. Through this water-cycling system, the city met the demands of water supply and reduces the risk of flood. Notwithstanding, not all risk was saved but was effectively achieved at this point which had been evidenced through centuries. Accordingly, the design and construction of urban water-cycling system was one of the most important wisdom of the ancient urban water management of China.

Through the above systemic design and construction of a water system, water was introduced from the nearby river to supply the city. Water cycling in the urban water system includes the urban rivers, channels, ponds, and moats, which then flows into the lower basin of the rivers or the farmlands outside the city. If rainstorm comes, the urban rivers, ponds, and towns surrounding moats would serve as sluice for the storm water to reduce the risk of flooding. Therefore, if a city was built with such a logical water system, a water-cycling system from the nearby river then returns the water to the river again. This puts the city in a superposition with its natural environment especially the water sources. In such cases, not just the citizen can use and enjoy the water conveniently but would also make the city flourish. Consequently, some cities even faced high flood risk, but the towns were still built close to the river or include the river as an urban river. For example, the Kaifeng City in Song Dynasty was built near the Yellow River. Also, the Bian river (汴河) inside the town, before the city was destroyed by flood, was from the Yellow River. The Bian riversides had become a very flourishing area of the city.

The Paradigm of the Urban Water System Construction

From Han Dynasty (202 B.C. ~ A.D. 220), the urban construction of China was going into a new age. Taking more than 400 years construction and development, Han had become one of the flourished tops of the dynasties in Chinese history. Also, many major cities were built with complex urban water system.

The founder of Han Dynasty founded its capital Chang'an City near today's Xi'an City, Shanxi province. According to the historical documents, this city was developed to be a very large city quickly after it was founded. It has also existed as the capital city for 15 dynasties until A.D. 907. Chang'an city was 35 km^2 in size at that time with a population of 500,000 (Yang, 1989). The archeological discovery showed a complex water system which was built in the city and which combines the functions of water supply, drainage, storage of water, and ship transportation. However, the main constructions of the water system are described below.

Water Supply: The water supply of the city was from the river naturally. The city was found at the south side of Wei Shui (渭水) River, but the water supply was from the Jue Shui (泬水) River because the location of the town was higher than the Wei Shui River. Jue Shui River flows from the south of the city and flows to the north into the town. It flows across the palaces and the city (this part was called Ming river, meaning open ditch, 9 km of length), and then out of the town into the Wei Shui river. Furthermore, other branch of Jue Shui River also flows across part of the town, and then into the Wei Shui river. However, for the purpose of improving water supply, a big pond was built to receive water from Jao Shui River (交水). This pond is a very famous pond called "Kunming Pond." After this pond was built, an aqueduct was built to introduce water into the town for urban water supply.

Urban Rivers: There are many rivers or canals inside the town which serves as water-cycling system. For example, the main water supply source, Jue Shui River, flows into the town directly. Firstly, it passes through the palaces for water supply, and then, it separates into two ways to the residential areas and finally into other rivers. As mentioned above, there are also aqueducts built from Kunming Pond or other sources to introduce water into the town. Hence, the aqueduct from the Kunming Pond was called "Kunming Aqueduct," which is the important water supply canal to the city. In addition, the urban river cycling inside the town to supply water to the town also performs the function of drainage.

The Ponds: There are 10 big ponds which are built for rainwater sluice in summer and water storage supply in winter. According to the documentary, the ponds was also use for training water war for the army, but fortunately, it became the waterscapes of the city mainly and gave adequate space for the citizens to enjoy water most periods.

The Drainage System: Drainage systems were built inside the town. They include the

Ancient Urban Water System Construction of China, Fig. 2 The brick structured sewer of Han

sewers, open ditches, channels, ponds and moats, and draining rivers. There are many earthen pipes and underground sewers which have been found. However, by archeological discovery shown, a sewer system was built in the palaces, and the residential areas then were linked to the urban rivers (Li, 1981). In 2008, a major sewer was found in the old Chang'an City. It was built with bricks of 2 m wide and 40 m length, Hence, we can see how large a sewer system was built in Han City (Figs. 2 and 3) (Feng, 2008).

The water systems are connected to each other through water supply rivers, ponds, drainage sluiceways, moat, and drainage rivers. However, not only wastewater can be drained, but also rainstorm water could be sluiced.

The Town Moat: Outside the town, a moat (length of 26 km) was built around the town. It was connected with the main urban river, Ming River, and also performs the function of rainwater sluice from the town (Wu, 2009).

Additionally, the water system include parts of the water supply rivers or aqueducts, urban rivers and channels, ponds, sewers, moat, and draining rivers, which combines to form a perfect urban water system. An important point was that the water system in Chang'an City also created a model of urban water system which influenced many Chinese cities subsequently. Consequently, Chang'an City was not just a flourishing city

Ancient Urban Water System Construction of China, Fig. 3 Part of the sewer of Han

historically but also a very important stage in the history of urban construction of water system in China (Zheng, 2013).

Reference

Cai, M. B. (2012). *A brief history of China* (pp. 5–8). Beijing: Social Sciences Academic Press.

Dong, J. H. (2004). *The history of Chinese urban construction* (pp. 73–82). Beijing: China Construction Industry Press.

Feng, G. (2008). Photo of Han Chang'an sewer. http://news.xinhuanet.com/photo/2008-10/24/content_10247383.htm. Accessed January 2, 2014.

Jin, H. C. (2005). City and water in Ancient China: With case of old capital cities. *The Journal of Hai He University, 7*(4), 23–27.

Li, Y. C. (1981). The Ruins of Han Chang'an town. *The Cultural Relic, 2*, 22–25.

Tang, X. M., Wang, Y. H., Li, Y. P., & Deng, J. (2012). *Chinese grand canal: Its form of heritage and evaluation on the value* (p. 5). Beijing: China Water & Power Press.

Wu, Q. Z. (2009). *Research on ancient flood control* (p. 88). China Construction Industry Press.

Yang, K. (1989). Re-discussion on the design of chang an in West Han dynasty. *Archaeology, 4*, 348–356.

Zheng, X. Y. (2013). Drainage in Ancient China: Historic wisdom and the lessons we learnt. In *Proceedings of 2013 IWHA international conference on the role of water in the history: Exploring historical wisdom for current water management*, Kunming, China, pp. 268–275.

Zheng, X. Y. (2014). The ancient urban water system construction of China: The lessons from history for a sustainable future. In *The proceeding of IWA-WWTAC symposium*, March 2014, Greece, pp. 67–72.

Animal Domestication

Christine M. Rodrigue
Department of Geography, California State University, Long Beach, CA, USA

Animal domestication is the process by which humans exert direct or indirect, partial or total, conscious or unconscious influence over the reproduction and evolution of animals that they own or otherwise manage (Rodrigue, 1987, p. 1). There is quite an extensive continuum between wild species utilized as resources by humans and fully domesticated species (Russell, 2002; Terrell et al., 2003; Marshall et al., 2014). The question of "origins" depends on a choice of where to draw the line between "wild" and "domesticated" along this continuum, and that choice is often the basis of arguments about the earliest domestication of many species.

A fully domesticated animal exhibits significant genotypic and phenotypic differences in both appearance and behavior from its nearest wild relatives due to its evolution under conditions dominated by humans. The domestication of animals and plants is one of the most significant impacts that humans have had on their natural environments, ultimately the root of the contemporary global economic system and its marvels and tragedies. Indeed, the increases in carbon dioxide and methane accompanying the diffusion of agriculture and animal husbandry into forest lands may well have sustained Holocene climate warming against orbital forcings that could have cooled climate (Ruddiman, 2003; Salinger, 2007). For most of our species' existence, however, human impacts were less thoroughgoing. People did not tend crops and maintain animals, living instead as seasonally migratory gatherers, hunters, and fishers of wild food sources.

The Geography of Domestication

The archeological record of settlements, bones, pollen, and artifacts indicates that settled societies based on plant cultivation and/or animal husbandry emerged roughly 10,000–11,500 years in certain areas of the world. Archeological research into the earliest domestications has tended to focus largely on the Near East. For example, suggestions of goat (*Capra hircus*) domestication reach back about 10,000 years in western Iran (Zeder & Hesse, 2000) and earlier than 10,400 years in Cyprus (Vigne et al., 2011). Sheep (*Ovis aries*) domestication goes back some 10,500 years in northernmost Iraq (Perkins, 1964; Zeder, 2011) and 10,200 years ago in central Turkey (Stiner et al., 2014), while pig (*Sus scrofa*) domestication developed possibly as early as 11,000 years ago in southeastern Turkey (Pringle, 1998a; Rosenberg, Nesbitt, & Peasnell, 1998) and some time before 10,400 years ago in Cyprus (Vigne et al., 2011).

The early domestication of barley (*Hordeum vulgare*) is evidenced in the Zagros foothills of the eastern Fertile Crescent and the northern Levant some 10,200 years ago (Fuller, Willcox, & Allaby, 2012; Zeder, 2011), while einkorn (*Triticum monococcum*) and emmer (*T. dicoccoides*) wheats trace back to southeastern Turkey and northern Syria (Lev-Yadun, Gopher, & Abbo, 2000; Özkan et al., 2002) and the southern Levant (Fuller et al., 2012) nearly 11,000 years ago. The cultivation and possibly the domestication of rye (*Secale cereale*) may arguably go back nearly 13,000 years in the northern Levant (Fuller et al. 2012; Pringle, 1998b; Zeder, 2011). Legumes evidence ancient domestication in the Near East as well, with peas (*Pisum sativum*) and lentils (*Lens culinaris*) going back nearly 11,000 years in the southern Levant and chickpeas (*Cicer arietinum*) going back 10,400 years in the northern Levant (Fuller et al., 2012). Within roughly a millennium, plant and animal domesticates were joined together in agriculture and husbandry complexes, which quickly spread throughout the ancient Near East and beyond.

Other parts of the world, however, saw similar, apparently independent domestications and assemblages of crop and animal complexes. Some of these include New Guinea with taro (*Colocasia esculenta*) going back 10,000 years and banana (*Musa* spp.) going back nearly 7,000 years (Denham et al., 2003; Denham, 2011); eastern China, with rice (*Oryza sativa*) cultivation going back at least 11,000 years (Mannion, 1999), with domestication solidified by 6,500 years ago (Gross & Zhao, 2014), and chicken (*Gallus gallus*) keeping tracing back nearly 8,000 years (West & Zhou, 1988); and Southeast Asia, with still controversial signs of cultivated cucumbers (*Cucurbita* spp.), water chestnuts (*Trapa natans*), peppers (*Piper* spp.), almonds (*Prunus dulcis*), and betel nuts (*Piper betel*) dating back 11,000–9,000 years and possible chicken domestication before 8,000 years ago (Gorman, 1969; Fumihito et al., 1996; Yen, 1977). Africa domesticated cattle (*Bos taurus*), donkeys (*Equus asinus*), African rice (*Oryza glaberrima*), pearl (*Pennisetum glaucum*) and finger millets (*Eleusine coracana)*, sorghum (*Sorghum bicolor*), teff cereal (*Eragrostis tef*), yam (*Dioscorea* spp.), cowpea (*Vigna unguiculata*), okra (*Abelmoschus esculentus*), oil palm (*Elaeis guineensis*), cola (*Cola* spp.), and coffee (*Coffea canaphora*) variously going back 10,000 before the present (cattle) to 2,000 BP, with several distinct centers of domestication: northeast Africa, west Africa, and the Ethiopian highlands (Hanotte et al., 2002; Harlan, 1971).

In the New World, northwestern South America and highland Mexico began the domestication of gourds and squashes (*Cucurbita* spp.) 10,000–12,000 years ago (Piperno & Stothert, 2003), while maize (*Zea mays*) domestication has been traced over 8,700 years before the present in Mexico (Piperno et al., 2009). Potatoes (*Solanum tuberosum*) go back about 8,000 years ago near Lake Titicaca in the Andes (Roach, 2002). Other crops domesticated in the New World include tomato (*Lycopersicon esculentum*), peppers (*Capsicum* spp.), tobacco (*Nicotiana tobaccum*), and cacao (*Theobroma cacao*) (Sauer, 1969). The New World domesticated few animals, however. Alpaca (*Lama pacos*) and llama (*L. glama*) domestication goes back 6,000–7,000 BP in Peru (Wheeler, 2003), as does guinea pig (*Cavia porcellus*) domestication there (Sandweiss & Wing, 1997). Turkey

(*Meleagris gallopavo*) is a much later domesticate in the New World, going back 500–2,200 years ago in the Pueblo cultures of the American Southwest and in Mesoamerica (Pinkley, 1965; Speller et al., 2010), as is the muscovy duck (*Cairina moschata*), which goes back 2,600 years ago in the lowlands of Ecuador (Hesse, 1980). A particularly intriguing plant domesticate is the bottle gourd (*Lagenaria siceraria*) that may have entered domestication near its wild home in Zimbabwe very early on and then accompanied African emigrants in the peopling of the rest of the Old World. Evidence for domesticated bottle gourds goes back to the ninth millennium BP in China and Japan and 10,000 years ago in Peru, implying that the domesticated plant, along with the dog, accompanied early Asian settlers of the New World during the Pleistocene–Holocene transition (Erickson et al., 2005; Zeder et al., 2006)!

Sequencing of Animal Species Entering Domestication

The dog (*Canis lupus familiaris*) is widely considered the first domesticate. The oldest tentative identification of domestic dog remains through traditional archeological methods goes back about 13,000–17,000 years in western Russia (Sablin & Khlopachev, 2002).

DNA analysis has transformed the archeology of domestication, most dramatically in its application to a large sample of living dogs of a variety of breeds, in order to determine how far back the domesticated breeds began to diverge from their common ancestor (Vilà et al., 1997). This approach yielded the startling and still contested figure of 135,000 BP, while analysis of patterns of variation in mitochondrial DNA suggests a concentration of genetic diversity (indicative of an ancestral population) in East Asia with divergence from wolf populations there roughly 15,000 BP (Savolainen et al., 2002). New World dogs were probably brought there by Paleoindian migrants from Asia, as their DNA resembles that of Asian wolves, rather than North American wolves (Wayne, Leonard, & Vilà, 2006). All dogs are now known to be domesticated Old World wolves (hence the Latin species name changes from *Canis familiaris* to *C. lupus*). The earliest dogs may have been pets, self-domesticating scavengers, and convenient sources of meat, evolving into hunting partners as their commensalist relationship with humans deepened.

Several animal species entered domestication in a second, nearly simultaneous development from 11,000 to 8,000 years ago: cattle, pigs, sheep, and goats, as discussed above, and possibly cats (*Felis sylvestris catus*) and pigeons (*Columba livia*) as well. Domesticated cattle are evidenced in south central Turkey some 10,400 years ago (Grigson, 1989; Perkins, 1969), but there is DNA evidence that a line of cattle was independently domesticated in northeast Africa about 10,000 BP (Hanotte et al., 2002) or that Near Eastern cattle may have been introduced into northeast Africa, but pastoralists there used wild indigenous bulls to improve their herds (Stock & Gifford-Gonzalez, 2013). Chickens appear in archeological sites throughout East Asia and Southeast Asia before 8,000 years ago (Fumihito et al. 1996; West & Zhou, 1988), and mtDNA studies imply they may have been domesticated as long ago as 10,000 BP in northern China (Xiang et al., 2014). Cats may have been domesticated as early as 10,300 years ago, judging from work in Cyprus (Vigne et al., 2011). Pigeons are first evidenced in Mesopotamian fertility shrine effigies about 6,500 years ago, but analysis of their staggering domesticated breed diversity suggests they may well be the first birds domesticated, perhaps as long ago as 10,000 BP (Johnston & Janiga, 1995; Price, 2002).

A third wave of animal domestications occurred roughly 7,000–4,000 years ago, this time involving the New World, too. The species involved included South American camels – llama and alpaca – in Peru approximately 6,000–7,000 years ago (Wheeler, 2003); the horse (*Equus caballus*) in the Ukraine, southernmost Russia, and westernmost Kazakhstan, about 6,000 years ago (Vilà et al., 2001; Warmuth et al., 2012); the donkey in northeast Africa about

5,000 years ago (Beja-Pereira et al., 2004; Kimura et al., 2011; Shackelford, Marshall, & Peters, 2013); the Bactrian camel (*Camelus bactrianus*) perhaps 4,000–5,000 years ago in Turkmenia and eastern Iran (Marshall et al., 2014; Zeder et al., 2006); the dromedary (*C. dromedarius*) in the Arabian Peninsula near the Persian Gulf about 4,000 years ago (Rosen & Saidel, 2010); water buffalo (*Bubalus bubalis*) in South Asia and Southeast Asia about 5,000–6,000 years ago (Yang et al., 2008); yak (*Bos grunniens*) in Tibet around 4,000–5,000 years ago (Rhode et al., 2007); and the silkworm (*Bombyx mori*) in China about 5,000 years ago (Yamauchi et al., 2000, p. 17). The honeybee (*Apis mellifera*) has been kept in hives, if arguably domesticated, over 7,000 years in Europe (Oldroyd, 2012).

A number of other domestications have taken place from that time to this, such as the turkey (*Meleagris gallopavo*), rabbit (*Oryctrolagus cuniculus*), guinea fowl (*Numida meleagris*), ferret (*Mustela putorius*), cormorant (*Phalacrocorax carbo*), Pekin duck (*Anas platyrhynchos*), muscovy duck (*Cairina moschata*), goose (*Anser anser*), carp and koi (*Cyprinus carpio*), and goldfish (*Carrasius auratus*). Domestications continue at the present, including parakeets (*Melopsittacus undulatus*), canaries (*Serinus canaria*), diamond doves (*Geopelia cuneata*), mink (*Mustela vison*), laboratory rats (*Rattus norvegicus*), foxes (*Vulpes fulvus*), hamsters (*Mesocricetus auratus*), aquarium fish, and ongoing experiments with promising livestock species, such as eland (*Taurotragus oryx*) and fallow deer (*Dama dama*) (National Research Council Board on Science and Technology for International Development, 1991).

Why Domesticate Animals?

Why did people give up the hunting of animals for the work entailed in domesticating them? The factors involved differ by species and human circumstance. The simple human tendency to pet keeping may have played a role, though utilitarian use of pets is a difficult obstacle to cross (Serpell, 1989), and animals imprinted on humans are commonly unable to breed (Rodrigue, 1987, p. 163).

Nomadic hunters–gatherers could have domesticated certain herd animals (Ingold, 1980). Such peoples as the reindeer-herding Saami of northernmost Europe sometimes follow the migratory herd species (*Rangifer tarandus*) all year and influence the direction and spatial cohesion of the animals through driving and herding. They selectively cull the animals, which amounts to the evolutionary pressure associated with domestication. The reindeer nomads may have been exploiting reindeer for as long as 20,000 years (NRC Board on Science and Technology for International Development, 1991, p. 285). It is not clear, however, whether migratory herding hunters in the past actually undertook independent domestications of the animals they hunted or adopted the idea later from nearby agriculturalists and associated pastoral nomads.

Settled cultivators may have had a variety of reasons to undertake the control and maintenance of animal populations. Their crops, food stores, and even their salty latrine areas attracted animals, inviting reciprocal exploitation and eventual domestication through a commensalism pathway (Zeder, 2012; Zeuner, 1963). Wolves would steal scraps of food and may have been tolerated as a garbage disposal system. Fields, grain stores, and latrine areas would attract bovine species. The granivorous and cliff-nesting pigeons would descend on early cereal fields and roost in nearby buildings (Johnston & Janiga, 1995; Woldow, 1972). Indeed, many of the smaller animals drawn to raid human crops and food stores would themselves attract still other animals to prey on them (e.g., cats), which would become inadvertent partners and sometimes eventual domesticates. The opportunities for coevolutionary interactions between people and animals increased once people settled and especially once they took up crop cultivation and food storage (Rindos, 1984).

Certain scholars have argued that settled cultivators had no particular economic or ecological need for animals, and animal management does entail work and can prove dangerous. They feel that the earliest animal domestications provided sacrifices for rituals or amusement for gamblers (e.g., Isaac, 1970). This argument has not done well in archeological testing (Rodrigue, 1992), but the argument cannot be dismissed (Fumihito et al. 1996, p. 6795). Of particular interest are recent discoveries of monumental architecture at a handful of very early Holocene sites (11,600 BP to 11,000 BP) in the early Pre-Pottery Neolithic A of both the northern and southern Levant, e.g., Göbekli Tepe to the north and Wadi Faynan 16 Structure O75 to the south (Dietrich et al., 2012; Mithen et al., 2011, respectively). Göbekli Tepe offers spectacular suggestions of feasting, alcohol consumption, dancing, and cultic symbols, with no evidence of animal husbandry or plant cultivation.

Other scholars have worked out coevolutionary ecological contexts for animal domestications (Rindos, 1984) and economic arguments relating to relative time costs and resource yields of hunting and husbandry in different contexts (Alvard & Kuznar, 2001; Layton, Foley, & Williams, 1991; Rhode et al., 2007).

In some cases, people may have at least partially domesticated an animal species and later abandoned it. Gazelles (*Gazella gazella*), for example, may have been in the process of domestication in the ancient Levant around 11,000 years ago, later being replaced by goats and sheep (Bar-Oz et al., 2004; Legge, 1972; Moore, Hillman, & Legge, 2000; Zeder, 2012). These latter imports may have had some sort of advantage over indigenous domesticates. Of relevance to this process of shifting focus is renewed attention to the concept of "domesticability," with attempts to identify "domestication genes" or genetic traits that responded more amenably to human selection (Zeder et al., 2006). Perhaps, it was less a question of domesticability and more an artifact of military displacement and conquest of one culture by another that could have replaced one constellation of animal domesticates with another. The development of religious taboos has caused species to be dropped from husbandry in given areas (e.g., pigs in areas of Jewish or Muslim religion).

Conclusion

To resolve these different issues and disputes over their interpretation will take considerable work. Much of the world has never had adequate coverage of its archeological heritage. Archeological funding has been biased toward those areas regarded rightly or wrongly by Westerners as somehow connected with their own culture histories, such as the Biblical Levant and Mesopotamia, Egypt, ancient Greece and Rome, Europe, and even Mesoamerica and Peru (due to Mormon religious interest in the region). There are many tantalizing indications that archeological work in other areas in the non-Western world, applying the many new techniques and technologies available, will transform our present perceptions of the origins of domestication.

References

Alvard, M. S., & Kuznar, L. (2001). Deferred harvests: The transition from hunting to animal husbandry. *American Anthropologist, 103*(2), 295–311.

Bar-Oz, G., et al. (2004). The Natufian economy at El-Wad Terrace with special reference to gazelle exploitation patterns. *Journal of Archaeological Science, 31*, 217–231.

Beja-Pereira, A., et al. (2004). African origins of the domestic donkey. *Science, 304*, 1781. doi:10.1126/science.1096008.

Clutton-Brock, J. (1989). Introduction. In *The Walking larder: Patterns of domestication, pastoralism, and predation* (pp. 7–9). Abingdon/New York, NY: Routledge.

Clutton-Brock, J. (1999). *A natural history of domesticated mammals* (2nd ed.). Cambridge: Cambridge University Press.

Davis Simon, J. M. (1995). *The archaeology of animals*. New Haven, CT: Yale University Press.

Denham, T. (2011). Early agriculture and plant domestication in New Guinea and Island Southeast Asia. *Current Anthropology, 52*(S4), S379–S395. doi:10.1086/65d8682.

Denham, T. P., et al. (2003). Origins of agriculture at Kuk Swamp in the highlands of New Guinea. *Science, 301*, 189–193. doi:10.1126/science.1085255.

Diamond, J. (1997). *Guns, germs, and steel: The fates of human societies*. New York, NY: W.W. Norton.

Diamond, J. (2002). Evolution, consequences and future of plant and animal domestication. *Nature, 418*, 700–707. doi:10.1038/nature01019.

Dietrich, O., et al. (2012). The role of cult and feasting in the emergence of Neolithic communities. New evidence from Göbekli Tepe, South-Eastern Turkey. *Antiquity, 86*(333), 674–695.

Erickson, D. L., et al. (2005). An Asian origin for a 10,000-year-old domesticated plant in the Americas. *Proceedings of the National Academy of Sciences of the United States of America, 102*(51), 18315–18320. doi:10.1073/pnas.0509279102.

Fuller, D. Q., Willcox, G., & Allaby, R. G. (2012). Early agricultural pathways: Moving outside the 'core area' hypothesis in Southwest Asia. *Journal of Experimental Biology, 63*(2), 617–633. doi:10.1093/jxb/err307.

Fumihito, A., Miyake, T., Takada, M., Shingu, R., Endo, T., Gojobori, T., Kondo, N., Ohno, S., et al. (1996). Monophyletic origin and unique dispersal patterns of domestic fowls. *Proceedings of the National Academy of Sciences of the United States of America, 93*, 6792–6795.

Gorman, C. F. (1969). Hoabinhian: A pebble-tool complex with early plant associations in Southeast Asia. *Science, 163*, 671–673.

Grigson, C. (1989). Size and sex: Evidence for the domestication of cattle in the Near East. In A. Milles, D. Williams, & G. Gardner (Eds.), *The beginnings of agriculture* (British archaeological reports international series, Vol. 496, pp. 77–109). Oxford: BAR.

Gross, B. L., & Zhao, Z. (2014). Archaeological and genetic insights into the origins of domesticated rice. *Proceedings of the National Academy of Sciences of the United States of America, 111*(17), 6190–6197. doi:10.1073/pnas.1308942110.

Hanotte, O., et al. (2002). African pastoralism: Genetic imprints of origins and migrations. *Science, 296*, 336–339. doi:10.1126/science.1069878.

Harlan, J. R. (1971). Agricultural origins: Centers and non-centers. *Science, 174*, 468–474.

Hemmer, H. (1990). *Domestication: The decline of environmental appreciation*. Cambridge: Cambridge University Press.

Hesse, B. (1980). Archaeological evidence for the Muscovy Duck in Ecuador. *Current Anthropology, 21*(1), 139–140.

Ingold, T. (1980). *Hunters, pastoralists, and ranchers*. Cambridge: Cambridge University Press.

Isaac, E. (1970). *The geography of domestication*. Englewood Cliffs, NJ: Prentice-Hall.

Johnston, R. F., & Janiga, M. (1995). *Feral pigeons*. Oxford: Oxford University Press.

Kimura, B., et al. (2011). Ancient DNA from Nubian and Somali wild ass provides insights into donkey ancestry and domestication. *Proceedings of the Royal Society B, 278*(1702), 50–57. doi:10.1098/rspb.2010.0708.

Layton, R., Foley, R., & Williams, E. (1991). The transition between hunting and gathering and the specialized husbandry of resources. *Current Anthropology, 32*(3), 255–263.

Legge, A. J. (1972). Prehistoric exploitation of the gazelle in Palestine. In E. S. Higgs (Ed.), *Papers in economic prehistory* (pp. 119–124). Cambridge: Cambridge University Press.

Lev-Yadun, L., Gopher, A., & Abbo, S. (2000). The cradle of agriculture. *Science, 288*, 1602–1603. doi:10.1126/science.288.5471.1602.

Mannion, A. M. (1999). Domestication and the origins of agriculture: An appraisal. *Progress in Physical Geography, 23*(1), 27–56.

Marshall, F. B., et al. (2014). Evaluating the roles of directed breeding and gene flow in animal domestication. *Proceedings of the National Academy of Sciences of the United States of America, 111*(17), 6153–6158.

Mithen, S. J., et al. (2011). An 11 600 year-old communal structure from the Neolithic of southern Jordan. *Antiquity, 85*, 350–364.

Moore, A. M. T., Hillman, G. C., & Legge, A. J. (2000). *Village on the Euphrates: From foraging to farming at Abu Hureyra*. Oxford/New York, NY: Oxford University Press.

National Research Council Board on Science and Technology for International Development. (1991). *Microlivestock: Little-known small animals with a promising economic future*. Washington, DC: National Academy Press.

Oldroyd, B. P. (2012). Domestication of honey bees was associated with expansion of genetic diversity. *Molecular Ecology, 21*, 4409–4411.

Özkan, H., et al. (2002). AFLP analysis of a collection of tetraploid wheats indicates the origin of emmer and hard wheat domestication in Southeast Turkey. *Molecular Biology and Evolution, 19*, 1797–1801.

Perkins, D., Jr. (1964). Prehistoric Fauna from Shanidar, Iraq. *Science, 144*, 1565–1566.

Perkins, D., Jr. (1969). Fauna of Catal Huyuk: Evidence for early cattle domestication in Anatolia. *Science, 164* (3876). 177–179. doi:10.1126/science.164.3876.177.

Pinkley, J. (1965). The Pueblos and the Turkey: Who domesticated whom? *Contributions of the Wetherill Mesa Archeological Project Memoirs, 19*, 70–72.

Piperno, D. R., & Stothert, K. E. (2003). Phytolith evidence for early Holocene *Cucurbita* domestication in Southwest Ecuador. *Science, 299*, 1054–1057.

Piperno, D. R., et al. (2009). Starch grain and phytolith evidence for early ninth millennium B.P. maize from the Central Balsas River Valley, Mexico. *Proceedings of the National Academy of Sciences of the United States of America, 106*(13), 5019–5024. doi:10.1073/pnas.0812525106.

Price, T. D. (2002). Domesticated birds as a model for the genetics of speciation by sexual selection. *Genetica, 116*, 311–327.

Pringle, H. (1998a). Neolithic agriculture: Reading the signs of ancient animal domestication. *Science, 282*, 1448. doi:10.1126/science.282.5393.1448.

Pringle, H. (1998b). The slow birth of agriculture. *Science, 282*, 1446. doi:10.1126/science.282.5393.1446.

Rhode, D., et al. (2007). Yaks, yak dung, and prehistoric human habitation of the Tibetan Plateau. *Developments in Quaternary Science, 9*, 205–220. doi:10.1016/S1571-0866(07)09013-6.

Rindos, D. (1984). *The origins of agriculture: An evolutionary perspective*. Orlando, FL: Academic Press.

Roach, J. (2002). Saving the potato in its Andean Birthplace. *National Geographic News*, 10 June 2002. Available at http://news.nationalgeographic.com/news/2002/06/0610_020610_potato.html

Rodrigue, C. M. (1987). *An evaluation of ritual sacrifice as an explanation for early animal domestications in the Near East*. Ph.D. dissertation, Clark University, Worcester, MA.

Rodrigue, C. M. (1992). Can religion account for early animal domestications? A critical assessment of the cultural geographic argument, based on near eastern archaeological data. *The Professional Geographer, 44*(4), 417–430.

Rosen, S. A., & Saidel, B. A. (2010). The camel and the tent: An exploration of technological change among early pastoralists. *Journal of Near Eastern Studies, 69*(1), 63–77.

Rosenberg, M. R., Nesbitt, R. W., & Peasnall, B. L. (1998). Hallan Çemi, pig husbandry, and post-pleistocene adaptations along the Taurus-Zagros Arc (Turkey). *Paléorient, 34*(1), 25–41.

Ruddiman, W. E. (2003). The anthropogenic greenhouse era began thousands of years ago. *Climatic Change, 61* (3), 261–293.

Russell, N. (2002). The wild side of animal domestication. *Society and Animals, 10*(3), 285–302. doi:10.1163/156853002320770083.

Sablin, M. V., & Khlopachev, G. A. (2002). The earliest ice age dogs: Evidence from Eliseevichi. *Current Anthropology, 43*(5), 795–799. doi:10.1086/344372.

Salinger, M. J. (2007). Agriculture's influence on climate during the Holocene. *Agricultural and Forest Meteorology, 142*, 96–102. doi:10.1016/j.agrformet.2006.03.024.

Sandweiss, D. H., & Wing, E. S. (1997). Ritual rodents: The guinea pigs of Chincha, Peru. *Journal of Field Archaeology, 24*(1), 47–58.

Sauer, C. O. (1969). *Seeds, spades, hearths, and herds: The domestication of animals and foodstuffs* (2nd ed.). Cambridge, MA: The MIT Press.

Savolainen, P., et al. (2002). Genetic evidence for an East Asia origin of domestic dogs. *Science, 298*, 1610–1613.

Serpell, J. (1989). Pet-keeping and animal domestication: A reappraisal. In J. Clutton-Brock (ed.), The walking larder: Patterns of domestication, pastoralism, and predation, pp. 10–21. London: Unwin Hyman.

Shackelford, L., Marshall, F., & Peters, J. (2013). Identifying donkey domestication through changes in cross-sectional geometry of long bones. *Journal of Archaeological Science, 48*, 4170–4179. doi:10.1016/j.jas.2013.06.006.

Speller, C. F., et al. (2010). Ancient mitochondrial DNA analysis reveals complexity of indigenous North American Turkey domestication. *Proceedings of the National Academy of Sciences of the United States of America, 107*(7), 2807–2812. doi:10.1073/pnas.0909724107.

Stiner, M. C., et al. (2014). A forager-herder trade-off, from broad spectrum hunting to sheep management at Aşıklı Höyük Turkey. *Proceedings of the National Academy of Sciences of the United States of America, 111*(23), 8404–8409. doi:10.1073/pnas.1322723111.

Stock, F., & Gifford-Gonzalez, D. (2013). Genetics and African cattle domestication. *African Archaeological Review, 30*, 51–72. doi:10.1007/s10437-9131-6.

Terrell, J. E., et al. (2003). Domesticated landscapes: The subsistence ecology of plant and animal domestication. *Journal of Archaeological Method and Theory, 10*(4), 323–368.

Vigne, J.-D., et al. (2011). The early process of mammal domestication in the Near East: New evidence from the pre-neolithic and pre-pottery neolithic in Cyprus. *Current Anthropology, 52*(S4), S255–S271. doi:10.1086/659306.

Vilà, C., et al. (1997). Multiple and ancient origins of the domestic dog. *Science, 276*, 1687–1689. doi:10.1126/science.276.5319.1687.

Vilà, C., et al. (2001). Widespread origins of domestic horse lineages. *Science, 291*, 474–477. doi:10.1126/science.291.5503.474.

Warmuth, V., et al. (2012). Reconstructing the origin and spread of horse domestication in the Eurasian steppe. *Proceedings of the National Academy of Sciences of the United States of America, 109*(21), 8202–8206. doi:10.1073/pnas.1111122109.

Wayne, R. K., Leonard, J. A., & Vilà, C. (2006). Genetic analysis of dog domestication. In M. A. Zeder et al. (Eds.), *Documenting domestication: New genetic and archaeological paradigms* (pp. 279–293). Berkeley, CA/Los Angeles, CA/London: University of California Press.

West, B., & Zhou, B.-X. (1988). Did chickens go North? New evidence for domestication. *Journal of Archaeological Science, 15*(5), 515–533.

Wheeler, J. (2003). Evolution and origin of the domestic camelids. *International Llama Registry Report*, *8*, 2. Available at http://www.rmla.com/origin_of_sa_camelids.htm

Woldow, N. (1972). Pigeons and man (sic): A spotty old friendship. *Natural History, 81*(1), 26–37.

Xiang, H., et al. (2014). Early Holocene chicken domestication in northern China. *Proceedings of the National Academy of Sciences of the United States of America, 111*(49), 17564–17569. doi:10.1073/pnas.1411882111.

Yamauchi, Y., et al. (2000). cDNA and deduced amino acid sequences of apolipophorin-IIIs from *Bombyx mori* and *Bombyx mandarina*. *Archives of Insect Biochemistry and Physiology, 43*, 16–21.

Yang, D. Y., et al. (2008). Wild or domesticated: DNA analysis of ancient water buffalo remains from North China. *Journal of Archaeological Science, 35*, 2778–2785. doi:10.1016/j.jas.2008.05.010.

Yen, D. E. (1977). Hoabihian horticulture: The evidence and the questions from Northwest Thailand. In J. Allen, J. Golson, & R. Jones (Eds.), *Sunda and Sahul: Prehistoric studies in Southeast Asia, Melanesia, and Australia* (pp. 567–599). London: Academic Press.

Zeder, M. A. (2011). The origins of agriculture in the Near East. *Current Anthropology, 52*(S4), S221–S235. doi:10.1086/659307.

Zeder, M. A. (2012). Pathways to domestication. In P. Gepts et al. (Eds.), *Biodiversity in agriculture: Domestication, evolution, and sustainability*. Cambridge: Cambridge University Press.

Zeder, M., & Hesse, B. (2000). The initial domestication of goats (*Capra hircus*) in the Zagros mountains 10,000 years ago. *Science, 287*, 2254–2257.

Zeder, M. A., et al. (2006). Documenting domestication: The intersection of genetics and archaeology. *Trends in Genetics, 22*(3), 139–155.

Zeuner, F. E. (1963). *A history of domesticated animals*. New York, NY/Evanston, IL: Harper and Row.

Animal Mummies

Salima Ikram

Although it is commonly known that the ancient Egyptians mummified humans, it is a less well-known fact that they also mummified animals. Animals were mummified for the same reason as humans: to preserve their bodies so that they could live forever. This suggests that a belief in animal souls was a part of Egyptian religion.

Mummification is the preservation of a body through artificial means. In terms of animal mummies it varied somewhat depending on the time period and the type of mummy that was being created. The basic principle, however, remained the same: to desiccate the body using natron (a naturally occurring compound of salt and soda found in the Wadi Natron in Egypt) or even salt. Once the corpse was desiccated, it was anointed with oils and resins and wrapped in linen bandages. There are four types of animal mummies: food offerings, pets, sacred animals, and votive offerings. Pets and sacred animals seem to be the most carefully mummified, while votive offerings are the most carelessly prepared. The preparation of food offerings varies.

Food or victual mummies consist of mummified foods for humans, such as beef ribs, steaks, joints of meat, ducks, and geese that were placed in tombs so the tomb owner could feast for eternity. The meat and poultry was prepared for consumption, so joints are cut, and the poultry is cleaned, ready for roasting. This mummy type was especially common in the New Kingdom (1549–1060 BCE) and the twenty-first Dynasty (1060–940 BCE).

Pet mummies were of animals beloved of their owners and therefore preserved so that they and their owners could enjoy eternity together. These appear throughout Egyptian history, though the better-known examples come from the New Kingdom and the twenty-first Dynasty, with the gazelle of Queen Isetemkheb D being an example from the latter period.

Sacred animals were animals that were worshipped during their lifetime as the spirit or *ba* of the god entered them, and upon their deaths mummified as were kings, and buried in sarcophagi which were interred in single or catacomb-like sepulchers. Whilst alive these animals would provide oracular advice. The Apis Bull, a manifestation of Ptah, and the Ram of Elephantine, the manifestation of Khnum are particularly well-known animal incarnations. Although the Apis is known from Dynasty I, the Serapeum at Saqqara where the mummies of these animals were kept dates to the eighteenth Dynasty (1549–1298 BCE) and later.

Votive offerings consisted of mummified animals that were dedicated to specific deities. Gods had specific animals that were their totems or symbols: cats were sacred to the goddess Bastet, goddess of pleasure, ibises and baboons to the god Thoth, god of learning, etc. These mummified animals were purchased and offered by pilgrims at shrines dedicated to these gods,

Animal Mummies, Fig. 1 A mummified cat in a sycamore wood coffin, CG 29783 from the Egyptian Museum, Cairo (Photo by Anna-Marie Kellen)

Animal Mummies, Fig. 2 CG 51098 food mummy from the Egyptian Museum, Cairo (Photo by Anna-Marie Kellen)

and finally buried in deep catacombs. The mummified animals would present the prayers of the pilgrim to the god throughout eternity, much in the way votive candles are purchased and burned in churches. This type of mummy was common from the seventh century BCE until the fourth century AD (Fig. 1).

Not all mummy packages contain animals. A group of "fake" mummies, generally found amongst the votive offerings, have come to light during scholarly investigations. These consist of packages that are wrapped to look like real creatures, but either contain fragments of real animals, or rags and bits of mud or wood. In the case of the former the idea is that a part signifies the whole, while in the latter case, one might suggest that the appearance of the package and the identification of the bundle as a certain creature turns it into that animal. Thus, when there was a paucity of actual animals to mummify the embalmers made these substitutions. On a more cynical note, these could be ways of defrauding unsuspecting pilgrims.

In the early days of archaeology most animal mummies were ignored and often discarded, or else taken away as casual souvenirs that illustrated the oddity of the Egyptians; they were never seriously considered as artefacts that could elucidate any relevant aspect of ancient Egypt. However, in more modern times scholars have realized that a study of these mummies can provide information about the fauna of the country and, indirectly, its climate, as well as animal domestication, veterinary practices, human nutrition, mummification itself, and the religious practices of the ancient Egyptians. Examining their wrappings can also inform us about chronological and geographical variations in production practices.

These mummies are currently studied in a variety of ways, all of which tend to be non-destructive. Visual examinations and radiography are most common. Sometimes CT-scans are employed. Destructive studies include tests on the wrappings and the flesh itself in order to determine the types of resins and other embalming materials used.

All sorts of animals were mummified, including: dogs, cats, ibises, raptors, shrews, crocodiles, snakes, cattle, rams, fish, and even scarab beetles. The practice of animal mummification reached is heyday in the Late and Graeco-Roman periods (700 BCE–AD 395), when sacred and votive animal mummies became increasingly popular. The many millions of ibis, cat, and dog mummies that have been found all date to these periods. The majority of animal mummies created in earlier periods belonged to the pet, food, and to some extent, sacred animal genres. Animal mummification ceased in the fourth century AD with the advent of Christianity (Fig. 2).

References

Armitage, P., & Clutton-Brock, J. (1980). Egyptian mummified cats held by the British museum. *MASCA Research Papers in Science and Archaeology, 1*, 185–188.

Armitage, P. L., & Clutton-Brock, J. (1981). A radiological and histological investigation into the mummification of cats from ancient Egypt. *Journal of Archaeological Science, 8*, 185–196.

Aufrere, S. (1997). Une Nécropole ptolemaique de taureaux Apis visitée en 1716 par Paul Lucas et Claude Sicard? In C. Berger & B. Mathieu (Eds.), *tudes sur l'Ancien Empire et la nécropole de Saqqara dédiées à Jean-Philippe Lauer* (pp. 55–68). Montpellier, France: Université Paul Valéry.

Bagnani, G. (1952). The great Egyptian crocodile mystery. *Archaeology, 5*(2), 76–78.

Boessneck, J., et al. (1987). *Die Münchner Ochsenmumie*. Hildesheim, Germany: Gerstenberg.

Callou, C., Samzun, A., & Zivie, A. (2004). A lion found in the Egyptian Tomb of Maia. *Nature, 427*, 211–212.

Charron, A. (1990). Massacres d'animaux à la Basse Epoque. *Revue d'Égyptologie, 41*, 209–213.

Charron, A. (1997). Des «momies» de lions à Saqqarah. *Bulletin Société d'Égyptologie Genève, 21*, 5–10.

Davies, S., & Smith, H. (1997). Sacred animal temples at Saqqara. In S. Quirke (Ed.), *The temple in ancient Egypt* (pp. 112–131). London, UK: British Museum.

Gaillard, C., & Daressy, G. (1905). *Catalgue Général des Antiquités Égyptiennes du Musée du Caire: La Faune Momifiée de l'Antique Égypte*. Cairo, Egypt: IFAO.

Goodman, S. (1987). Victual Egyptian bird mummies from a presumed late 17th or early 18th dynasty tomb. *Journal of the Society for the Study of Egyptian Antiquities, 17*(3), 67–77.

Goudsmit, J., & Brandon-Jones, D. (2000). Evidence from the baboon catacomb in North Saqqara for a West Mediterranean monkey trade route to Ptolemaic Alexandria. *Journal of Egyptian Archaeology, 86*, 111–119.

Hanzak, J. (1977). Egyptian mummies of animals in Czechoslovak collections. *Zeitschrift für ägyptische Sprache und Altertum, 104*, 86–88.

Ikram, S. (1995a). *Choice cuts: Meat production in ancient Egypt*. Leuven, Belgium: Peeters.

Ikram, S. (1995b). Did the ancient Egyptians Eat biltong? *Cambridge Journal of Archaeology, 5*(2), 283–289.

Ikram, S. (2000a). The pet gazelle of one of the ladies of the Pinudjem family. *KMT, 11*(2), 58–61.

Ikram, S. (2000b). Animals for the afterlife. *Egypt Revealed, 1*(1), 55–61.

Ikram, S. (2000c). Meat production. In P. Nicholson & I. Shaw (Eds.), *Ancient Egyptian materials and technologies* (pp. 656–671). Cambridge: Cambridge University Press.

Ikram, S. (2001). The animal mummy project. *KMT, 12*(4), 18–25.

Ikram, S. (2003a). The animal mummy project at the Egyptian museum, Cairo. In Z. Hawass (Ed.), *Egyptology at the dawn of the twenty-first century* (pp. 235–239). Cairo, Egypt: American University in Cairo.

Ikram, S. (2003b). *Death and burial in ancient Egypt*. London, UK: Longman.

Ikram, S. (2004a). *A zoo for eternity: Animal mummies in the Cairo museum*. Cairo, Egypt: Supreme Council of Antiquities.

Ikram, S. (2004b). *Beloved beasts: Animal mummies from ancient Egypt*. Cairo, Egypt: Supreme Council of Antiquities.

Ikram, S. (2004c). Victual, ritual, or both? Food offerings from the funerary assemblage of isitemkheb. *Studi di Egittologia e di Papirologia, 1*, 87–92.

Ikram, S., & Dodson, A. (1998). *The mummy in ancient Egypt: Equipping the dead for eternity*. London, UK: Thames and Hudson/American University in Cairo.

Ikram, S., & Helmi, A. (2002). The history of the collection of the animal mummies at the Egyptian museum, Cairo. In M. Eldamaty & M. Trad (Eds.), *Egyptian museum collections* (pp. 563–568). Cairo, Egypt: Supreme Council of Antiquities.

Ikram, S., & Iskander, N. (2002). *Catalogue général of the Egyptian museum: Non-human remains*. Cairo, Egypt: Supreme Council of Antiquities.

Kessler, D. (1989). *Die Heiligen Tiere und Der Konig, I*. Wiesbaden, Germany: Harrasssowitz.

Lortet, C., & Gaillard, C. *La faune momifiée de l'ancienne Egypte*. Lyon: Archives du Muséum Histoire Naturelle de Lyon VIII: 2, IX: 2, X: 2, 1903–09.

Martin, G. T., & Sacred, T. (1981). *Animal necropolis at North Saqqara*. London, UK: Egypt Exploration Society.

Marx, M., & d'Auria, S. (1986). CT examination of eleven Egyptian mummies. *RadioGraphics, 6*, 321–330.

Nicholson, P., Jackson, C., & Frazer, K. (1999). The north ibis catacomb at Saqqara: The tomb of the birds. In A. Leahy & J. Tait (Eds.), *Studies on ancient Egypt in honour of H. S. Smith* (pp. 209–214). London, UK: Egypt Exploration Society.

Smith, H. S. (1974). *A visit to ancient Egypt: Life at Memphis and Saqqara (c. 500–30 BCE)*. Warminster, UK: Aris and Phillips.

Smith, H. S. (1992). The death and life of the mother of Apis. In A. B. Lloyd (Ed.), *Studies in pharaonic religion and society in honour of J. Gwyn Griffiths* (pp. 201–225). London, UK: Egypt Exploration Society.

te Velde, H. (1980). A few remarks upon the religious significance of animals in ancient Egypt. *Numen, 27*, 76–82.

Vos, R. L., & Apis, T. (1993). *Embalming ritual*. Leuven, Belgium: Peeters.

Zivie, A., & Ginsburg, L. (1987). La nécropole des chats de Saqqara en Égypte: recherches récentes. *Le Chat Ethnozootechnie, 40*, 5–10.

Approximation Formulae in Chinese Mathematics

Jean-Claude Martzloff

Approximation formulae may be used for various reasons. In some cases, certain computations (such as for example, the extraction of roots digit by digit) are by nature inexact. It may also be that exact solutions of certain problems are unknown or else that such solutions are theoretically known but deemed too complex, so that users prefer elaborating alternative solutions more or less accurate with respect to a certain context of utilization. The history of Chinese mathematics illustrates well these two aspects of the question.

Remarkably, many Chinese approximation formulae are also attested in Babylonian, Greek, Roman, Indian, and Mediaeval European mathematics. For example, the so-called "Hero's iteration formula" for the approximation of square roots converges quadratically to x is also found in the ▶ Jiuzhang suanshu (Computational Prescriptions in Nine Chapters, also translated as Nine Chapters on the Mathematical Arts) from the Han dynasty (206 BCE–AD 220).

Hero's iteration formula:

Let $x = \sqrt{n}$. Then, the sequence

$$x_k = x_k = \frac{1}{2}\left(x_{k-1} + \frac{n}{x_{k-1}}\right)$$

The approximation formula for the computation of the area of a quadrilateral by taking the product of the half sum of its opposite sides appears not only in the *Wucao suanjing* (Computational Canon of the Five Administrative Services), and the ▶ *Xiahou Yang suanjing* (Xiahou Yang's Computational Canon) (fourth century AD) but also in the Babylonian mathematical corpus (More precisely in YBC 4675 (Neugebauer & Sachs, 1945, pp. 44–47)), in the writings of the Roman agrimensors (surveyors) (References are given in Martzloff, 1997, p. 325), in Alcuin's *Propositiones ad acuendos juvenes* (Propositions to Sharpen the Minds of the Youth) (The *Propositiones* have been translated into German by M. Folkerts and H. Gericke, "Die Alkuin Zugeschriben Propositiones ad Acuendos Iuvenes (Aufgaben für Schärfung des Geistes der Jugend)" *Science in Western and Eastern Civilization in Carolingian Times*. Eds. L. Butzer and D. Lohrman. Bale: Birkhaüser Verlag, 1993. 288) and numerous other places. The same remark also applies to the *false* formula for the computation of the area of a segment of a circle:

$$A = \frac{h(b+h)}{2}.$$

In the *Jiuzhang suanshu*. Such examples are much more numerous than historians of mathematics formerly imagined.

This striking phenomenon is an indicator of the strong unity of ancient mathematics. Recent research unceasingly confirms that ancient mathematics were not so much "Chinese" than "written in Chinese," "Indian" than "written in Sanskrit" and so on, even though, by any standard, the cultural imprint they bear is certainly very strong in each case. Nevertheless, this unavoidable conclusion has opened the way to controversial issues, especially when the famous mathematician and historian of mathematics van der Waerden deduced from this that all ancient mathematics have a common Indo-European origin (van der Waerden, 1983). This new theory has gained little acceptance and it is a fact that it surpasses by far the data on which it is based.

However, Chinese mathematics also contains examples of approximation formulae apparently not attested anywhere else. These all occur in Chinese astronomy and concern astronomical problems such as that of the determination of gnomon shadows or questions of conversions between the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) and equatorial coordinates.

The monograph on mathematical astronomy of the Song Dynasty, the *Songshi* (Song History), an official text compiled between 1343 and 1345, for example, reports that between AD 1102 and 1106, Chinese imperial astronomers devised a new theoretical algorithm for the determination of the length of the shadow of the sun cast by a standard gnomon 8 *chi* (feet) long, each day, at noon, during a whole year. If $t =$ the number of days elapsed since the last winter solstice and

$$s_1(t) = 12.83 - \frac{20,000t_2}{100\left(100,617 + 100t + \frac{10,000t_2}{725}\right)},$$

$$s_2(t) = 1.56 + \frac{4t^2}{7,923 + 9t},$$

$$s_3(t) = 1.56 + \frac{7,700t^2}{13.584,271.78 + 44,718t - 100t^2},$$

at Kaifeng, the Song imperial capital whose latitude is 34°48′45″, the length of the shadow of the gnomon is computed as follows (the original text is formulated in words, with no symbols, but its interpretation is straightforward):

if $t < 662.2$	$l(t) = s_1(t)$
if $< 62.2 < t < 91.31$	$l(t) = s_3(182.62 - t)$
if $< 91.31 < 182.62$	$l(t) = s_2(182.62 - t)$
if $< 182.62 < t < 273.93$	$l(t) = s_2(t - 182.62)$
if $< 273.93 < t < 303.04$	$l(t) = s_3(t - 182.62)$
if $< 303.04 < t < 365.24$	$l(t) = s_1(365.24 - t)$

The various numerical coefficients appearing in these formulae all depend on the lengths of the seasons.)

Chen Meidong, a contemporary historian of Chinese astronomy from the Academia Sinica in Beijing, has compared the results provided by these approximate formulae and those of actual observations (simulated for the years 1102–1106 by using the modern astronomical theory of the sun backward). He has concluded that the error never exceeds 0.02 *chi*, that is much less than a centimeter! Yet Song astronomers were still not satisfied with their approximation and sought new formulae; some of these have reached us. Incidentally, these formulae are vaguely reminiscent of the Indian approximation formula for the sine, cosine, and other trigonometric functions cited in (Gupta, 1972). In both cases the approximations use rational fractions.

Another interesting approximation formula occurs in the *Yuanshi* (Yuan History), an official compilation written about AD 1370 but reporting on Guo Shoujing's astronomical reform undertaken one century earlier. (Guo Shoujing (1231–1316) was a specialist on canal draining and astronomy.) Without going into too much detail, we note that Guo's technique was devised to compute certain segments corresponding to given arcs of circles similar to those which arise when converting ecliptic coordinates into equatorial coordinates. For us the question is solved in a relatively simple way by means of spherical trigonometry. But plane and spherical trigonometry were both unknown in China at the time, so that the mathematical techniques of Chinese astronomy had necessarily to rely on approximation formulae. In particular, Guo's technique relied on the three following formulae:

1. $p = \sqrt{r^2 - q^2} = \sqrt{(2r - v)v}$,
2. $x = p + \frac{v^2}{2r}$,
3. $v^4 + (4r^2 - 4rx)v^2 - 8r^3v + 4r^2x^2 = 0$,

where r represents the radius of the "trigonometric" circle, and p, q, and v the sine, cosine, and versed sine of the arc x, respectively.

Formula (1) is exact; (2) and (3) are approximate. The polynomial of the fourth degree in v, (3), is the consequence of the elimination of the half chord p between the second part of (1) and (2); (3) serves to compute v given the arc x by finding a root (in fact the smallest positive one) of (3) by means of a technique similar to that which is usually known as "Horner's method" (from a method attributed to the British mathematician William George Horner (1786–1837) who lived five centuries after Guo Shoujing). Lastly we also observe that Guo Shoujing divides the length of the circumference into as many degrees as there are days in a year (365.25°) and computes the radius of the corresponding circle by dividing the circumference by 3 (i.e., by taking $\pi = 3$). A priori, the reliance on such a value of π would indicate a severe mathematical deficiency. However, when Guo Shoujing devised his techniques, better values of π, such as Zu Chongzhi's (429–500) celebrated approximation $\pi = 355/113$, were currently available in China. In fact, according to Toshio Sugimoto, a mathematical analysis of the above formulae shows that when (1), (2), and (3) are computed using approximations of π better than 3, worse results are obtained! The recourse to approximations disturbs the impeccable logic which would hold if exact representations were used.

These various examples show that approximation formulae are well represented everywhere but that some of them are attested only in China. As recent works by historians of Chinese astronomy indicate, the recourse to such formulae seems typical of Chinese astronomy (see the articles in the journal *Ziran Kexue shi yanjiu*, 1982–1994). Are Chinese approximation formulae really original or are they also found elsewhere? Further historical researches not limited to Chinese mathematics will perhaps shed some light on a question which has never really been studied in depth.

See Also

▶ Guo Shoujing
▶ Jiuzhang Suanshu
▶ Mathematics
▶ Pi in Chinese Mathematics
▶ Zu Chongzhi

References

Bruins, E. M., & Rutten, M. (1961). *Textes mathématiques de Suse*. Paris: P. Geuthner.

Gericke, H. (1990). *Mathematik im Abenbland von den romischen Feldmessern bis zu Descartes*. Berlin, Germany: Springer.

Gupta, R. C. (1972). Indian approximations to sine. Cosine and verse sine. *Mathematics Education, 6*(2), 59–60.

Libbrecht, U. (1973). *Chinese mathematics in the thirteenth century: The Shu-shu chiu-chang of Chin Chiu-shao [i.e. Qin Jiushao]*. Cambridge, MA: The MIT Press.

Martzloff, J.-C. (1987). *Histoire des mathématiques chinoises*. Paris: Masson. English translation by Stephen S. Wilson. *A history of Chinese mathematics*. New York: Springer, 1997 and 2006.

Meidong, C. (1989). Huangyou, Chongning gui chang jisuan fa zhi yanjiu (Researches on the length of the shadow of the sun cast by a gnomon during the Huang You and Chongning eras). *Ziran kexue shi yanjiu, 8*(1), 17–27.

Neugebauer and Sachs. (1945). *Mathematical cuneïform texts*. New Haven, CT.

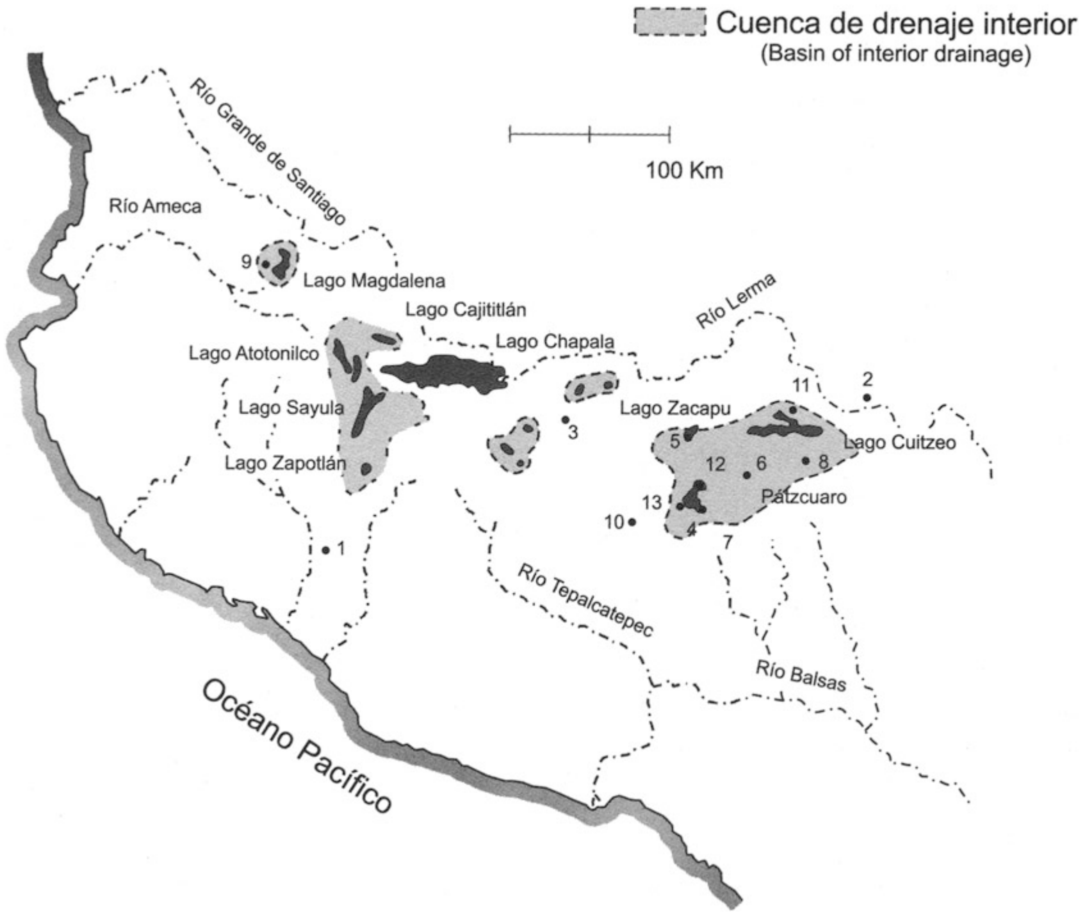
Sugimoto, T. (1987). Guanyu Shoushili de Shen Gua de nizhengxian gongshi de jingdu (On the precision of Shen Gua's arcsine formula in the Shoushi calendar). *Meiji gakuin ronso, 429*, 1–12.

van der Waerden, B. L. (1983). *Geometry and algebra in ancient civilizations*. Berlin, Germany: Springer.

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities

Eduardo Williams
Centro de Estudios Arqueológicos (CEArq), El Colegio de Michoacán, Zamora, Michoacán, Mexico

Pre-Hispanic Mesoamerica was the only civilization in the ancient world which flourished without access to major domesticated animals such as horses, cattle, pigs, and sheep (Diamond, 1999). Therefore, fishing, hunting, and gathering had to provide all the nutritional complement to agriculture (Parsons, 2006, 2010, 2011; Rojas, 1998), and aquatic environments were by far the most productive landscapes in Mesoamerica (Parsons, 2010, 2011). Ethnohistorical and ethnographic research has allowed us to characterize the Mesoamerican aquatic lifeway by means of three basic subsistence activities: (a) fishing, which included many edible water species besides fish; (b) hunting, including aquatic species such as waterfowl, reptiles, amphibians, and many others, as well as terrestrial species from the lake basin and the nearby hills; and (c) gathering of plants obtained for nutritional, medicinal, and many other purposes, such as building material and basket weaving, and finally



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 1 Main lakes and rivers of Western Mexico. *Shaded* areas indicate interior drainage basins including the major archaeological sites: (*1*) Capacha, (*2*) Chupícuaro, (*3*) El Opeño, (*4*) Ihuatzio, (*5*) Loma Alta, (*6*) Loma Santa María, (*7*) Pátzcuaro, (*8*) Queréndaro, (*9*) Teuchitlan/Etzatlán, (*10*) Tinganio, (*11*) Tres Cerritos, (*12*) Tzintzuntzan, and, (*13*) Urichu (Base map adapted from Tamayo & West, 1964, Fig. 4)

insects and their eggs, which were an important source of protein (García Sánchez, 2004, p. 27; Parsons, 2006; Williams, 2009a, 2009b, 2014a, 2014b). To these three activities, we should add the manufacture of many implements, features, and artifacts which were indispensable for the survival and reproduction of social groups.

Subsistence Activities in Aquatic Environments

What follows is a brief discussion of fishing, hunting, gathering, and manufacture using wild aquatic species in several areas of Mesoamerica during ancient and modern times, from the perspective of ethnography, ethnohistory, and archaeology. This is a study of pre-Hispanic technology, highlighting material culture and many examples of its survival from ancient times into the twenty-first century. The areas under discussion are the Cuitzeo and Pátzcuaro lakes in Michoacán and Lake Texcoco in the Basin of Mexico (Fig. 1).

Fishing

In pre-Hispanic times, Mesoamerica's lakes, marshes, and rivers had a great abundance of

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 2 The *corral* is a fish trap made of *carrizo* reeds, used in Lake Cuitzeo

fish, reptiles, and many other animal species which contributed to human subsistence. Several fishing techniques are still used in Lake Cuitzeo, such as nets, fishhooks, and traps known as *corrales*, which are made of reeds (Fig. 2). Many kinds of fish are caught in these traps, as well as animals such as frogs and ducks. As much as 5 kg of fish are caught in the corral in 1 day, and in the dry season, when the level of the lake is lower, the daily catch can be 10 kg. A single fisherman can have 20 or 30 *corrales*, although in some cases the number can be as high as 50, and tending them is a full-time occupation.

At present, some fishermen still make their own fine-mesh nets fixed on a round circular frame with a long handle, both made of *pirul* wood or willow twigs, which are notably flexible (Fig. 3). Several other kinds of nets that were used around Lake Cuitzeo in the early twentieth century are no longer seen, but the *chinchorro*, or seine net (Fig. 4), and the *atarraya* (Fig. 5) are still important at both Lake Cuitzeo and Lake Pátzcuaro.

Another fishing technique, known as *tumbo* in lake Cuitzeo, involves a long, narrow gill net held in a vertical position by floaters (today plastic bottles have replaced the traditional pieces of reed stalks) and reed posts (Fig. 6a). The *tumbo* is 40–50 cm high and may be up to 100 m long. Each fisher has his own nets and uses personal marks, such as distinctive knots, to distinguish them from others. On average, 10 kg of fish are caught daily in each *tumbo* and then sold in

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 3 The *red de aro* (ring net) was used for fishing in Lake Cuitzeo until recent times

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 4 At Lake Pátzcuaro, the *chinchorro* is handled mostly by men. In this case, however, a fisher from the town of Tareiro is helped by his two daughters

lakeside towns. A similar gill net is called *cheré mekua* at Lake Pátzcuaro (Fig. 6b).

The *nasa* is a fish trap that was used until some 50 years ago in the Lake Cuitzeo Basin, which

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 5 The *atarraya* is a small throw net used in Lake Cuitzeo (this specimen) and Lake Pátzcuaro

was made by weaving willow twigs (Fig. 7) in a process very similar to that of making a basket. Making *nasas* as a craft has died out in the Lake Cuitzeo Basin, but they are still manufactured in Lake Chapala by a single family of artisans.

Hunting

Many animal species were hunted in the Lake Cuitzeo Basin in the past. In pre-Hispanic times, hunting wildfowl may have been an important activity in this area, as it was in the late sixteenth century, according to the extant historical sources (see Williams, 2009a for a discussion of the ethnohistorical information). The Lake Cuitzeo and Pátzcuaro basins are relatively rich in wildlife, although most wild animals have decreased in number in recent years.

Hunting has decreased in importance for local subsistence and the economy of Lake Pátzcuaro, as well as at Lake Cuitzeo. Though duck hunting has virtually disappeared from many lakeside communities, up to just a few decades ago, this activity was still quite important. The number of ducks that visit Lake Pátzcuaro has declined sharply, but duck hunting is still regarded as a distinctive feature of the Tarascan (or Purépecha) Indians of Lake Pátzcuaro. Every year around the end of October, there is

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 6 The gill net is called *tumbo* in Lake Cuitzeo (**a**) and *cherémekua* in Lake Pátzcuaro (**b**). This net is still used to catch many species of fish

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 7 The *nasa* is a trap once used to catch fish in Lake Cuitzeo but still in use at Lake Chapala, where this specimen was found

a communal duck hunt known as *kuirisi atakua* – an ancestral tradition that renews contacts and social bonds among several Indian communities (Toledo et al., 1980).

Many species of aquatic birds are hunted in Lake Pátzcuaro, including those known as *gallaretas*, and several duck species, all of which arrive at the lake from North America around September. According to one of the fishers from this lake, "Birds used to arrive here by the millions." In Jarácuaro, fishers used to hunt ducks seasonally for food (from early November to late December) using the *fisga* (a harpoon-like weapon made of *carrizo* reed; see Fig. 8), thrown with an *atlatl* (spear thrower) called *tzipaki* in Tarascan (Figs. 9 and 10). According to the same informant quoted above, "Ducks no longer come here; it used to be they'd start to arrive in October and on October 31st we used to go hunting." The hunters would go out in their canoes from eight in the morning to three in the afternoon to look for ducks on the lake. On one trip, they might catch as many as 140 birds. According to our informants, this took place between 1945 and 1950, but as late as 1960 wild ducks still formed part of the diet in Jarácuaro (in the Lake Pátzcuaro Basin), while some were taken to Pátzcuaro for sale.

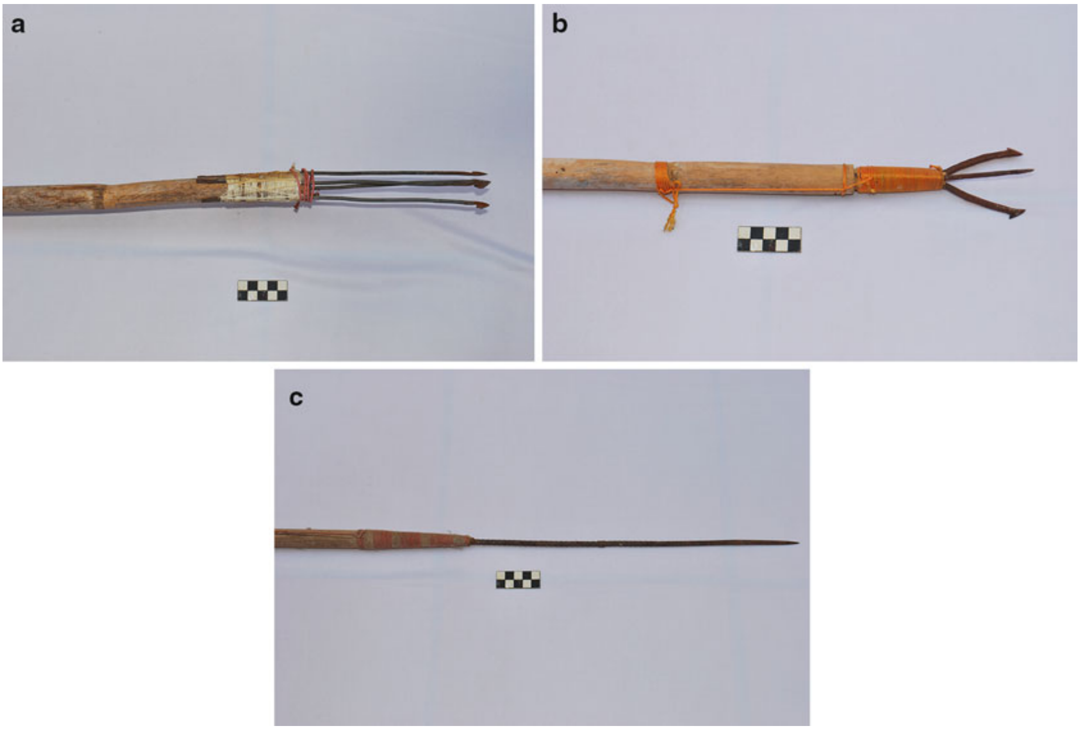
The *Florentine Codex* is one of the best sources of information about ancient Mesoamerican subsistence activities (Sahagún, 2012). This book is dedicated to documenting the civilization of the Aztecs of the Basin of Mexico, and its value for archaeologists resides in its faithful and detailed portrayal of material culture. Figure 11, taken from the *Florentine Codex*, shows a net used by Aztec fishers and hunters to catch wild ducks in the shallow waters and marshes of the Basin of Mexico. This hunting technique was also used until recent years in the lakes and marshes of the Upper Lerma River Basin (Albores, 1995).

Gathering and Manufacture

The Lake Cuitzeo Basin has an abundance of wild plants, which have been used for food and medicine since early times, according to the extant sources from the sixteenth century. The *Relación de Cuiseo de la Laguna*, for example, mentions several medicinal plants: "There is a weed called *andumucua* [tobacco, *Nicotiana* sp.] . . .which is greatly esteemed by the natives. . . and. . .it gives them so much heat and strength. . . There is likewise a tree the natives call *chupirini*, which they use for the bubonic illness: they cut a branch and milk comes out. . . and. . . they take it with a little chicken soup. . ." (Acuña, 1987, p. 87).

Several wild plants are still used for food and medicine in the Lake Cuitzeo Basin. An edible tuber known as *Nymphaea gracilis* is similar to the potato in taste and manner of cooking, although it has become scarce in recent years. Another edible wild plant is called *Berula erecta*, which is also good for making infusions used in stomach and kidney ailments. Lastly, the local people also eat the *berro* (*Rorippa nasturtium-aquaticum*) (Rojas & Novelo, 1995, p. 14).

Among Lake Cuitzeo's aquatic plants, two *tule* species are the most important: *Typha latifolia* and *T. domingensis* (Ávila, 1999, p. 186), as well as carrizo (*Arundo donax*). Reeds and rushes have been very important for the local economy since ancient times, and they still are, although less so now than before. *Tule* and *carrizo* are still used for building houses, which are quite fresh, but people have to be careful, since these plants are quite flammable when dry. Most houses were made of tule and carrizo (or carrizo covered with mud) in the



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 8 The *fisga* is a *carrizo* spear around 3 m in length with metal prongs. It is used for hunting frogs and fishing in Lake Cuitzeo (**a**), while in Lake Pátzcuaro, it is used to hunt waterfowl (**b**) and for fishing (**c**)

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 9 This *atlatl*, called *tzipaki* in Tarascan, was used to hunt waterfowl in Lake Pátzcuaro. This item comes from Tareiro, Lake Pátzcuaro Basin

villages and towns around the lake until about 50 years ago, but this type of "vernacular architecture" is becoming scarce to the point of virtual extinction. Tule is cut from the plant using a scythe-like tool called *hoz* in Spanish (Fig. 12); in ancient times, sawlike chert implements may have been used to cut reeds (Fig. 13).

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 10 A fisher from Tareiro showing how the *tzipaki* was used to hunt ducks in Lake Pátzcuaro

Fishermen in a lakeside town called Mariano Escobedo catch insects known as *mosco de agua* or *nizpo* (*Corisella texcocana* and *Ephydra* sp.), which are used as bird feed. Four varieties of

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 11 Nets were used to hunt ducks and other aquatic birds at Lake Texcoco in ancient times, as recorded by Father Bernardino de Sahagún in the *Florentine Codex* (Adapted from Sahagún, 2012, Figure 187)

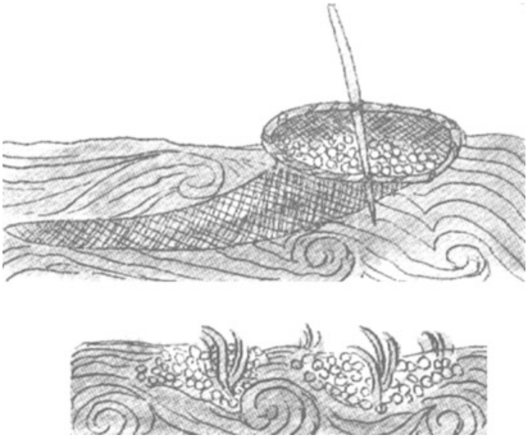
Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 12 The sickle is used to cut *tule* and *carrizo* in both Lake Cuitzeo and Lake Pátzcuaro

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 13 The ancient aquatic lifeway included activities, like cutting *tule* and *carrizo*, that might be characterized by items like this sawlike (serrated) cutting tool found in Lake Texcoco, Basin of Mexico (Courtesy of Jeffrey Parsons)

nizpo are known here (*picalón, barrilito, paloma*, and *de sangre*), and they all lay eggs which may also have been exploited in ancient times. The season for gathering *mosco* is during the months of August, September, and October, when the lake level is low. According to the fishermen, in shallow areas of the lake (with a depth of 8–20 cm), murky water is ideal for gathering the insects. The net used for this activity is called red *mosquera*. It is of finer mesh than the one used for fishing; it is 4 m wide by 180 m long and is dragged by four men in order to capture the insects that are on the water surface. In a good season, as much as 50–60 kg of *mosco* is taken in 1 day, although this is a diminishing resource.

A method used for harvesting mosco eggs is known as *costalera*, which consists of several sacks tied to wooden stakes sunk in the bottom of the lake. Once the insects lay their eggs, the sacks are taken out of the water and dried under the sun during 3 or 4 days. After this, the sacks are shaken and the eggs are collected in plastic bags (Argueta et al., 1986, p. 142).

Fishers at Lake Texcoco still gathered insect eggs until recent years using a special kind of net (Parsons, 2006). This was an important source of protein in ancient times, and together with algae collecting, fishing and hunting, aquatic insects and their eggs contributed to a complete and balanced diet (Parsons, 2011; Rojas, 1998). Father Sahagún recorded the techniques used for gathering aquatic insects at Lake Texcoco in the sixteenth century (Fig. 14).



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 14 In Aztec times, many aquatic insects were caught in nets (*top*), and their eggs were laid among aquatic plants in shallow lake areas, where they were gathered by fishers (*bottom*) (according to the *Florentine Codex*; adapted from Sahagún, 2012, Figures 224 and 225)

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 15 An artisan weaving a reed mat or *petate* in Coro, a town in the Lake Cuitzeo Basin. The only tools used in this activity are a stone called *piedra petatera* and a metal knife

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 16 The tool kit linked to *petate* weaving is quite simple, consisting of a stone (*piedra petatera*) and a metal knife. In the background of this figure is a *guangoche*, or sack made of *ixtle* (maguey) fiber, still used in the Lake Cuitzeo Basin

Lake Cuitzeo was once well known for the *petates*, or reed mats, made with tule from the lake. Petate weaving is still important for the domestic economy in the Lake Cuitzeo Basin, although it has been in decline since the 1950s. After cutting and drying the reed stalks, they have to be slightly moistened in order to weave a petate. The weaver uses a stone known as *piedra petatera* or *petatura* which is 7–10 cm in diameter and 3–4 cm thick; its shape is well adapted to the hand of the artisan who uses it to flatten the tule fibers as he or she weaves the petate. These stones sometimes are found when people dig canals, ditches, or even tombs in the local graveyard, so they may be quite old. Each *petatero* (tule weaver) (Fig. 15) has his or her own stone (Fig. 16), which may be passed down from generation to generation. In some towns around the lake, there are specialists who manufacture these stones. The only other tool used for tule weaving is a metal knife to cut the fibers and finish the reed mat.

The *carrizo* reed is no less important than tule for the local economy. Carrizo needs to be mature in order to be worked. Once the plant is cut and taken to the workshop, the artisan spends 3 days a week cutting the reeds in order to have the fibers used in making a basket (Fig. 17). Two days a week are dedicated to weaving the bottom of the basket and 2 days in weaving the rest of the basket. The tools used to make a carrizo basket in several towns such as Colonia Guadalupe (see map, Williams, 2014a, Fig. 2) are the stone hammer and anvil (called *piedras de majar*, see Fig. 18) and several metal knives.

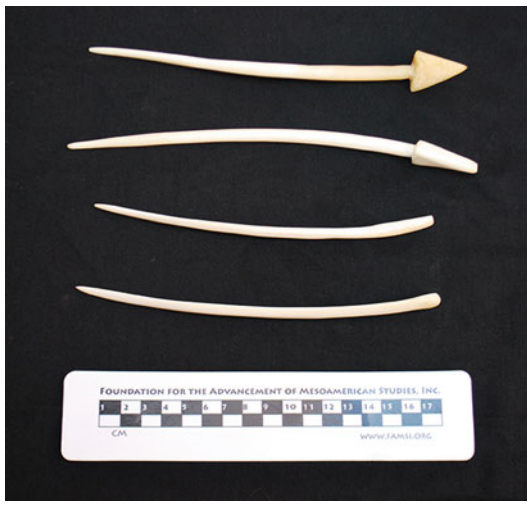
Some fishermen still weave their own nets of cotton or synthetic thread, which has replaced the *maguey* (*Agave* sp.) fiber still used in the first half of the twentieth century. Weaving is carried out using wooden tools called *malacate*, *astilla*, and *aguja plana* (Fig. 19). Don Fidencio, a fisherman

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 17 Artisan in Ihuatzio (Lake Pátzcuaro Basin) trimming *carrizo* reed with a steel knife used in basket-making

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 18 Hammer and anvil stones used for making *carrizo* reed baskets in the domestic workshop shown in Fig. 17

in Estación Querendaro, showed us how these artifacts are made. The wood he uses comes from the *zapotillo* tree, which has to be green. A machete and several knives of different sizes are used for making these wooden artifacts. Don Fidencio told us that many years ago, he used to make needles for weaving fishnets out of cattle bone. He agreed to make some for us, which are shown in Fig. 20. Similar pre-Hispanic artifacts have been found at Lake Sayula, Jalisco (Fig. 21); they may have been used for weaving baskets or making nets.

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 19 Wooden tools used for weaving a net. From *top* to *bottom*: *malacate* (two shown, one with cotton thread), *aguja plana*, and *astilla* (Estación Queréndaro, Lake Cuitzeo Basin)



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 20 A fisher from Estación Queréndaro (Lake Cuitzeo Basin) made *malacates* and needles from cow bone that were similar to pre-Hispanic artifacts. In ancient times, such items might have been made of animal bone or deer antler

Conclusions

The ethnographic, archaeological, and ethnohistorical data discussed in this entry help shed light on the cultural processes and the resulting archaeological correlates (i.e., artifacts and features)

Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 21 These pre-Hispanic artifacts were found at Lake Sayula, Jalisco; they may have been used as awls for weaving baskets or as needles for making nets (Photo courtesy of Ericka Blanco)

linked to aquatic subsistence in Michoacán and other areas of Mesoamerica. This information is vital for interpreting the archaeological record in all those regions of Mesoamerica where lakes, rivers, marshes, and streams offered their natural bounty for human exploitation (Williams, 2009a, 2009b, 2014a, 2014b).

In the last 60 years or so, many traditional activities and manufactures have all but vanished from the Mexican lake basins discussed here, such as maguey fiber processing and *pulque* (i.e., an alcoholic drink made from maguey sap) making. Because of the serious problems affecting most aquatic environments in Mexico, such as pollution, deforestation, and desiccation, the present generation of researchers may well be the last one to document a traditional aquatic lifeway reminiscent of the pre-Hispanic past.

References

Acuña, R. (1987). *Relaciones geográficas del siglo XVI: Michoacán*. Mexico City, Mexico: UNAM.

Albores, B. (1995). *Tules y sirenas: el impacto ecológico y cultural de la industrialización en el Alto Lerma*. Toluca, Mexico: El Colegio Mexiquense and Secretaría de Ecología, Gobierno del Estado de México.

Argueta, A., Merino, M., Zubieta, T., Campos, S., Chávez, J. L., Rauda, J., et al. (1986). Japondarhu anapu, o de la pesca en los lagos michoacanos. In A. Argüeta, D. Cuello, & F. Lartigue (Eds.), *Los pescadores de México*. Cuadernos de la Casa Chata 122. Mexico City, Mexico: Ciesas.

Avila, P. (1999). El valle Morelia-Queréndaro y su deterioro ambiental. In E. Barragán (Ed.), *Frutos del campo michoacano*. Zamora, Mexico: El Colegio de Michoacán.

Diamond, J. (1999). *Guns, germs, and steel: The fates of human societies*. New York: Norton.

García Sánchez, M. (2004). El modo de vida lacustre en el valle de México: ¿mestizaje o proceso de aculturación? In E. Florescano & A. Virginia García (Eds.), *Mestizajes tecnológicos y cambios culturales en México*. Mexico City, Mexico: Centro de Investigaciones y Estudios Superiores en Antropología Social.

Parsons, J. (2010). The Pastoral Niche in pre-Hispanic Mesoamérica. In J. E. Staller & M. D. Carrasco (Eds.), *Pre-Columbian foodways: Interdisciplinary approaches to food, culture, and markets in ancient Mesoamerica*. New York: Springer Science and Business Media.

Parsons, J. (2011). El 'nicho pastoral' en la Mesoamérica prehispánica: ¿cómo funcionó una civilización sin ganado domesticado. In E. Williams, S. Magdalena García, G. Manuel, & P. C. Weigand (Eds.), *Mesoamérica: debates y perspectivas*. Zamora, Mexico: El Colegio de Michoacán.

Parsons, J. (2006). *The Last Pescadores of Chimalhuacan, Mexico: An archaeological ethnography* (Anthropological Papers 96). Ann Arbor, MI: Museum of Anthropology, University of Michigan.

Rojas, T. (1998). *La cosecha del agua en la cuenca de Mé xico*. Mexico City, Mexico: Ciesas.

Rojas Moreno, J., & Novelo, A. (1995). Flora y vegetación acuáticas del Lago de Cuitzeo, Michoacán, México. *Acta Botánica Mexicana, 31*, 1–17.

Sahagún, B. (2012). General History of the Things of New Spain. In C. E. Dibble & A. O. Anderson (Eds.), *Florentine codex: Book 11, the earthly things*. New Mexico, Mexico: The School of American Research.

Tamayo, J., & West, R. C. (1964). The hydrography of Middle America. In R. Wauchope (Ed.), *Handbook of middle American Indians* (Vol. 1). Austin, TX: University of Texas Press.

Toledo, V. M., Caballero, J., Mapes, C., Barrera, N., Argüeta, A., & Núñez, M. (1980). Los purépecha de Pátzcuaro: una aproximación ecológica. *America Indigena, 40*(1), 17–56.

Williams, E. (2009a). Producción e intercambio de recursos estratégicos en la cuenca de Cuitzeo, Michoacán, durante el periodo Protohistórico. In W. Eduardo, M. Lorenza López, & E. Rodrigo (Eds.), *Las sociedades complejas del Occidente de*

México en el mundo mesoamericano: homenaje al Dr. Phil C. Weigand. Zamora, Mexico: El Colegio de Michoacán.
Williams, E. (2009b). The exploitation of aquatic resources at Lake Cuitzeo, Michoacán, Mexico: An ethnoarchaeological study. *Latin American Antiquity, 20*(4), 607–627.
Williams, E. (2014a). *Water folk: Reconstructing an ancient aquatic lifeway in Michoacán, Western Mexico* (BAR International Series 2617). Oxford, UK: Archaeopress.
Williams, E. (2014b). *La gente del agua: etnoarqueología del modo de vida lacustre en Michoacán*. Zamora, Mexico: El Colegio de Michoacán.

Archaeoastronomy of North Africa

César Esteban
Instituto de Astrofísica de Canarias, La Laguna, Santa Cruz de Tenerife, Spain

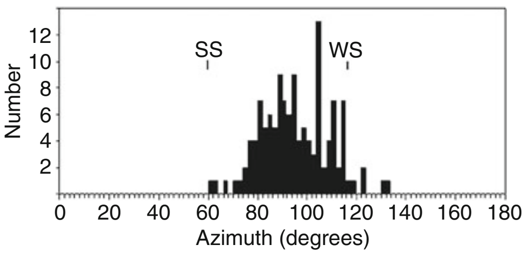
In this entry, I review data on orientations of pre-Islamic funerary and religious monuments in North Africa, including Sahara and the Maghreb and excluding Egypt, which has been extensively discussed elsewhere. The time span of the monuments discussed is extremely wide, from the Neolithic up to the Arabic invasion. The main conclusion is that there were enduring patterns in the orientations, very likely related to the ritual or symbolic importance of the rising sun. The overwhelming evidence confirms the strong solar aspects of the North African religion that the ancient writers indicated.

The prehistoric drystone funerary monuments of the Sahara are called *idebnan* (in plural) and *idebni* (in singular) by the present-day Tuareg. There are several different architectural types, and they are distributed in a very extended geographical area. Early European visitors realized that a large proportion of these monuments tend to be orientated with their main distinctive elements towards the east. The earliest type of *idebnan* is called "keyhole monument." Paris (1996) obtained radiocarbon dates for some of these monuments in Niger (Emi Lulu) finding that they date from 3600 to 220 BCE. This kind of monument is found even more densely at Tassili (Algeria). Savary (1966) obtained that the orientations of 158 keyhole monuments in Fadnoun (Algeria) lie in the azimuth range where the sunrise (or moonrise) takes place and can be described as a clear case of sunrising (SR) custom following Michael Hoskin's definitions (Hoskin, 2001, pp. 19–20). Gauthier and Gauthier (2006) collect information about the orientation of 205 of these monuments in different geographical areas, finding a rather Gaussian distribution centered on an azimuth of about 98° without any local variation.

Another relevant type of Saharan drystone prehistoric burial is the so-called V-shaped monument which consists of a tumulus and two lines or arms of stones – also called antennae – that could be about some tens of meters or even up to 200 m long (see Fig. 1). These monuments are more concentrated in the Messak Settafet in the Fezzan region of Libya. The earliest monuments of this kind are dated about 3200–2900 BCE (Cremaschi & di Lernia, 1998). Hachid (2000) has compiled data for many *idebnan* in Tassili indicating that the antennae of most of the V-shaped monuments of this zone are oriented to the east. Some of them are located in the middle of wonderful landscapes, facing the borders of the impressive mountain ranges of Tassili. Recent statistical studies of the orientations of 49 and 31 V-shaped monuments of the Messak plateau (Fezzan, Libya) and Immidir Mountains (Algeria) by Gauthier and Gauthier (1999, 2003; see Fig. 1) show that the bisectors of the antennae show a narrow range of orientations also consistent with an SR custom. Other kinds of drystone monuments as the "platforms cairns with an arm" (Gauthier & Gauthier, 1999) and "L-shaped monuments" (Gauthier & Gauthier, 2001–2002) of Fezzan, as well as the "goulets" (narrow parts) of Immidir (Gauthier & Gauthier, 2003), show exactly the same orientation pattern (Fig. 2).

Later types of Saharan stone burials such as "crater tumulus" and "monuments with an alignment," which are dated from 1900 BCE down to the start of Islamic culture locally, also have their structural elements as well as the head or faces of their skeletons oriented to the east (Hachid, 2000).

Archaeoastronomy of North Africa, Fig. 1 Example of a typical Saharan V-shaped drystone monument, located 30 km to the southeast of Al Awaynat (Fezzan, Libya) (Photo by Yves Gauthier (February 2006). Used with his permission)

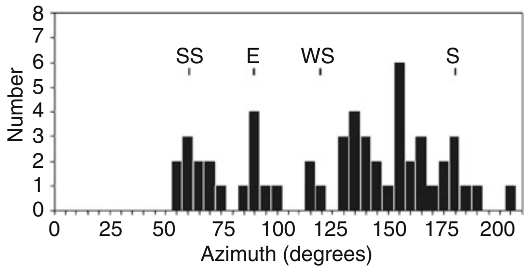


Archaeoastronomy of North Africa, Fig. 2 Number histogram of orientations of 132 V-shaped monuments, "goulets," and "platform cairns with an arm running eastwards" of Immidir (Algeria) and Fezzan (Libya). Data are binned in 2° intervals. SS and WS indicate the azimuths of the rising sun at summer and winter solstices, respectively (Diagram adapted from Gauthier and Gauthier (2003)). This is an example of a sun-rising (SR) custom of orientations

Gauthier and Gauthier (2008), based on a large number of orientation measurements of "monuments with an alignment," estimated from Google Earth satellite images found possible relation with the rising moon and rather clear regional variations. Other Saharan stone monuments – not necessarily related to tombs – as the so-called "horseshoe" structures with a straight line of little towers or altars are usually also oriented to the east, although with a much wider azimuthal distribution. These monuments are also known as "tents of Fatima" and are supposedly rural shrines. However, some kinds of monuments such as the single or triple crescents of the Messak Settafet, some crescents of south Algeria, and the bazina/tumulus with small auxiliary towers of Morocco and Algeria do not follow the typical Saharan orientation customs (Gauthier & Gauthier, 2002, 2003, 2005). In fact, the orientations of the last group of monuments could be oriented towards the rising or setting moon. It would be interesting to reassess the orientation data of Saharan monuments considering the correction due to the real (non-flat) horizon where the monuments are actually facing, a kind of analysis that has not yet been carried out in the area.

Earlier possible evidence of astronomical observances by the Neolithic Saharan people has been found at Nabta Playa in Egypt, on the border of the Libyan Desert (McKim Malville et al., 1998). Here a group of megalithic circles and stone rows dating from some time earlier than 4500 BCE are oriented to the summer solstice or zenith passage of the sun.

Burial monuments of coastal and pre-desert zones of North Africa from the first millennium BCE up to the Islamic conquest are extremely diverse. One can find simple and monumental dolmens, tumuli of very different typology, rock-cut tombs (*hawanat*), hypogaea (the subterraneous portions of a building or subterranean galleries, such as the catacombs), and the later great mausolea. In his magnificent book about protohistoric funerary monuments of North Africa, Camps (1961) admits that the orientation of the main entrances, façades, and corridors of those burial monuments is in most cases consistent with a general east–west arrangement. This fact makes one wonder if the protohistoric



Archaeoastronomy of North Africa, Fig. 3 Number histogram of orientations of 53 dolmens at Elles (Tunisia). Data are binned in 5° intervals. SS and WS indicate the azimuths of the rising sun at summer and winter solstices, respectively; E and S indicate east and south, respectively (Data taken from Belmonte et al. (1998)). This is an example of a sun-rising/sun-climbing (SR/SC) custom of orientations

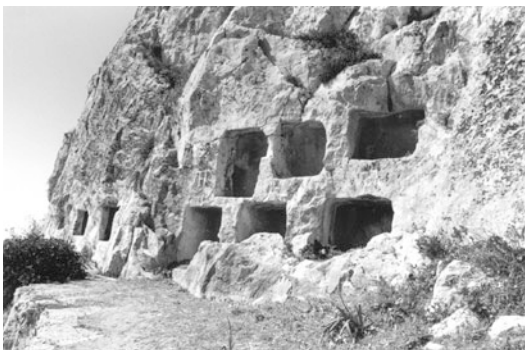
orientation pattern is related to the ancient Neolithic Saharan traditions discussed above.

Savary (1969) analyzed the precise orientations of 13 North African dolmens at Beni Messous (Algeria). He found that the orientation pattern could be classified as a sun-rising/sun-climbing (SR/SC) custom following Hoskin's scheme (Hoskin, 2001, pp. 19–20); this definition covers a range of azimuths from about 60° to due south or thereabouts. This range includes the sunrise and the position of the sun while it is climbing in the sky or around culmination. Belmonte, Esteban, and Jiménez González (1998) have measured dolmens in different necropolises of Northern Tunisia. These authors find a clear SR/SC pattern for the orientations of megalithic monuments of the necropolis of Elles (see Fig. 3). An SC and an SR/SC orientation pattern seems applicable to the dolmenic necropolis of Thugga and the complex megalithic tombs of Mactar (see Fig. 4), respectively. On the other hand, the very rough and simple dolmens of Bulla Regia show a highly unusual westerly orientation. Hoskin and Foderà Serio (private communication) and Hoskin (2001) consider that the reason for the orientation of the dolmens in the Tunisian necropolises of Elles, Henchir Midad, and some others around the town of Mactar is simply topographical: they are facing downhill. However, the orientations of Henchir Midad have been further discussed by Belmonte et al. (2003) stressing their astronomical significance. They have studied the several groups of Numidian dolmens of Northern Tunisia, finding a general SR/SC orientation pattern. Finally, it is remarkable that several groups of rock-cut tombs (*hawanat*) of Northern Tunisia analyzed by Belmonte et al. (1998, 2003) also show orientations following the typical SR/SC scheme (see Fig. 5).

It is mostly accepted that the North African dolmens were earlier than the Roman conquest, perhaps prior to the Phoenician expansion, and clearly after the Neolithic (Camps, 1961, pp. 146–148). The distribution of the North African dolmens along the Maghreb suggests that their origin is not autochthonous and should be the Iberian Peninsula for the monuments of the north of Morocco and Sardinia, Corsica, Italy, and/or Malta for the Algerian–Tunisian group (Camps, 1961, pp. 149–152, 1995a, pp. 2508–2509). In this context, Camps remarks on the important role that Sardinia could play in this transmission. He notes that Diodorus Siculus (Diodorus V, 8) and later Pausanias affirmed the Libyan origin of the Sards. In fact, Hoskin (2001, pp. 175–192) has found that the 97.7 % of around 200 Sardinian dolmens, *corridoi dolmenici* and *tombe di giganti*, show the same orientation custom as the North African dolmenic and *hawanat* necropolises. Therefore, taking into account the differences with respect to the most common ancient Saharan pattern of orientations – which is clearly SR – the data are consistent with an alien origin of the North African dolmens and *hawanat*.

Information about the orientations of the most common protohistoric North African burial monuments – stone and earth tumulus and *bazinas* – is rather scarce, mostly because of the impossibility of defining an axis of symmetry in most of them. However, we have information about some groups of stone monuments: chapel tumuli, niche monuments, and the great Algerian mausolea. In the case of the chapel tumuli, there are detailed studies of two necropolises of the Tafilatl: the chapel tumuli of Taouz (see Fig. 6) show an apparent SR custom in their orientation (Belmonte et al., 1999; Castellani, 1995), while

Archaeoastronomy of North Africa, Fig. 4 Complex megalithic tomb of Mactar (Tunisia) with six chambers



Archaeoastronomy of North Africa, Fig. 5 Group of rock-carved tombs (*hawanat*) at Chauach (Tunisia)

the monuments at Hassi Beraber seem to be oriented somewhat more southerly, consistent with an SC custom (Castellani, 1995). Camps (1961) reviews data for the chapel tumuli of the necropolises of Bouia (Tafilatl) and Negrine, pointing out that all the monuments are oriented with their entrances facing east. From published plans of the chapel-tumuli of Djorf Torba, Belmonte et al. (1999) find two predominant orientations, to nearly due east and to southeast. Southeast and east seem also to be the orientation of a sample of circular niche monuments at d'El-Esnam and Kef Sidi Attalah, respectively. Belmonte et al. (1999) also study 34 skylight-tumuli in the necropolis of Foum al Rjam in the Saharan Morocco, finding a clear SR/SC custom in their orientation.

The most evolved and impressive pre-Islamic burial monuments of North Africa – the Algerian great mausolea (Medracen, Blad el-Guitoun, Tombeau de la Chrétienne, Djedar), which show clear Punic architectural and stylistic influences – have their ceremonial corridors and external platforms oriented towards the east (Camps, 1961, pp. 199–205). In particular, the Djedar of north Algeria are especially interesting because of their late chronology, which is as late as the fifth and sixth century AD, just before the Arabic conquest (Camps, 1995b, pp. 2419–2422). They represent the end-point of the genuine pre-Islamic North African funerary traditions.

Elements of the proto-Berber culture survived in the Canary Islands until its conquest by the Castilians in the fifteenth century. Belmonte et al. (1997) obtained orientation diagrams of the burial chambers of several important tumular necropolises in the islands of Gran Canaria and Fuerteventura, finding an SR (or sunsetting) custom in the necropolis at Tirba Mountain (Fuerteventura) and for the drystone tumuli of Maipez (Gran Canaria). Perhaps as a reflection of the mixed trends found in the continent, an SC custom is found for the tumuli of Arteara (Gran Canaria).

In the land of the Garamantes (Fezzan, Lybia), one finds burials of very different typology perhaps associated with the different cultural contacts experienced by this warrior people.

Archaeoastronomy of North Africa, Fig. 6 East-facing chapel tumulus of Taouz (Morocco) (Photograph reproduced from Belmonte et al. (2002))

Archaeoastronomy of North Africa, Fig. 7 Field of Garamantian pyramidal tombs at El Hatir (Fezzan, Libya)

The extensive excavations carried out by Daniels (1989) point out that the Garamantian tombs are mainly dated from Roman times. Belmonte et al. (2002b) have studied the orientation of funerary monuments in some of the most representative Garamantian necropolises as the pyramidal tombs of Charaig and El Hatir (see Fig. 7), the mud-brick tombs of Saniat ben Howedi, and the mastaba-like royal tombs at Germa. The pyramidal tombs are arranged with their four sides oriented approximately to the cardinal points. Many of the tombs of Saniat ben Howedi have stone offering tables and are facing near due east or due west. The most clear orientation pattern is shown by the mastaba-like and circular tumulus (with a stele showing the relevant direction) of the royal necropolis of Germa; all the tombs measured are oriented to the east, following a clear SR custom. Although the formal similarity to the Egyptian monuments is evident and even the presence of obelisks or stelae in their proximity could suggest a direct Nilotic influence, this is not entirely clear. Camps (1961, pp. 165–166) indicates that the Garamantian monuments are not very different to the pre-Islamic rectangular *bazinas* of late chronology that can be found elsewhere in North Africa, whose geographic distribution cannot be explained by a gradual diffusion from Egypt. Moreover, their orientation pattern is also consistent with the typical customs of the rest of the contemporary North African funerary monuments and especially with the much older and autochthonous *idebnan* of the Fezzan.

It is generally accepted that the impact of the Punic culture was profound and enduring on the Libyan or proto-Berber culture and especially on their religion (Bénabou, 1975, pp. 377–380; Picard, 1954). There are interesting facts about the orientations of Punic funerary monuments. Belmonte et al. (1998) find a clear SR custom in the early Punic necropolis of Utica and a doubled-peaked distribution centered on the sunrise at the equinoxes and the winter solstice in Menzel Temine and the early Phoenician necropolis of Villaricos in the southern Mediterranean coast of the Iberian Peninsula (Belmonte, 1999; his Fig. 5.5). A general east–west orientation is also found for the Punic necropolises of Tipasa in Algeria (Baradez, 1969) and of Aïn Dalia Lekbira in north Morocco (Alaoni, 2000). González García et al. (2006) have measured a large number of tombs in the Punic necropolises of Sardinia and Ibiza, finding a general tendency of orientations towards the solstices and equinoxes. However, there is not a regular orientation in all Phoenician/Punic necropolises studied. In Byrsa (Carthage), Belmonte et al. (1998) have found a rather unusual south–west distribution. In Dermech (Carthage), the orientations show an azimuth preference between 120° and 160°. Finally, the Maltese shaft tombs and burial chambers studied by Ventura (2000) show a clear preference for the approximate north–south direction. It is also interesting to remark that the general planning of the Punic sacred areas or tofets in Sicily and Sardinia is usually arranged along the cardinal axes (Ribichini & Xella, 1994). Finally, an additional interesting archaeological indication was obtained by Carton, who found that in an open sacred area in Thuburnica (Sidi-Ali-Bel-Kassem, Tunisia), all Neo-Punic stelae were orientated to the east (see Leglay, 1961, p. 276). In summary, there is not a regular pattern in the orientations of the Punic tombs, although many necropolises and funerary areas show an east–west custom. This has also been observed in the Phoenician–Punic necropolises of south Spain, where the archaic tombs (eighth–seventh centuries BCE) tend to be oriented to the east and the later ones do not follow that rule so strictly (Ramos Sainz, 1986, pp. 32–33).

The Roman custom of building mausolea or monumental tombs was also common in North Africa, especially from western Algeria to Tripolitania. Belmonte et al. (2002) compiled data on some different monuments of Roman epoch, and most of them were oriented following an SR custom. However, the largest concentration of mausolea from the late Roman epoch is in the settlement of Ghirza, in the Libyan pre-desert. The plans published by Brogan and Smith (1984) show that the doorways or the ornamental false doors of the tombs of the northern group show a clear SR custom, while the tombs of the northern complex are oriented towards the north (Esteban, 2003).

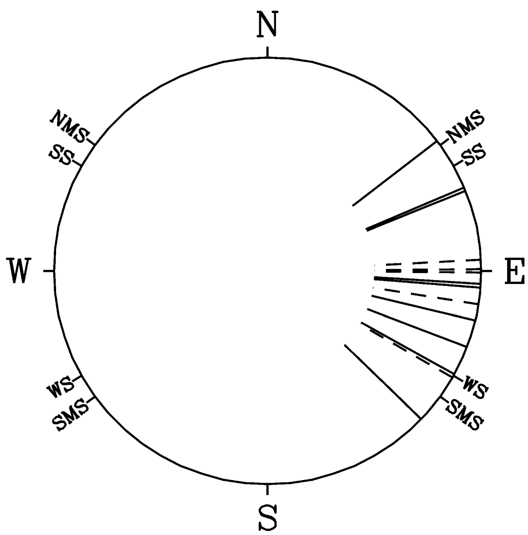
Perhaps the earliest known constructions that can be considered sanctuaries or temples in North Africa to the east of the Nile Valley are of Punic origin. The importance of the orientation in the Punic ritual is documented in a stone inscription found in the zone of Salammbo in Carthage. This stone was an offering placed in a sanctuary dedicated to Baal Hammon. The text indicates explicitly that the stone was orientated with its front side to the sunset and its back side to the sunrise (Xella, 1991, p. 48).

Esteban (2002) reports that the *Decumanus Maximus* of Roman Carthage – as well as the layout of the Roman and the Punic city and acropolis – is oriented towards the winter solstice sunrise. This author also compiled the orientations of five Punic and Neo-Punic temples and sanctuaries from published plans and measurements, finding that the temples were orientated towards a fairly narrow zone of the horizon, from 90° to 127°. It is remarkable that three of them are also oriented to or near the winter solstice sunrise.

Esteban et al. (2001) have carried out an extensive survey of the orientations of a large number of Roman and pre-Roman temples of Morocco, Tunisia, and Libya. Belmonte et al. (2006) measured additional temples of Northern Tunisia. Esteban et al. (2001) found that the complete sample of temples built in Roman times show a definite random distribution of orientations. Moreover, there is no correlation between the dedication of the temples and their orientation, except for those dedicated to Saturn. Most of the religious buildings dedicated to this deity are oriented following an SR custom (see Fig. 8).

Saturn was the most important deity worshipped in Northwest Africa in Roman times (Bénabou 1975, pp. 370–375; Leglay, 1966; Picard, 1954, pp. 100–129) from ancient Numidia

A



Archaeoastronomy of North Africa, Fig. 8 Orientations of temples dedicated to Saturn from Roman North Africa. Continuous lines: direct measurements by Esteban et al. (2001) and Belmonte et al. (2006); *dashed lines*: orientations obtained from published plans. *SS* and *WS* indicate the azimuths of the rising/setting sun at summer and winter solstices, respectively. NMS and SMS indicate the points where the rising/setting of the moon takes place at northern and southern major standstills, respectively

to Mauretania (present-day Tunisia to Morocco). Its cult had strong pre-Roman roots and was the inheritor of the ancient cult of the Punic Baal Hammon, who was the most important god of both the rural and Punicised Libyan population, probably because of the strong similarities of the Carthaginian deity with a former ancient supreme Libyan god (Leglay, 1966, pp. 417–447).

The cult to Saturn is almost completely absent in the deeply Punicised Tripolitania (Brouquier-Reddé, 1992, pp. 255–265; Leglay, 1966, pp. 267–268). In this region Jupiter Hammon was an adaptation of the great god of the Eastern Libyans, the ram-headed Ammon (see Bénabou 1975, pp. 335–338; Mattingly, 1994, pp. 167–168). The spread of the cult of Ammon is demonstrated by the many rural (mostly indigenous) temples or *ammonia* for which we have evidence in Tripolitania and among the Garamantes and the Libyan Desert oases of Siwa and Augila (Mattingly, 1994, pp. 36, 168). Esteban (2003) has collected published data for rural shrines built in Roman times in Tripolitania (Brouquier-Reddé, 1992, Esteban et al., 2001, and references therein) and for the Garamantian ashlar masonry temple at Germa (Esteban et al., 2001). It is remarkable that the range of orientations of many of the rural sanctuaries of Tripolitania show an orientation similar to those dedicated to Saturn in the rest of the Maghreb, a fact that could be related to the common pre-Roman substrate in the popular religion in both territories.

Among the Tripolitanian rural shrines, the one of Ghirza (Brogan & Smith, 1984, pp. 80–92) is especially interesting due to its strong Punic elements; these make it a unique monument in Tripolitania. Brogan and Smith (1984, p. 88) suggest that the building was perhaps devoted to the cult of Baal-Saturn in his role of earthly fecundity, but Brouquier-Reddé (1992, p. 146) proposes that the sanctuary was dedicated to the Libyan bull-headed god Gurzil, son of Ammon. From the plans published by Brogan and Smith (1984; their Figs. 25 and 26), Esteban (2003) finds that the orientation of the building is towards the east, very similar to that of Germa (Esteban et al., 2001) and also consistent with the SR range.

Finally, Esteban et al. (2001) have also measured the orientation of some temples built in the epoch of the Numidian and Mauretanian kingdoms, prior to the Roman annexation of all North African provinces. These kingdoms were autochthonous but deeply Punicised in their culture, especially in religion (Camps, 1979). All these monuments show orientations consistent with the patterns found for the temples of Saturn and the rural temples of Tripolitania.

The possible astronomical motivation of the orientation patterns of the North African funerary and religious monuments discussed above has further support in some remarkable astronomical markers that have been found in important archaeological sites of the area, from Libya to Morocco.

Belmonte et al. (2002a) report the discovery of an impressive solstitial marker over a distant foresight from the east edge of the top of Zinchecra, the capital city of the Garamantes of the Fezzan (Libya) and inhabited since the ninth

Archaeoastronomy of North Africa, Fig. 9 Carved cupmarks at the eastern border of the cliff of Zinchecra, the hilltop fortified capital of the ancient Garamantes of the Fezzan (Libya). The *arrow* indicates the place where the sun rises at the summer solstice, just on the intersection of the escarpment of the black plateau of the Messak and the sand sea of Ubari. That zone of the escarpment corresponds to the long-lasting sacred area known as Al-Fugar

century BCE. The sun at summer solstice rises just on the most conspicuous distant topographical element of the skyline: the intersection of the flat escarpments of the Messak and the southern border of the sand sea of Ubari (see Fig. 9). This precise zone of the escarpment is called Al-Fugar and contains a major Garamantian and a later marabout cemetery. It is a sacred area used from prehistoric times until recently and continues to be today a place for pilgrimage and prayer (Barnett & Mattingly, 2003). The discovery of a striking astronomical marker in the first known political center of the Garamantes gives further support to the importance and continuity of the astral elements of the genuine Libyan funerary and religious world, just before the contacts with the Phoenicians and Greeks.

Esteban et al. (2001) found another possible pre-Roman solstitial marker at the Numidian city of Simithus (Tunisia). From the Roman forum, which is located above the preceding Numidian tombs dated from the fourth to the first centuries BCE, it is possible to see the Numidian sanctuary (dedicated to Saturn in Roman times) just on the top of the Sacred Hill of Simithus. Esteban et al. find that the line of sight of the sanctuary as seen from the Numidian tombs at the forum coincides with the summer solstice sunrise. Moreover, a large Numidian monumental tomb is oriented precisely to the hill summit.

The group above found another spectacular astronomical marker in the temple of Apollo of Mactar (Tunisia). The Numidian-Punic traditions were very strong in this city and survived for several centuries after the Roman conquest (M'Charek, 1982, p. 12). The temple is located outside the city; it is oriented east–west and built over a previous Punic or Libyan sanctuary (Picard, 1984). The temple faces a small natural cut in a mountain (Fig. 10) which is exactly where the sunrise takes place at the midday in time between solstices, very close to the equinox (see definition in Esteban, 2003). Although the Punic Baal Hammon was conflated with Saturn in most of the Roman province of Africa, there is some controversy that this could be not the case in the region of Mactar (see the discussion by M'Charek & Ghaki, 1991 and references therein). Bisi (1978) suggests that in Mactar, the ancient cult of Baal Hammon was assimilated to Apollo, the sun-god of the Romans. If this hypothesis is true, the presence of an equinoctial marker at the temple of Apollo would provide proof of the transmission of the solar elements from the ancient Punic–Libyan religion to the Romanized local cults.

Another possible relation with the equinoxes or a date close to it has been found at the temple B of Volubilis (Morocco) that shows all the characteristics of the temples of Saturn but lacks a direct confirmation of its dedication. It has a very precise orientation towards the sunrise

Archaeoastronomy of North Africa, Fig. 10 Remains of the Temple of Apollon in Mactar and its eastern horizon. The *arrow* indicates the place where the sunrise takes place at the equinoxes. The *upper left box* shows an enlargement of the horizon, and the *white circle* indicates the size of the solar disk (Figure reproduced from Esteban et al., 2001 and Esteban, 2003). The cutting in the mountain at the *left* of the arrow coincides with the point where the sunrise takes place at the midday in time between solstices (see Esteban, 2003)

around the equinoxes (Esteban et al., 2001; Morestin, 1980, pp. 56–57) that takes place over the nearby mountain Zerhoun, the most famous holy mountain of Muslim Morocco (see Morestin, 1980, p. 135). The actual Roman building was built over a previous *tofet*, the westernmost Punic funerary sacred area known in Africa.

A last possible equinoctial marker could be at the temple of Saturn at Thugga (Tunisia). As in the case of the temple B of Volubilis, the Roman temple was built over a previous Punic *tofet*. The temple is oriented inside the range of the sunrises but not related to the solstices or equinoxes (Esteban et al., 2001). Esteban (2003) found that the peak of Zaghouan (the highest peak of Tunisia and the most important water source of ancient Carthage) seems to be located in the general direction of the horizon where the sunrise takes place around the equinoxes.

As we can see, there are possible equinoctial markers – or markers towards the midday in time between the solstices – in three sacred areas or *tofets* of important cities of Libyan–Punic origin (Mactar, Volubilis, and Thugga). In the three cases, the sanctuaries were reutilized in Roman times and were dedicated to Saturn (the great North African deity) or to the Roman sun-god Apollo. It is interesting to note that several equinoctial markers (analogous to the one found at Mactar) have been found in sanctuaries belonging to the Iberian culture in the southeast of Spain (Esteban, 2003, 2013) which was also influenced by the Punic civilization in many aspects and especially in its religion. Finally, the discovery of striking equinoctial markers in important pre-Hispanic sanctuaries of the Canary Islands also suggests that this element was important in the ritual of the proto-Berber peoples of the archipelago (see Esteban & Delgado, 2005). In the light of the results gathered, it seems very probable that the ancient settlers from the continent imported this astronomical tradition. This original population was culturally Punicised to some degree.

References

Alaoni, M. K. (2000). A propos de la chronologie de la nécropole rurale d'Äin Dalia Lekbira (région de Tanger, Maroc). In E. A. María & M. Barthélemy (Eds.), *Actas del IV Congreso Internacional de Estudios Fenicios y Púnicos* (Vol. III, pp. 1185–1195). Cádiz: Servicio de Publicaciones de la Universidad de Cádiz.

Baradez, J. (1969). Nécropole orientale côtière de Tipasa de Maurétanie. *Antiquités Africaines, 3*, 83–114.

Barnett, T., & Mattingly, D. (2003). The engraved heritage: Rock-art and inscriptions. In D. Mattingly (Ed.), *The archaeology of Fazzan* (Synthesis, Vol. 1, pp. 279–326). London: The Society for Libyan Studies.

Belmonte, J. A. (1999). *Las leyes del cielo*. Madrid: Ediciones Temas de Hoy, S. A.

Belmonte, J. A., Esteban, C., & Jiménez González, J. J. (1998). Mediterranean archaeoastronomy and archaeotopography: Pre-roman tombs of Africa proconsularis. *Archaeoastronomy, 23*(Supplement to Journal for the History of Astronomy 29), S7–S24.

Belmonte, J. A., Esteban, C., Schlueter Caballero, R., Perera Betancort, M. A., Génova, R., & Cruz, M. (1997). Astral Gods, tombs and sacred mountains: The case of Mediterranean Africa. In C. Jaschek, & A. Fernando (Eds.), *Proceedings of the IVth SEAC meeting "astronomy and culture"* (pp. 247–53). Barandela.Salamanca: Universidad de Salamanca.

Belmonte, J. A., Esteban, C., Cuesta, L., Perera Betancort, M. A., & Jiménez González, J. J. (1999). Pre-islamic burial monuments in northern and Saharan Morocco. *Archaeoastronomy, 24*(Supplement to Journal for the History of Astronomy 30), S21–S34.

Belmonte, J. A., Esteban, C., Perera Betancort, M. A., & Marrero, R. (2002a). The Sun in the north of Africa before Islam. A solstitial marker in the Sahara. In T. Potyomkina & V. Obridko (Eds.), *Astronomy of ancient civilisations* (pp. 199–205). Moscow: Nauka.

Belmonte, J. A., Esteban, C., Perera Betancort, M. A., & Marrero, R. (2002b). Archaeoastronomy in the Sahara: The tombs of the garamantes at Wadi el Agial (Fezzan, Libya). *Archaeoastronomy, 27*(Supplement to Journal for the History of Astronomy 33), S7–S24.

Belmonte, J. A., Perera Betancort, M. A., Marrero, R., & Tejera Gaspar, A. (2003). The Dolmens and Hawanat of Africa proconsularis revisited. *Journal for the History of Astronomy, 34*, 305–320.

Belmonte, J. A., Tejera Gaspar, A., Perera Betancort, M. A., & Marrero, R. (2006). On the orientation of pre-Islamic temples of North Africa: A reappraisal (new data in Africa proconsularis). *Mediterranean Archaeology and Archaeometry, 6*(3), 77–85.

Bénabou, M. (1975). *La résistance africaine à la romanisation*. Paris: Librairie François Maspero.

Bisi, A. M. (1978). A proposito di alcune stele del tipo della Ghorfa al British museum. *Antiquités Africaines, 12*, 21–88.

Brogan, O., & Smith, D. J. (1984). *Ghirza. A Libyan settlement in the Roman period*. Tripoli: Department of Antiquities.

Brouquier-Reddé, V. (1992). *Temple et cultes de Tripolitaine*. Paris: Éditions du CNRS.

Camps, G. (1961). *Aux origines de la Berbérie. Monuments et rites funéraires protohistoriques*. Paris: Arts et Métiers Graphiques.

Camps, G. (1979). Les Numides et la civilisation punique. *Antiquités Africaines, 14*, 43–53.

Camps, G. (1995a). Dolmens. *Encyclopédie Berbère, 16*, 2490–2509.

Camps, G. (1995b). Djedar. *Encyclopédie Berbère, 16*, 2409–2424.

Castellani, V. (1995) Necropoli di tumuli ed archeoastronomia. *Archeologia e astronomia: Esperienze e prospettive future* (Atti dei Convegni Lincei No. 121, pp. 83–98). Rome: Accademia Nazionale dei Lincei.

Cremaschi, M., & di Lernia, S. (1998). *Wadi Teshuinat. Palaeoenvironment and prehistory in south-western Fezzan*. Milano: C.N.R.

Daniels, C. M. (1989). Excavation and fieldwork amongst the Garamantes. *Libyan Studies, 20*, 45–61.

Esteban, C. (2002). Temples and astronomy in Carthage. In M. Blomberg, P. E. Blomberg, & G. Henriksson (Eds.), *Calendars, symbols, and orientations: Legacies of astronomy in culture* (Uppsala Astronomical Observatory Report No. 59, pp. 135–142). Uppsala.

Esteban, C. (2003). Equinoctial markers and orientations in pre-Roman religious and funerary monuments of the western Mediterranean. In A.-A. Maravelia (Ed.), *Ad Astra per Aspera et per Ludum. European archaeoastronomy and the orientation of monuments in the Mediterranean basin* (BAR international series, Vol. 1154, pp. 83–100), Oxford.

Esteban, C. (2013). Arqueoastronomía y religión ibérica. In C. Rísquez & C. Rueda (Eds.), *Santuarios ibéricos: territorio, ritualidad y memoria* (pp. 465–484). Jaén: Asociación para el desarrollo rural de la Comarca de El Condado.

Esteban, C., & Delgado, M. (2005). Sobre el análisis arqueoastronómico de dos yacimientos tinerfeños y la importancia de los equinoccios en el ritual aborigen. *Tabona, 13*, 187–214.

Esteban, C., Belmonte, J. A., Perera Betancort, M. A., & Jiménez González, J. J. (2001). Orientations of pre-Islamic temples of northwest Africa. *Archaeoastronomy, 26* (Supplement to Journal for the History of Astronomy 32), S65–S84.

Gauthier, Y., & Gauthier, C. (1999). Orientation et distribution de divers types de monuments lithiques du Messak et des régions voisines (Fezzân, Libye). *Sahara, 11*, 87–108.

Gauthier, Y., & Gauthier, C. (2001–2002). Sur des monuments à antenne en L du Fezzân. *Sahara, 13*, 136–147.

Gauthier, Y., & Gauthier, C. (2002). In M. Blomberg, P. E. Blomberg, & G. Henriksson (Eds.), *Orientation of some dry stone monuments: V shape monuments and Goulets of the Immidir mountains (Algeria)* (Uppsala Astronomical Observatory Report No. 59, pp. 143–151). Uppsala.

Gauthier, Y., & Gauthier, C. (2003). Monumens à alignement de petite tours de l'Immidir (Algérie). *Almogaren, 34*, 47–77.

Gauthier, Y., & Gauthier, C. (2005). Monumens à alignement du Sahara occidental et leur place dans le contexte saharien. *Almogaren, 36*, 147–190.

Gauthier, Y., & Gauthier, C. (2006). Monuments en trou de serrure et art rupestre: sur la distribution du groupe d'Iheren-Tahilahi/Wa-n-Amil et ses relations avec les autres groupes culturels. *Cahiers the l'AARS, 10*, 79–110.

Gauthier, Y., & Gauthier, C. (2008). À propos des Monuments À Alignements du Sahara. *Almogaren, 39*, 27–88.

González García, A. C., Costa Ferrer, L., Zedda, M. P., Belmonte, J. A. (2006). The orientation of the Punic tombs of Ibiza and Sardinia. In M. Zedda & J. A. Belmonte (Eds.), *Light and shadows in cultural astronomy* (pp. 47–57). Isili: Associazione Archeofila Sarda.
Hachid, M. (2000). *Les premiers Berbères*. Alger, Aix-en-Provence: Ina-Yas, Édisud.
Hoskin, M. (2001). *Tombs, temples and their orientations. A new perspective on Mediterranean prehistory*. Bognor Regis: Ocarina Books.
Leglay, M. (1961). *Saturne africain. Monuments tome I*. Paris: Arts et Métiers Graphiques.
Leglay, M. (1966). *Saturne africain. Histoire*. Paris: Éditions E. de Boccard.
Mattingly, D. J. (1994). *Tripolitania*. Ann Arbor, MI: The University of Michigan Press.
M'Charek, A. (1982). *Aspects de l'evolution démographique et sociale à Mactaris aux II^{e} et III^{e} siècles ap. J.C*. Tunis: Publications de l'Université de Tunis.
M'Charek, A., & Ghaki, M. (1991). La romanisation du culte de Ba'al Hammon dans la region de Maktar (antique Thusca). In M. H. Fantar (Ed.), *Actes du III^{e} congrès international des études phéniciennes et puniques* (pp. 245–257). Tunis: Publications de l'Université de Tunis.
McKim Malville, J., Wendorf, F., Mazar, A. A., Schild, R. (1998). Megaliths and neolithic astronomy in southern Egypt. *Nature, 392*, 488–491.
Morestin, H. (1980). *Le Temple B de Volubilis*. Paris: Éditions du CNRS.
Paris, F. (1996). *Les sépultures du Sahara nigérien, du Néolithique à l'Islamisation*. Bondy: ORSTOM.
Picard, G. C. (1954). *Les religions de l'Afrique antique*. Paris: Plon.
Picard, G. C. (1984). Le temple du musée a Mactar. *Revue Archeologique, I*, 13–29.
Ramos Sainz, M. L. (1986). *Estudio sobre el ritual funerario en las necrópolis fenicias y púnicas de la Península Ibérica*. Madrid: Ediciones de la Universidad Autónoma de Madrid.
Ribichini, S., & Xella, P. (1994). *La religione fenicia e punica in Italia*. Roma: Istituto Poligrafico e Zecca dello Stato.
Savary, J. P. (1966). *Monuments en pierres sèches du Fadnoun*. A. M. G. Mém. du CRAPE, VI. Paris.
Savary, J. P. (1969). L'Architecture et l'orientation des dolmens de Beni-Messous (Région d'Alger). *Libyca, XVII*, 271–330.
Ventura, F. (2000). Orientations of the Phoenician and Punic shaft tombs of Malta. In C. Esteban & J. -A. Belmonte (Eds.), *Oxford VI and SEAC99 astronomy and cultural diversity* (pp. 59–63). Santa Cruz de Tenerife: Organismo Autónomo de Museos del Cabildo de Tenerife.
Xella, P. (1991). *Baal Hammon. Recherches sur l'identité et l'histoire d'un dieu phénico-punique*. Rome: Consiglio Nazionale delle Richerche.

Architectural Decoration in Islam: History and Techniques

Ruba Kana'an

Architectural decoration has been one of the most resilient of the Islamic arts. The partial and more often overall decoration of buildings has been a characteristic feature of Islamic architecture from the eighth century onwards. Religious monuments as well as secular complexes have been decorated with an array of styles and techniques that reflected the multiplicity of Muslim societies and their cultural expressions. The importance given to decorating one's built environment has also been applied to temporary settlements such as tented encampments.

Up until the eleventh century, most decorative techniques such as the use of decorative brickwork or moulded stucco in the Muslim east, and mosaics, *ablaq* and carved stone in the central Muslim world were inherited from pre-Islamic cultures and societies. Muslim artisans transferred these skills into their respective contexts and adapted them to their architectural needs. It was only in the eleventh to thirteenth centuries that the use of repetitive patterns and intricate designs of geometric, calligraphic, and abstract vegetal motifs became the dominant decorative repertoire (Jones, 1978). These elements permeated architectural decoration throughout the Muslim world resulting in a new and distinct decorative language (Fig. 1).

Decorative elements such as the use of arabesque, geometric interlace (*girih*) and *muqarnas* or stalactite vaults became widely spread. Common among these decorative elements are notions of modularity, geometry and rhythm. Arguably, these forms are manifestations of a geometric pattern that is based on the subdivision of space, form or surface and the infinite repetition of the structural modules and motifs. Division and repetition, for example, applied to abstract forms of vegetation that are subjected to the rules of

Architectural Decoration in Islam: History and Techniques, Fig. 1 Dome of the Al-Ashrafiyyah Madrasa in Taʿizz, Yemen. 1398–1400. Showing painted decorations and carved stucco

geometry and then extended indefinitely in all directions, formed the arabesque. Geometric interlace patterns (*girih*) also follow the same structural principle; these decorative compositions are based on the folding and repetition of regular shapes using circles, triangles and squares. The resulting patterns are purely mathematical and their artistic value lies in the choice of what aspect of the geometric pattern to highlight and which colours to use. (See "The nature of Islamic art", MET timeline http://www.metmuseum.org/toah/hd/orna/hd_orna.htm.)

Subtle mixtures of geometry and rhythm also characterized the *muqarnas* or stalactite vault which is distinctive to Islamic architecture and decoration. The *muqarnas* is both a structural element filling zones of transition between walls and domes and a decorative element that follows the same structural composition (Fig. 2). *Muqarnas* domes, vaults, niches and decorative friezes are found in different construction materials including brick, stone, wood and stucco all over the Muslim world. (See a good survey of *muqarnas* types and their geographical distribution http://www.tamabi.ac.jp/idd/shiro/muqarnas/.) In its simplest form the *muqarnas* can be described as layers of superimposed

Architectural Decoration in Islam: History and Techniques, Fig. 2 Mihrab of the mausoleum of Haseki Hürrem wife of Süleyman the Magnificent, Istanbul, Turkey. 1550–1557

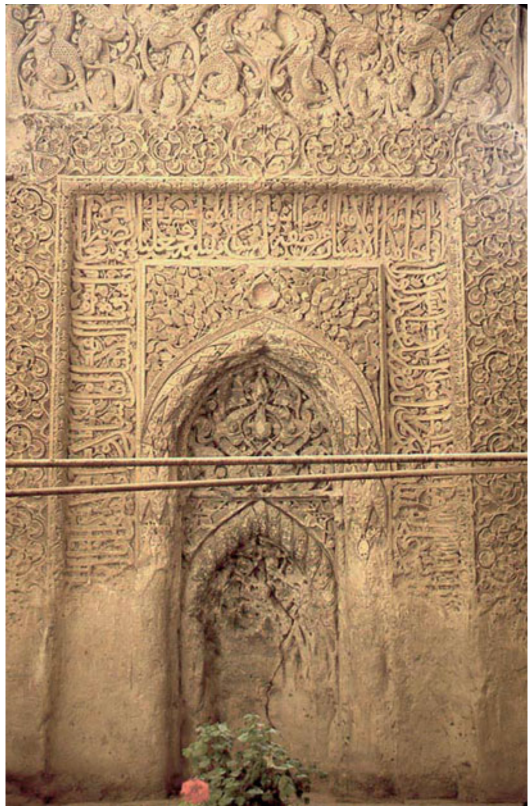
Architectural Decoration in Islam: History and Techniques, Fig. 3 Mihrab of the mausoleum of Gur-i Emir, Samarqand, Uzbekistan. 1404. Decorated with painted and gilded arabesque designs and *square* Kufic inscriptions

niches that link or decorate two surfaces. The earliest surviving mathematical treatise on *muqarnas* was written during the fifteenth century by the mathematician Ghiyāth al-Dīn Masʿūd al-Kāshī (d. 1429). The treatise was used to inform the simulation of a model of a *muqarnas* in Necipoğlu's book on a Timurid period scroll found in the Topkapi Saray Museum in Istanbul (Asad, 1995). The earliest surviving drawing of a *muqarnas*, however, was found in the Takht-i Sulaiman excavations in the northwest of Iran. The plaster panel of (50 × 50 cm) inscribed with a design of a *muqarnas* dating to ca. 1270 currently housed in the archaeological museum of Berlin was drawn into an exact plan (Harb, 1978) and later studied and analysed by a numerical geometry group at the University of Heidelberg in Germany. (See the numerical geometry study group http://www.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/ and the Takht-I Sulaiman muqarnas drawing http://www2.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/Img/suleyman_plate.jpg).

The use of calligraphy in architectural decoration pre-dates Islam. However, after the birth of Islam words and calligraphic compositions became a primary component of a collective aesthetic. Notably, decorative inscriptions were not often applied in isolation as calligraphy was most commonly used as part of an overall composition that at times overlapped with other decorative techniques such as arabesque. Like other decorative forms, calligraphic compositions are based on a modular principle where letters, words, or full sentences are subject to geometric rendition and repetition. The purpose, form, content and location of inscriptions on buildings varied according to time and place (Blair, 1998). A large percentage of surviving inscriptions are Qur'anic or religious in nature but inscriptions with historical information providing the name of the building's patron, its date of construction and at times the name of a builder are also common (Fig. 3). Whereas Arabic served as the main language for monumental inscriptions, Persian, Ottoman Turkish and in a few cases Pahlavi and Swahili were also used. The location of calligraphy on a building followed stylistic developments and regional variations. Most commonly, calligraphic friezes tend to delineate structural zones in a building such as between walls and zones of transition, the bases of domes, entrances and on the voussoirs (wedge-shaped stone building blocks used in constructing an arch or vault) or tympana (the triangular area in a pediment) of arches. Calligraphy was also used as a form of overall decoration such as the large buff and turquoise brick inscriptions in the *hazārbāf* technique (see below) that adorned walls and minarets of monuments during the Timurid period. (See the Islamic Art and Architecture Organization http://www.islamicart.com/main/calligraphy/index.html).

The application of different decorative elements on a building was wide-spread in Muslim architecture. Nevertheless, the form of decoration and its location followed regional preferences and local traditions. For example while monuments of Fatimid and Mamluk Egypt were decorated with carved inscriptions, *ablaq* stonework, and architectonic features, the facades of monuments in Khurasan and Transoxiana were decorated with overall brick patterning, blind arches, glazed and moulded tiles, terracotta inlays, stucco and ornamental inscriptions. Even in buildings where the exteriors were left almost totally unadorned such as the Ilkhanid period mosques of Iran and Iraq (1256–1353), interiors and particularly the mihrab niche was the focus of sumptuous stucco decoration (Fig. 4). So too is the case in fourteenth century North Africa and Spain as for example in the courtyard arcades of the Nasirid palace in Granada or the complex decoration of the Marinid ʻAṭṭārīn Madrasa in Fez built between 1323 and 1325.

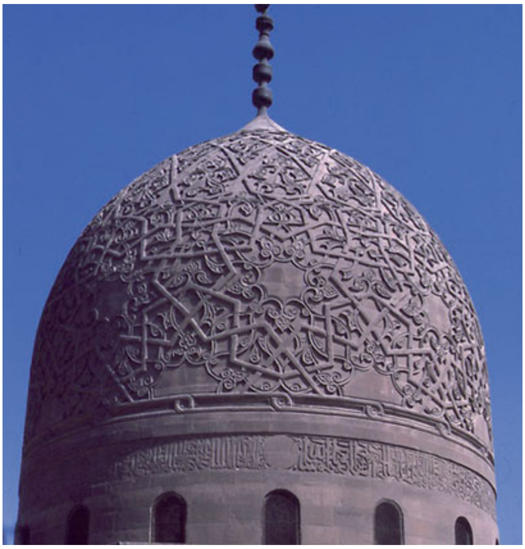
Decorative elements applied to architecture were used singularly or in combinations. Of particular significance was the use of overlapping patterns in two or more dimensions. An example is the tile mosaic design on the dome of the Shah Mosque in Isfahan, Iran (1611–1638), with its ochre lattice screen pattern and white and blue arabesque. Another example with a similar overlapping composition yet a different effect is the stone dome of the Sultan Qaytbay mausoleum in Cairo (1472–1474) with its geometric interlace design and flowering arabesque (Fig. 5). Whereas the former is two-dimensional, the Cairo example has a sculptural effect as both elements are carved in a precise bas-relief. The use of complex and overlapping decorative patterns was also subject to stylistic changes. The pre-Mongol arabesque based on twining vine tendrils and acanthus or palm leaves gave way from the turn of the fourteenth century to lotus scrolls with peony sprays and serrated leaves (*hatāʼī*). This aesthetic became popular in Iran and was later adopted in the early sixteenth century Iznik ceramic tiles produced by the Ottomans.



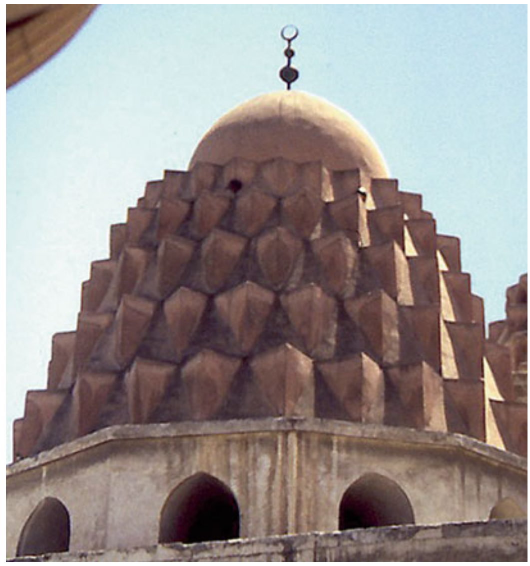
Architectural Decoration in Islam: History and Techniques, Fig. 4 The mihrab of the Shrine of Pir-i Bakran in Linjan, Iran. 1299–1312

The Meaning, Purpose and Transmission of Architectural Decoration: Problems of Interpretation

Because of the perennial emphasis on geometric patterns and abstract vegetal motifs, the decorative language of Islamic architecture is commonly perceived to reflect a Muslim ethos that is aniconic and unchanging. (When referring to a deity image, aniconic denotes a symbol which does not attempt an anthropomorphic (humanlike) or representational likeness.) This perception is at the heart of a number of debates in the study of Islamic art and culture including: was the use of



Architectural Decoration in Islam: History and Techniques, Fig. 5 Dome of the mausoleum of Sultan Qaytbay, Cairo, Egypt. 1472–1474



Architectural Decoration in Islam: History and Techniques, Fig. 6 Muqarnas dome of the mausoleum of Nūr al-Dīn in the al-Nūriyya Madrasa, Damascus, Syria. 1168

geometry and arabesque patterns a reflection of Islam's antipathy to images? Was it a reflection of the special status of mathematics and geometry in Muslim cosmology? Or was it, perhaps, a reflection of a cultural process with its social, political and religious ramifications? These debates represent the two main current schools of thought on the meaning and purpose of architectural ornament: the "iconological" and the "cosmological".

In the iconological approach all works of art, including architectural decoration, are interpreted as visual signifiers of the cultural context which they embody. As such, a work of art has a meaning that is culturally constructed and related to a specific time, place and context of production. It is read and considered as evidence or representation of its context on par with other historical, political, social or literary documents. Such an approach is at the heart of Tabbaa's analysis of the transformation of architectural decoration in the central Muslim lands between the middle of the eleventh and the middle of the thirteenth centuries (2001). He argues that the evolution of an artistic language which is characterized by the use of arabesque, geometric interlace, *muqarnas* vaulting, and monumental calligraphy was largely brought on by a Sunni revival that strived to standardize religious norms in a period of political and sectarian upheaval (Tabbaa, 2001, p. 6). The evolution of the gravity-defying and ever changing effect of the *muqarnas* domes, for example, is interpreted in his study as an embodiment (or abstraction) of the Ash'arite Sunni theology which is based on an occasionalistic cosmology (133). As such, the evolution of the *muqarnas* dome, as well as the other decorative techniques, is explained within a precise political and religious context within which it would have had a symbolic meaning (Fig. 6).

For the proponents of the cosmological approach, geometric and decorative patterns are interpreted as manifestations of underlying principles of faith that are regarded as both universal and timeless. This approach attributes a functional role to ornament that is first and foremost a reminder of the principle of Tawḥīd: the Oneness and Transcendence of the Divine (Al-Faruqi Isma'il & al-Faruqi, 1986, pp. 163–169). Islamic art and geometric patterns used in architectural decoration are thus seen as means to reconcile multiplicity with Unity. They depict a physical mathematical pattern which reflects a sacred cosmology. Islamic art is thus regarded as an aniconic art where the spiritual world is reflected through geometry, rhythm, arabesque and calligraphy. For example, the circle is read as symbol for the origin and the end, an archetypal form from which the three primary shapes (triangle, hexagon and square) emerge (Critchlow, 1976). The same ideas are expressed by Burckhardt (1976, p. 63) who sees geometric interlace as a direct expression of the idea of Divine Unity. Thus unlike the iconological approach, the cosmological approach does not take into account the socio-political context of a decorative programme or the vicissitudes of artistic influences.

These two approaches often regard each other as incompatible. The iconological school sees the attempt to interpret style through faith too speculative and at best normative. Whereas for those who consider Islamic art as an expression of Muslim faith and Divine Unity in particular, the temporal contextual analysis of decorative patterns misses the point. What the two approaches agree on, however, is the need for intermediaries to translate these complex mathematical and philosophical ideas into patterns that could be understood and applied by craftsmen. For example, Nasr explains geometric patterns as being the "results of the vision of the archetypal world by seers and contemplatives who then taught craftsmen to draw them upon the surfaces of tiles or alabaster" (1987, p. 49). Tabbaa (2001, p. 100) and Necipoğlu (1995, p. 123), on the other hand, propose that one of the reasons for the development of these complex and geometrically based decorative techniques is that geometric treatises were increasingly available for artisans. This presumed relationship between the artisan and the mathematician in medieval Islam, however, was dismissed by George Saliba, Professor of Arabic and Islamic science at Columbia University. Saliba argued that based on the available evidence from the few surviving mathematical treatises the assumption is hard to entertain, let alone prove (1999, p. 641). He also provides textual evidence for the difference in the technical language used by mathematicians and artisans, and the need therefore to avoid the assumption that the presence of mathematical treatises means that they are used or understood by artisans. Theoretical mathematicians, according to Saliba, "rarely taught artisans directly, and seldom wrote for them specifically" (643).

Another important issue that arises in debates about architectural decoration is the manner in which architectural or decorative designs were transmitted. Jonathan Bloom (1993, p. 25) argues that the form and general characteristics of early mosques were transmitted mostly by example. That is, the general features of one building were copied by another in the same region. Bloom also argues that such buildings could have been described orally or in geographical works, and thus what was transmitted was a notional idea of a building or a decorative detail. These suggestions remain to be fully proven. It is worth noting that there are also a few historical accounts which mention the involvement of patrons in drawing designs of a desired monument, but no material evidence survives before the fourteenth century (O'Kane, 1987, p. 34). In this connection, the presence of a notational convention used by craftsmen based on drawings and models is only attested to from the thirteenth century with the 1270s stucco panel with a *muqarnas* plan (discussed above) as the earliest surviving example. Early drawings on paper survive from the sixteenth and seventeenth century in Tashkent, and the fifteenth and sixteenth century in Istanbul (Necipoğlu, 1995). Finally, one of the important ways of transmitting knowledge about decorative techniques and practices was through the movement of craftsmen who brought with them new traditions and technical know-how.

Architectural Decoration by Media

Studies on the building crafts in Muslim societies are sparse and mostly regional or media specific. The best example is Hans Wulff's book on Iran (1966) which provides an invaluable detailed study of building and decorative traditions concentrating on local practices and techniques. Iran's craft industry during the nineteenth and the early twentieth centuries and its encounter with Western technical development are also documented (Floor, 2003). For Syria and Egypt dictionaries of traditional crafts (al-Qasimi, 1988) and architectural terms (Amin & Ibrahim, 1990) provide glimpses into local technical practices. IRCICA, the Research Centre for Islamic History, Art and Culture based in Istanbul has had since 1990 a programme for the study and development of crafts in Muslim societies. The programme hosted conferences and seminars in different regions and recently published some of their proceedings (see www.ircica.org). What follows is a summary of the history and techniques of stone, brick, tile and stucco decoration.

Stone

Stone was used as a decorative medium in Syria, Anatolia, Egypt after the eleventh century, Spain, and India (Fig. 7). North Syria, especially the area around Aleppo during the period between the twelfth and fifteenth centuries, seems to have been a source of technical innovation for stereotomic stone techniques that are based on the precise cutting and assemblage of stone blocks (Clévenot & Degeorge, 2000, p. 68). (Stereotomy is the science or art of cutting solids into certain figures or sections, as arches; the art of stonecutting.) The decorative use of stone exploited the natural variety of stone colours to produce polychrome compositions for the interior and exterior of buildings. Some techniques such as alternating the colours of stone courses (*ablaq*) or interlocking the stones of arches (joggled voussoirs) were used in pre-Islamic monuments but became more sophisticated and more widely used after the spread of Muslim culture. Stone mosaic designs of *opus sectile* (pavement or wall decoration made of shaped tiles of coloured marble) and its stone paste derivatives were used only for decorative purposes (Fig. 8). In most cases, however, structural and decorative techniques overlapped. The most common decorative stonework techniques were:

Architectural Decoration in Islam: History and Techniques, Fig. 7 Portal of the Ayyubid palace. Aleppo Citadel, Syria. ca. 1210

Stone Mosaic

This is a technique that was inherited from the Byzantines in Syria and Palestine. It was used for land covering and paving during the Umayyad periods in Syria and Spain.

Ablaq

This is a simple technique of alternating different colours of stone courses in order to achieve a colouristic impact. The most commonly used colours were light sand or limestone alternating with dark basalt and in some cases a third layer of reddish stone. This technique spread from Syria to Egypt under the Mamluks and Turkey under the Rum Saljuqs and the Ottomans.

Joggled or Interlocking Stones

This is a technique in which stone blocks with precisely cut scallops, zigzags and complex carved

Architectural Decoration in Islam: History and Techniques, Fig. 8 The Fatḥiyyah Madrasa, Damascus, Syria. 1743

profiles were fitted together without the use of mortar. Single or multiple coloured stones were used to create a beautiful effect. Interlocking stones, however, were technically challenging as the desired shape was cut into a regular block that was bonded into the masonry. They decorated horizontal decorative bands on facades or had a structural function in lintels and arch voussoirs.

Muqarnas Vaulting Over Portals

These vaults consist of three or more tiers of staggered *muqarnas* cells usually surmounted by a scalloped or centrifugal half-dome. Muqarnas became the main decorative feature of monumental portals between the thirteenth and the fifteenth century. It seems to have developed in Aleppo in Northern Syria and spread from there south to the rest of Syria and Egypt and north to Anatolia and Turkey.

Monochrome and Polychrome Geometric Interlace

Stone geometric interlace was introduced during the twelfth century and used mostly in the spandrels above arched gates and prayer niches (mihrabs). Technically, the geometric interlaces are different from surface cladding as each component of the geometric interlace is cut on the face of a regular block that is built within the structure of the arch spandrel, and as such, fully bonded to the masonry (Tabbaa, 2001, p. 156).

Stone Cladding and Inlay

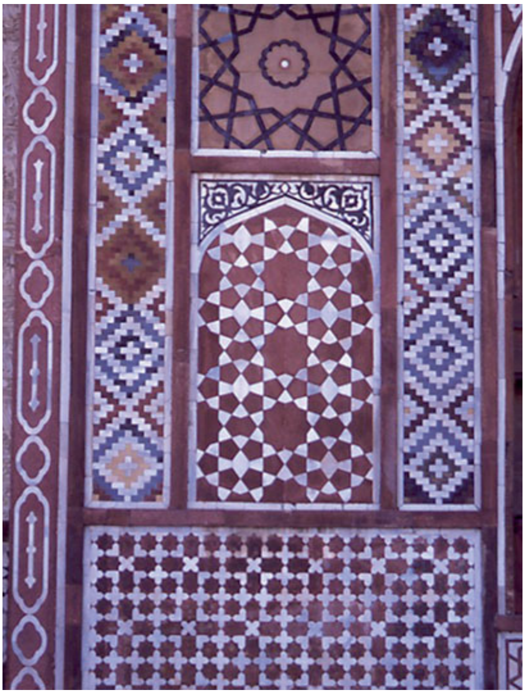
This technique included the decorative use of marble panelling which was common in Syria, Palestine and Egypt. Stone inlay in *opus sectile* and marble intarsia reached its apogee under the Mughals of India (Fig. 9). Inlay in hard stones and semi-precious stones (*pietra dura*) where lapis, onyx, jasper, topaz, cornelian and agate were inlaid in marble made its first major appearance in the Tomb of Iltimād al-Dawla in Agra (1622–1668).

Stone Sculpture

The most common form of stone sculpture was relief carved inscriptions and decorative patterns. Dense patterns created through carving out or hollowing the stone surface is also demonstrable in the façade of the Mushatta palace in Jordan (ca. 740) currently in the museum of Islamic Art in Berlin. The surface is carved in the form of triangles housing rosettes that are surrounded by dense foliage at times inhabited by birds and mythical creatures. An exceptional example of a more plastic modelling in stone sculpture comes from the portals of the Great Mosque of Devriği in Anatolia built in 1228–1229 (Fig. 10).

Bricks

Decorative brickwork was used to articulate the structural walls of monuments built over a vast area including Iraq, Iran, Afghanistan and central Asia. Brick was readily used as a medium of structure and decoration as it was cheap to make and fast to build. The alluvial plains of the various rivers in the region provided rich sources of clay that were used for manufacturing rammed-earth (*pisé*), mud brick, baked brick and terra cotta in addition to clay pipes and tiling roofs (Wulff, 1966, pp. 108–113). Although the size of the brick differed from one region to the other, the overall visual effect of plainly built brick walls was similar. The indigenous builder was able to develop various decorative uses for brick construction based on simple alternate layering of bricks in horizontal and vertical rows creating patterns in the otherwise plain facades. Bricklayers also used half-bricks, quarter-bricks, and moulded bricks along with the full size bricks to create more dynamic decorative patterns (Fig. 11). The ability to design a small composition based on a simple brick pattern and multiply the design vertically and horizontally meant that the bricklayers were able to maximize the effect of the pattern and minimize the human effort.



Architectural Decoration in Islam: History and Techniques, Fig. 9 Tomb of Akbar. Sikandra, India. 1614

Hazārbāf and Bannā' ī

In addition to the basic technique of forming decorative patterns in brick walls through varying the orientation of bricks, builders used the contrast between light and shadow that resulted from alternating flush and protruding bricks to create intricate decorative patterns. The most widely spread technique of ornamental brickwork is known as *hazārbāf*, from Persian, meaning a thousand twisting or a 1,000 weaving, accentuating the structural similarities between creating continuous brick patterns and weaving a textile.

Architectural Decoration in Islam: History and Techniques, Fig. 10 The northern gate of the Great Mosque of Devriği, Turkey. 1228–1229

Architectural Decoration in Islam: History and Techniques, Fig. 11 Mausoleum of the Samanids. Bukhara, Uzbekistan. 914/43

This technique is also known as the *bannā'ī* or the 'builder's art', as the decorative patterns are part of the structure of the building and not an afterthought or a later cladding. Carved brick plugs and carved and moulded plaster joints were developed to enhance the overall effect.

The earliest surviving example of decorative brickwork comes from Abbasid Iraq and dates to the eighth century in (the city gate in Raqqa ca. 772). In the Ukhaydir Palace south of Baghdad (possibly begun around 762) the south wall of the courtyard has an *iwān* with *hazārbāf* decorative patterns using one-third, two-third, and full size bricks. (An *iwān* is a large, vaulted chamber with a monumental arched opening on one side.) Early examples from Iran and Central Asia are later than those in Iraq but more complex. The decorative use of bricks in the tomb of the Samanid ruler Ismāʿīl in Bukhara, Uzbekistan (913–943), for example, created a weaving effect by highlighting the contrast between recessed and protruding bricks in an overall decorative design. This play between shadow and light in brick construction continued to be a dominant decorative medium for building exteriors such as the twelfth century Gunbad-i ʻAlawiyān in Hamadan (Iran) where bricks were used to create a 'key' and 'swastika' patterns (Shani, 1996, p. 61) or the minaret of Masʿūd of Ghazna in Afghanistan where the builder used brick layering, brick mosaic, sculpted bricks and brick inscriptions in a sumptuous decorative composition.

Glazed Bricks

Glazed bricks were also a pre-Islamic tradition inherited from Babylonian and Achaemenid times. The earliest examples in the eastern Muslim provinces date back to the early twelfth century when moulded tiles or 'end plugs' were used as a contrast to the natural buff colour of bricks. During the twelfth century glazed tiles were used in inscription bands such as the Tower of Jam, Afghanistan (late twelfth century), or the minaret of the Kalayān mosque in Bukhara (1127) (Fig. 12). One might argue that colour was introduced in brick architecture to render the complex decorative and inscription friezes more legible from the distance. Under the Ilkhans (1256–1353) the use of glazed bricks became a prominent feature of monumental architecture as domes and large surfaces were covered in decorative compositions of glazed bricks and tiles. The Timurid opulence of Tamerlane's mausoleum in Samarqand, the Gur-i Emir, (ca. 1400–1404), or the royal necropolis of Shah-i Zand demonstrate the skilful

Architectural Decoration in Islam: History and Techniques, Fig. 12 Minaret of the Kalayan Mosque. Bukhara, Uzbekistan. 1127

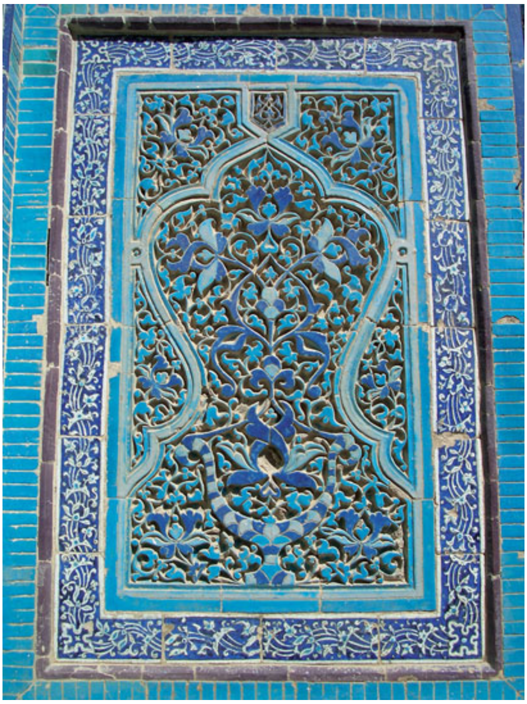
combinations of plain bricks, glazed bricks and glazed tiles that were used to maximize the decorative effect (Fig. 13).

To create glazed bricks, brickmakers used glazes or filmy glass layers that were fired and fused over the porous clay body of the brick for functional and aesthetic reasons. Glazes were added to the brick in a powder format that coated the body and melted in the kiln. The colour and opacity of the glazes were determined by their chemical composition. The most commonly used colours in Iran and the Muslim east were turquoise and blue. These colours were achieved by using an alkaline fluxing agent composed of powdered pebbles and potash for copper oxide and cobalt, respectively (Al-Hassan & Hill, 1986).

Glazed Tiles

Decorative tiles comprise glazed slabs made out of clay or frit (stone paste) that were used in a variety of forms and shapes to create impervious surfaces with stunning visual impacts. The surface of the tile can be left plain before glazing but it can also be carved, incised or moulded for

Architectural Decoration in Islam: History and Techniques, Fig. 13 Façade of the Shir Dor Madrasa. Samarqand, Uzbekistan. 1619–1636



Architectural Decoration in Islam: History and Techniques, Fig. 14 Details of carved and glazed tiles from the Shah-i Zinda necropolis. Samarqand, Uzbekistan. End of fourteenth or beginning of the fifteenth century

additional effect. Glazed tiles were used to cover different parts of a building including walls, domes and zones of transition. The technical know-how and desired final decorative effect dictated the development of the glazed tiles tradition in different regions of the Muslim world. A good, yet incomplete, starting point for the study of Islamic ceramics including glazed tiles is the teaching website developed by the Ashmolean museum in Oxford, UK (see http://islamicceramics.ashmol.ox.ac.uk/). Tiles are covered with a layer of glaze and fired in a kiln in the same manner as glazed brick (Fig. 14).

Many decorative techniques were used with glazed tiles including painting in the glaze, under the glaze and over the glaze. Glazes are either transparent or opaque depending on their chemical compositions. They are found in different colours and at times colour combinations. The most commonly used metals by Muslim potters were cobalt for blue, manganese for purple, iron for green, and copper for turquoise. Changing the chemical agent used for fluxing the glaze produced different colours. Copper, for example, turned into green if fluxed with a lead glaze, and turquoise-blue if fluxed with an alkaline glaze. Cobalt turned sapphire-blue in an alkaline glaze, and turquoise in lead glaze (Al-Hassan & Hill, 1986).

Lustre Tiles

The best-documented tradition of lustre tile production is the city of Kashan in Iran where there is evidence of continuous production between the twelfth and the early fourteenth centuries. Lustre production (for vessels and tiles) requires special materials, double firing and a special kiln. The metal oxides added to the tile after the first firing form a metallic deposit upon firing in a reducing kiln at a much lower temperature. The recipe and the process of making lustre vessels and tiles were described in a 1301 treatise [http://islamicceramics.ashmol.ox.ac.uk/Glossary/abulqasim.htm] (Allan, 1973). Abu al-Qāsim's treatise suggests that that vessels and tiles were covered with an alkaline glaze and fired for 12 h. They would then have six and a half days of cooling in the kiln before the lustre design was applied. The recipe for lustre glaze comprised a mixture of red and yellow arsenic, gold and silver marcasite, yellow vitriol, copper, and silver ground with sulphur dissolved in grape juice or vinegar. The second firing takes place in a low-temperature reducing kiln which allows the metal oxides to fuse with the alkaline glaze and create the lustrous sheen. Star-and-Cross tile patterns with figural and vegetal motifs, at times moulded in bas relief, as well as moulded and painted inscription friezes were the most common patterns of decoration. The buff-and-blue aesthetic that characterises the early use of glazed bricks on the exterior of buildings was also predominant in the decoration of interiors with lustre tiles. Cobalt blue was used to highlight relief-moulded inscriptions on lustre tiles

Architectural Decoration in Islam: History and Techniques, Fig. 15 Detail of a floral tile mosaic from the Gur-i Emir Mausoleum. Samarqand, Uzbekistan. 1404

as is clear from the *mihrab* tile now in the Los Angeles County Museum of Art (see http://www.lacma.org/islamic_art/figures/fig_a31.htm).

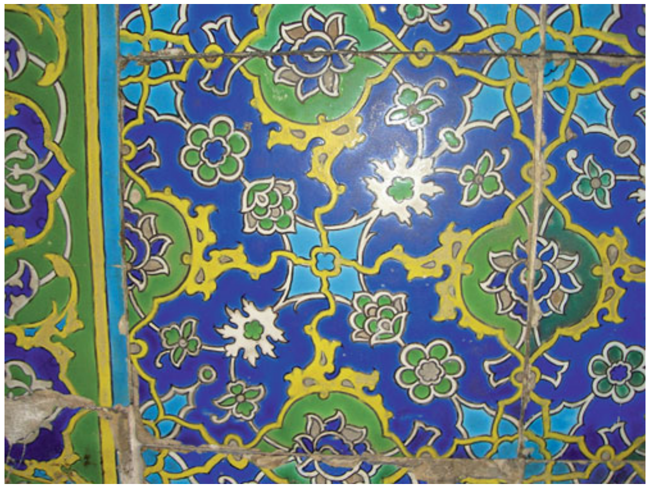
The earliest surviving lustre tiles known to have decorated Muslim monuments are the tiles that adorned the *qibla* wall of the Great mosque of Qayrawan in Tunisia (ca. 862). According to the historian Ibn Nājī (d. 1433), who cites al-Tujībī (d. 1031), some of those tiles were sent from Baghdad but an Iraqi craftsman who knew the lustre technique manufactured some locally. There is also evidence for the use of lustre in Egypt and Syria before the technical know-how was transmitted to the potteries of Kashan in Iran.

Cut Tiles or Tile Mosaic

The earliest examples surviving in this technique are from twelfth century Iran and thirteenth century Anatolia. Technically, tiles are glazed and fired separately and then cut according to the desired design or pattern. They are placed face down and a layer of plaster is applied to the back of the pattern which, once dried, turns into a panel that can be easily fitted onto a wall. The same technique is used for the application of tile mosaics on concave or convex curved surfaces. The heyday of the tile-mosaic technique was under the Timurids when designs became increasingly complex with overlapping layers of arabesque and geometric patterns on flat or curved surfaces (Fig. 15). See also the fourteenth century mihrab from Isfahan, Iran currently in the Metropolitan Museum of Art, New York. http://www.metmuseum.org/Works_Of_Art/viewOne.asp?dep=14&viewmode=0&item=39.20.

Cut tile mosaic has the advantage of maintaining the brilliance of the colour of each tile. The different coloured tiles are fired separately according to the specific temperature needed by the chemical component that gives the colour of the glaze (Wulff, 1986, p. 120). In North Africa, there was a phase of experimentation in cutting the *zillīj* components from a clay panel after the first firing and then glazing each piece separately. The result, however, was less precise patterns (shrinkage), and less smooth surfaces, as the glaze would bulge around the sides (Hedgecoe & Damluji, 1992). This technique, however, is still practiced in some workshops in Titwan in Morocco.

Tile mosaic technique was the predominant form of tile decoration in North Africa. Known as *zillīj*, the ceramic cut tiles are put together in a complex geometric design. Each component of the *zillīj* is monochromic but the final design is a polychrome matrix. Glazed tiles first appear in North Africa in the archaeological context of tenth century Qal'at Banū ḥammād, possibly inspired by the Aghlabids, who in turn were copying Abbasid models. During the twelfth and thirteenth centuries glazed tiles were nailed to or embedded in minarets and towers. The *zillīj* tradition in North Africa, however, reached a stunning maturity under the Marinids who ruled



Architectural Decoration in Islam: History and Techniques, Fig. 16 Detail of *cuerda seca* tiles currently embedded in a re-constructed wall in the Topkapi Palace. Istanbul, Turkey. Late fifteenth century

from Fez between 1244 and 1465. In Spain *zillīj* became common only during the late thirteenth and early fourteenth centuries. There are some differences in the colour palette between Spain and North Africa as Spanish tiles made more use of various shades of blue using cobalt as a colouring agent. The colour palette also used ochre yellow, copper for green and manganese for purple, brown and black.

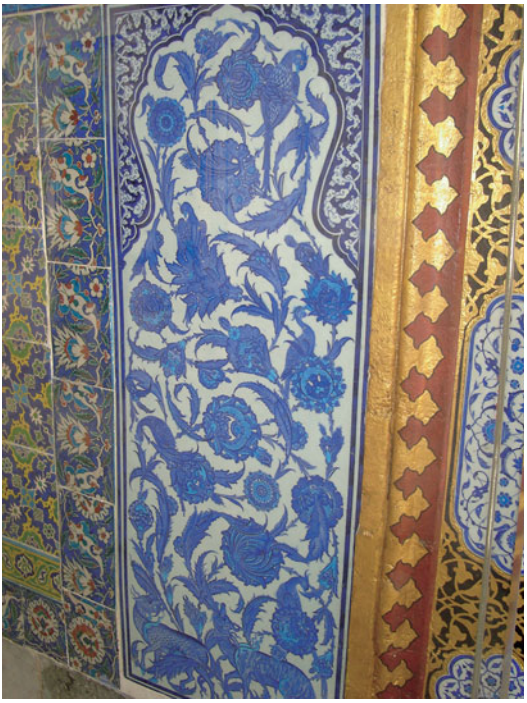
The Cuerda Seca (Dry Thread) Tiles

This is a method of painting with different colour glazes on a single tile in order to achieve the overall colouring effect that cut tile techniques provide in a less expensive and less time consuming manner. Tiles were painted with different colours of glazes that were separated by a greasy or wax material that leaves a black matt line between the different glazes when fired. The waxy material stops the colours from running into each other in the kiln and acts as a pencil line or drawing line that defines the different components of a pattern. The tiles, however, were fired at a preset temperature and as a result, the glazes were not fired to their ultimate brilliance (as in the case of separate firings for the different colours). The colours achieved were less brilliant but the method was much faster and cheaper than tile mosaic. This technique started to replace tile mosaic in popularity during the reign of Shah Abbas in Isfahan.

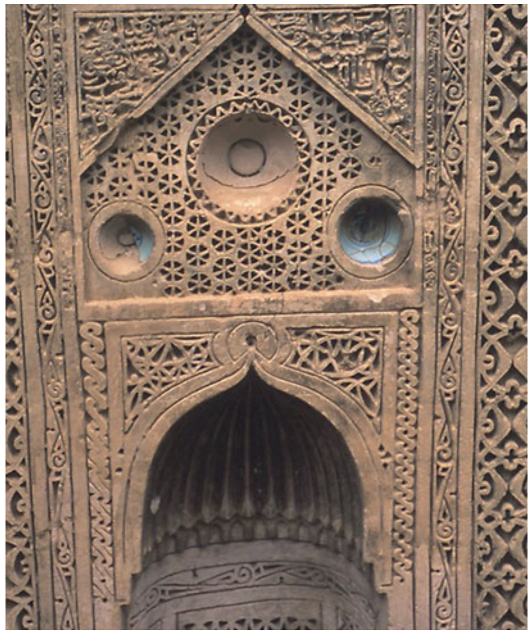
The colour palette of this technique is necessarily limited to the chemicals that melted or fluxed at reasonably close temperatures. The predominant colours used in the *cuerda seca* technique are known as the *haftrang* or seven colours. This range of colours was used in Iran and central Asia from the late eleventh century and reached its apogee in the late fourteenth and early fifteenth centuries. To create overall patterns for large areas square tiles are put side by side and the overall design is transferred on to them. The colour glazes were then added and each tile fired separately (Fig. 16).

Underglaze Painting: Ottoman Tiles and the Iznik Tradition

Blue-and-white underglaze painted tiles evolved in Central Asia and Anatolia during the thirteenth and fourteenth centuries. Their popularity under the Ottomans is linked to a group of Iranian craftsmen known as the 'Masters of Tabriz' who are responsible for the decoration of the Yeşil Mosque in Bursa (1419–1424). The full



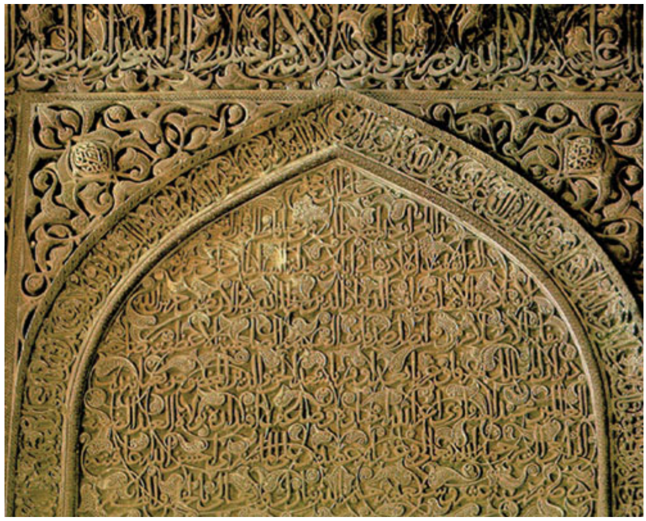
Architectural Decoration in Islam: History and Techniques, Fig. 17 Underglaze painted tile, circumcision room, Topkapi Palace. Istanbul, Turkey. ca. 1520



Architectural Decoration in Islam: History and Techniques, Fig. 18 Evidence of the use of stencils to copy stucco patterns, the mihrab of the Mosque of al-'Uwaynah. Wādī Banī Khālid, Oman. ca. 1540

repertoire of their work included *cuerda seca* tiles, monochrome glazed tiles, and underglaze painted blue-and-white tiles. Tile production in Ottoman Turkey went through various phases of development that became linked to the court workshops from the early sixteenth century (1525–1550 blue and white from the Freer Gallery http://www.asia.si.edu/collections/singleObject.cfm?ObjectId=25488). One of the most stunning examples of early Ottoman underglaze painted tiles is a group of large tiles dated to the 1520s now decorating the exterior of the Circumcision Room in the Topkapi Saray (Fig. 17). The tiles are painted in the *sāz* style featuring serrated leaves, lotus blossoms and rosettes inhabited with birds and mythical creatures in a blue and turquoise palette on a white background. This painting style is associated with Shahkulu who served as the court designer between 1526 and 1556. This period of experimentation led to the development of a more natural floral repertoire that featured tulips, carnations, roses and hyacinth, the hallmarks of the exuberant floral style that distinguishes Ottoman decorative language.

The colour palette of the underglaze painted tiles also went through changes in the early part of the sixteenth century. In addition to blue, turquoise and green, purple was introduced in the late 1540s. It was only in the 1550s when the well known architect Sinan became in charge of the royal workshops of Iznik producing ceramics and tiles that tile sizes became standardized allowing for vast pictorial compositions and monumental calligraphy. It was also under Sinan in 1557 that the colour red was introduced into the palette of Iznik tiles (Fig. 2 above) (1575 typical Iznik with red Freer http://www.asia.si.edu/collections/singleObject.cfm?ObjectId=37077).



Architectural Decoration in Islam: History and Techniques, Fig. 19 Detail of the mihrab of Oljeitu, Friday mosque of Isfahan. Iran. 1310

Stucco

Stucco is a plaster-based decorative medium that was used throughout the Muslim world as a decorative finish as it was cheap and created a considerable effect in a relatively short time. It was perhaps the most common form of decorating building interiors until some of its role was taken over by tile revetments from the thirteenth century. Stucco can be applied to all sorts of surfaces rendering the basic rammed-earth structures (*pisé*) into buildings with sumptuous decoration (Milwright, 2001).

Stucco is commonly made out of gypsum, but lime stucco is also used especially for exterior decoration and for rendering exteriors and special features impervious. A watertight variety of stucco made out of lime and wood ashes bonded with goat hair is used for water channels and for decorating buildings in Oman (known as *ṣārūj*) and in Yemen (known as *Qudād*) (Al-Radi, 1994). In some regions certain substances are rubbed onto the surface of the final pattern to provide a shiny patina. Colour or gold leaf could then be added to the surface.

Stucco is prepared by the calcinations of gypsum or lime through mixing the sifted powder with water while continuously stirring in order to slow down the process of crystallization (Clévenot & Degeorge, 2000, p. 84). It is usually applied in several layers then smoothened. A pattern is then traced either through the use of dry point, ruler and compass or stencil paper which is blotted with charcoal powder. The pattern can be cut out or carved and some of the components further articulated through hatching, perforating and quilting (Fig. 18). Decorative patterns could also be moulded onto the wet stucco by pressing a pre-carved mould (probably hardwood) into the last layer of gypsum – each being allowed to set separately providing a faster way of achieving decorative patterns. For stucco grills which were common all over the Muslim world designs were knife cut in semi-set gypsum boards.

The different techniques for cutting and shaping stucco followed regional and historical patterns. In Samarra, the Abbasid capital of the ninth century, three styles of stucco were excavated. Stucco styles developed from hollowed out background creating patterns of vine leaves and grapes to one where the design is abstract and cut in a bevelled style. Stucco panels with the bevelled style were excavated in a house in Nishapur (Iran) and are now in the Metropolitan Museum of art in NY (http://www.metmuseum.org/toah/hd/nish/ho_gallery_view.htm). The major change to the stucco tradition, however, took place under the Ilkhans (1256–1353) who decorated the *mihrabs* of their mosques with stucco compositions of arabesque, calligraphy and geometric interlace modelled in plastic compositions in tiers and on different planes. One of the most famous examples is the mihrab built in the winter prayer hall of the Friday mosque of Isfahan during the reign of Oljeitu in 1310 (Fig. 19).

References

Al-Faruqi, I. R., & al-Faruqi, L. L. (1986). *The cultural atlas of Islam*. New York: Macmillan Publishing Company. Especially Chap. 8. The Arts and Chap. 21. Ornamentation in the Islamic Arts.

Al-Hassan, A. Y., & Hill, D. R. (1986). *Islamic technology. An illustrated history*. Cambridge: UNESCO.

Allan, J. (1973). Abu'l- Qasim's treatise on ceramics. *Iran, 11*, 111–120.

Al-Qasimi, Z., et al. (1988). *Qamus al-Sinaat al-Shamiyah*. Damascus, Syria: Dar Tlas li 'l-dirasat wa 'l-tarjama wa 'l-nashr.

Al-Radi, S. (1994). Qudad. The traditional Yemeni plaster. *Yemen Update, 34*, 6–13.

Amin, M. M., & Ibrahim, L. A. (1990). *Architectural terms in Mamluk documents 648–923/1250–1517*. Cairo, Egypt: American University in Cairo Press.

Blair, S. (1998). *Islamic inscriptions*. Edinburgh, UK: Edinburgh University Press.

Blair, S., & Bloom, J. (2000). Tiles as architectural decoration. In M. Hattstein & P. Delius (Eds.), *Islam. Art and architecture* (pp. 448–451). Cologne, Germany: Könemann.

Bloom, J. (1993). On the transmission of designs in early islamic architecture. *Muqarnas, 10*, 21–28.

Burckhardt, T. (1976). *Art of Islam. Language and meaning*. London: World of Islam Festival Trust.

Clévenot, D., & Degeorge, G. (2000). *Ornament and decoration in Islamic architecture*. London: Thames and Hudson.

Critchlow, K. (1976). *Islamic patterns. An analytical and cosmological approach*. London: Thames and Hudson.

Floor, W. (2003). *Traditional crafts in Qajar Iran (1800–1925)*. Costa Mesa, CA: Mazda Publishers.

Harb, U. (1978). *Ilkhanidische Stalactitengewölbe*. Berlin, Germany: Dietrich Reimer Verlag.

Hedgecoe, J., & Damluji, S. S. (1992). *Zillij. The art of Moroccan ceramics*. Reading, UK: Garnet Publishing.

Jones, D. (1978). The elements of decoration: Surface, pattern, and light. In G. Michell (Ed.), *Architecture of the Islamic world. Its history and social meaning* (pp. 144–175). London: Thames and Hudson.

Milwright, M. (2001). Fixtures and fittings. The role of decoration in Abbasid Palace design. In C. Robinson (Ed.), *A medieval islamic city reconsidered. An interdisciplinary approach to Samarra* (pp. 79–100). Oxford: Oxford University Press.

Nasr, S. H. (1987). *Islamic art and spirituality*. Lahore, Pakistan: Suhail Academy.

Necipoğlu, G. (1995). *The Topkapi scroll: Geometry and ornament in islamic architecture*. Santa Monica, CA: Getty Center for the History of Art and the Humanities.

O'Kane, B. (1987). *Timurid architecture in Khurasan*. Costa Mesa, CA: Mazda Publishers.

Saliba, G. (1999). Artisans and mathematicians in Medieval Islam. *Journal of the American Oriental Society, 119*(4), 637–645.

Shani, R. (1996). *A monumental manifestation of the shiete faith in late twelfth-century Iran. The case of the Gunbad-i ʿAlawiyān, Hamadān* (Oxford Studies in Islamic Art, Vol. 11, p. 172). Oxford: Oxford University Press.

Tabbaa, Y. (2001). *The transformation of islamic art during the Sunni revival*. London: I. B. Tauris.

Wulff, H. E. (1966). *The traditional crafts of Persia*. Cambridge, MA: The MIT Press.

Websites

Ashmolean museum in Oxford, UK. http://islamicceramics.ashmol.ox.ac.uk/

Ashmolean museum in Oxford, UK (1301 treatise) http://islamicceramics.ashmol.ox.ac.uk/Glossary/abulqasim.htm

IRCICA, the research centre for islamic history, art and culture, Istanbul www.ircica.org

Islamic Art and Architecture Organization http://www.islamicart.com/main/calligraphy/index.html

Los Angeles county museum of art http://www.lacma.org/islamic_art/figures/fig_a31.htm

Metropolitan museum of art, New York. http://www.metmuseum.org/Works_Of_Art/viewOne.asp?dep=14& viewmode=0&item=39.20

Metropolitan museum of art. http://www.metmuseum.org/toah/hd/orna/hd_orna.htm

Numerical Geometry Study Group, University of Heidelberg. http://www.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/ and the Takht-I Sulayman muqarnas drawing http://www2.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/Img/suleyman_plate.jpg

Architecture and Landscape in India

Alexandra Mack
Pitney Bowes, Strategic Technology and Innovation Center, Shelton, CT, USA

Architecture and landscape are connected on many levels in India. The meanings imbued in the architectural forms create diverse conceptual landscapes overlain on the same geographical area. Architecture defines the landscape, and the presence of different architectural traditions helps create these multiple landscapes. Architecture is used to highlight the landscape's association with the cosmos, with mythological events, and with historical and current events and is also the frame for where people live and work (Mack, 2004).

Evidence for humans symbolically embuing the natural landscape with additional meaning through the built environment dates to the Neolithic in South India. Ashmounds, large stratified deposits constructed between 3000 and 1200 BC, were loci of social relationships placed with regard to the surrounding landscape (Johansen, 2004).

The connection between the earthly landscape and the celestial landscape has been apparent in India for thousands of years. There is evidence at Dholavira and other Harappan sites that the cities were planned with axial orientations, apparently following the placement of sky-based features (Bisht, 2000). Danino (2008) has noted that this demarcation of space is a key factor in cultural definition. In other words, it is the space, more so than the buildings that inhabit it, that is the focus of attention and energy.

Celestial orientations become more apparent in cities and towns built based on the sixth-century architectural manuals known as the *vāstuśāstras*, which mandate a grid plan based on the maṇḍala form (Deva, 2000). The maṇḍala can take many forms but is essentially a series of concentric geometric figures which represent the structure of the universe. The figures of circle, square, and triangle can be interpreted as representing the elements of light, water, and wind, respectively. They can also represent the four directions, the nine planets, and the three mythic realms (Singh, 2000). Maṇḍala-inspired architectural arrangements reflect the cosmological structure in the earthbound landscape, thus connecting the two.

The maṇḍala is frequently represented in Hindu temple complexes and the surrounding towns. This structure is most apparent at sacred sites which serve as pilgrimage centers. The maṇḍala is first reflected at the level of the individual structure of the temple. The temple is ideally situated on a north-south axis, with enclosure walls and circumambulatory paths creating a series of concentric squares. The *vāstuśāstras* even dictate a formal ritual for measuring and laying out the shrine. Temple towns are frequently laid out to continue the maṇḍala plan, with the temple complex at the center of the town and streets running around the walls and leading out from the gateways in the cardinal directions (Michell, 1993). At Srirangam, the temple is enclosed by seven sets of walls, creating a clear maṇḍala form radiating outward and encompassing part of the town (Fig. 1). Likewise, Madurai and Chidambaram have multiple enclosures around the central temple, with main streets running parallel and perpendicular to the complexes. Some temple towns, such as Kanchipuram and Kumbukonam, house multiple temples, and the spatial arrangement in the town reflects this. Each temple is the center of its own district, and each district has a distinct geometric form. Roadways in these towns tend to link these distinct neighborhoods, forming a unifying whole in that way. The geometry of the built environment spreads out into the landscape, thus imposing a structure on the landscape through architecture.

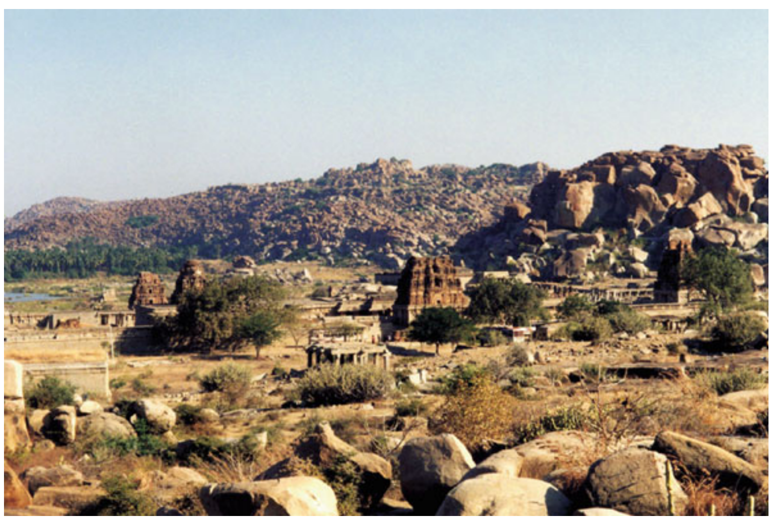
While the built environment can structure the landscape, the physical features of the landscape determine the placement of architecture and influence the nature of the geometric forms of the towns. Vijayanagara is set in a landscape of bouldery granite outcrops, leaving the valleys between as prime construction areas (Fig. 2).

Architecture and Landscape in India, Fig. 1 A view from a gateway into one of the interior courtyards of the Ranganatha temple at Srirangam shows how the complex is a series of embedded rectangles

While the landscape strongly influenced the placement of structures, the city shows an axial layout and cosmological affinities (Malville, 1994; Fritz and Michell, 1987).

Circumambulation reinforces the connection of the natural and built environment and draws connections to the celestial world, since circulatory paths in India are often represented by the maṇḍala. Physically moving though the geometric pattern symbolizes a cosmic journey. The *panchakroshi* route at Varanasi moves pilgrims through 108 shrines spaced in a mathematical pattern which embeds the geography of the site into the psyche of the pilgrim. The 108 shrines also represent a cosmic circuit based on 12 zodiac signs and the nine planets of Hindu mythology (Singh & Fukunaga, 2010).

While the maṇḍala is an ideal form, influencing architectural constructions, the landscape itself is a key determinant in the location of these structures. Landscape features have sacred qualities, but the built environment is fundamental to imbuing the land with meaning. Landscape and architecture thus are intertwined physically and conceptually. The *vāstuśāstras* prescribe the placement of settlements near water sources, such as river confluences. Rivers represent confluences of sacred and profane and provide homes for deities. Therefore rivers become



Architecture and Landscape in India, Fig. 2 The Vithala temple complex at Vijayanagara is set in a valley below granite outcrops, near the Tungabhadra River

Architecture and Landscape in India, Fig. 3 A shrine on the top of Malyavanta Hill at Vijayanagara blends with the rocks

magnets for settlements and sacred sites, though a nearby water source is essential for sustaining a population, irrespective of the holiness of the site. Most of the ancient towns in India are found of the banks of sacred rivers, such as the Ganga and Yamuna. The seven cities (*Saptāpurī*) of Varanasi, Mathura, Ayodhya, Ujjain, Dvarka, Kanchipuram, and Hardvar are all located on peninsulas, surrounded on three sides by water.

Hills and mountains are also an important landscape element in the Hindu tradition, and like water these features provide domiciles for gods (Fig. 3). The mountain of Tirumala is the home of the god Sri Venkateswara, and the temple there draws the largest number of pilgrims of any Hindu temple. The town of Tirupati at the base of the mountain developed in support of this holy site (Nag & Reddy, 1994). The hill at Tiruvannamalai symbolizes the column of fire from which Shiva emerged and serves as the basis for the conceptual spatial organization for the town. Patterns of movement also serve to connect buildings with the natural landscape. Circumambulatory routes and ritual paths extend far beyond the temple complex, connecting multiple shrines, in cases such as Varanasi, or encompassing the landscape itself, such as the circumambulation of the sacred mountain at Tiruvannamalai, which also includes a journey through the town itself (L'Hernault, 1993). These routes blur the line between the built and natural environments.

Beyond the water and hills, entire landscapes are often imbued with symbolic and mythological meaning. Landscapes associated with the Ramayana legend are key examples of this phenomenon, as seen at sites such as Ayodhya, Chirtrakut, and Vijayanagara (Sinha, 2010). The pilgrimage circuit at Ayodhya, the site of Rama's birth, takes worshippers to shrines along the banks of the Saryu River, which encircles the town. The river, ghats, and shrines combine to form the total landscape. At Chirtrakut, the physical landscape is dominated by the Mandakini and Payasvini rivers and enhanced by the specific sites associated with Rama and Sita. The area around Vijayanagara is associated with Kishkinda, the monkey kingdom. The Tungabhadra River cuts through the landscape, through the hills, to form the most significant natural features, and many are associated with the Ramayana – Hanuman is said to have been born on Anjenadri Hill, and Rama and Lakshmana waited out the monsoon on Malyavanta Hill. These hills have been adorned with temples commemorating these events, intertwining the man-made and the natural.

The importance of place on the creation of these spaces is further emphasized by the willingness of people to renovate shrines, often entirely rebuilding *vimanas* and even migrating deities from subsidiary to central and vice versa. Branfoot (2013) attributes this to the fact that it is the sites themselves – the landscape – that is sacred.

Architectural associations with important events and personages are seen at a variety of sites in India. Stupas, which themselves represent

Architecture and Landscape in India, Fig. 4 Humayun's tomb in Delhi sits in man-made landscape, where the tanks, gardens, and walkways follow a grid pattern

the body of the Buddha, house relics, though in these cases the relics have been brought to the site and were not necessarily an inherent part of the landscape before construction of the stupa. Nonetheless, there is evidence that the stupas themselves were built with a mind toward celestial import. Rao (1992) has posited that the stupas of Sanchi have an axial alignment that orients them toward moonrise and sunset on Buddha Purnima.

Elaborate tombs built by Muslim rulers include tanks, gardens, and well-defined paths, creating their own landscape (Fig. 4). Muslim dargahs [Sufi Islamic shrines built over the grave of a revered religious figure] often attract pilgrims who honor the holy men entombed within and mark the importance of a specific place on the landscape. Religious claims on the landscape are not necessarily exclusive; multiple religious shrines from different traditions share the landscape at sites such as Ellora and Mathura (Ray, 2004).

This historic and mythological significance of the landscape and the associated religious architecture was also used by rulers to lend credence to their claims to power. Basu has argued that the Buddhist Kushan rulers at Mathura built structures specifically to associate themselves with the site's existing sacred geography (2010). Early in the development of the Garhat states of Orissa, forts and settlements were placed on the landscape with defense and supplies from nearby villages. Forts were protected by hills and jungles. However, rulers maintained their link with the villages by associations with local deities, who were worshipped within the walls (Kulke, 1993). This legitimation through the ritual landscape grew in scale as the towns grew. The Ramachandra temple at Vijayanagara was used by the kings to enhance their legitimacy, by associating themselves with the god-king who spent time in the surrounding area. They used the architecture and specifically the placement of the buildings to build those associations. The temple was built in the heart of the Royal Center, amid palaces and the kings' seat of power. Fritz has argued that the city was planned such that the Ramachandra temple lays at the center of routes of circumambulation and was on an important north-south axis in the city, so that the overall structure of the city was planned to draw associations between the rulers and Rama (Fritz, 1986). In this case, the mythic associations of the site were manipulated by Vijayanagara rulers to enhance their own power and to legitimate their rule in the eyes of local chiefs and other high-ranking citizens. However, the sheer act of construction was also used for legitimation, with or without mythic associations. Medieval temples

Architecture and Landscape in India, Fig. 5 Children playing and grinding food on a side street near the Banashankari temple, occupying the "quotidian landscape"

with towering gateways were, and in many cases still are, the most dominant landscape features and were directly associated with rulers whose funds aided their construction.

While research into the importance of cosmology, mythology, and legitimation has dominated landscape studies in India, the most common usage of the landscape has been for day-to-day residential and subsistence activities. Most importantly, these activities occur in the midst of all the other happenings. For instance, while axial layouts and cosmological orientations are applied to temples and surrounding towns in order to maintain a ritual integrity, these neighborhoods are also the centers of everyday life. At Srirangam, which was mentioned earlier as an archetypal maṇḍala shape, boys play cricket in the streets on the outer circuits of the walls. A few steps from the primary circumambulatory routes in any temple town lead to residential areas, local shops, and mundane activities – a quotidian landscape (Fig. 5). This overlay of secular and religious use of the same landscape is seen throughout India, at sites sacred to all religious traditions.

References

Basu, C. (2010). Place, space and community in Kushan Mathura: Sociology of an early Indian "Tirtha". In J. M. Malville & B. Saraswati (Eds.), *Pilgrimage: Complexity and cosmos*. New Delhi: D. K. Printworld.

Bisht, R. S. (2000). Urban planning at Dholavira: A Harappan city. In J. M. Malville (Ed.), *Ancient cities, sacred skies: Cosmic geometries and city planning in ancient India* (pp. 11–23). New Delhi: Indira Gandhi National Centre for the Arts.

Branfoot, C. (2013). Remaking the past: Tamil sacred landscape and temple renovations. *Bulletin of the School of Oriental and African Studies, 76*(1), 21–47.

Danino, M. (2008). Insights into Harappan town-planning, proportions and units, with special reference to Dholavira. *Man and Environment, XXXIII*(1), 66–79.

Deva, K. (2000). Urban planning in Vāstuśāstra. In J. M. Malville (Ed.), *Ancient cities, sacred skies: Cosmic geometries and city planning in ancient India* (pp. 24–32). New Delhi: Indira Gandhi National Centre for the Arts.

Fritz, J. M. (1986). Vijayanagara: Authority and meaning in a South Indian capital. *American Anthropologist, 88*, 44–55.

Fritz, J. M., & Michell, G. (1987). Interpreting the plan of a medieval hindu capital. *World Archaeology, 19*, 105–129.

Johansen, P. G. (2004). Landscape, monumental architecture, and ritual: A reconsideration of the South Indian ashmounds. *Journal of Anthropological Archaeology, 23*, 309–330.

Kulke, H. (1993). *Kings and cults: State formation and legitimation in southeast Asia*. New Delhi: Manohar.

L'Hernault, F. (1993). Tiruvannamalai. *Marg, 44*(3), 40–57.

Mack, A. (2004). One landscape, many experiences: Differing perspectives of the temple districts of Vijayanagara. *Journal of Archaeological Method and Theory, 11*(1), 59–81.

Malville, J. M. (1994). Astronomy at Vijayanagara: Sacred geography confronts the cosmos. *National Geographical Journal of India, 40*, 171–188.

Michell, G. (1993). Introduction. *Marg, 44*(3), 2–17.

Nag, S. C., & Reddy, M. V. (1994). The urban origin of Tirupati temple town. *National Geographer, 29*(2), 115–120.
Rao, N. K. (1992). Astronomy with Buddhist Stupas of Sanchi. *Bulletin of the Astronomical Society of India, 20*, 87–98.
Ray, H. P. (2004). The archaeology of sacred space: Introduction. In H. P. Ray & C. M. Sinopoli (Eds.), *Archaeology as history in early south Asia* (pp. 350–375). New Delhi: ICHR.
Singh, R. P. B. (2000). Kashi as cosmogram: Sacred geometry of Varanasi. In J. M. Malville (Ed.), *Ancient cities, sacred skies: Cosmic geometries and city planning in ancient India* (pp. 58–81). New Delhi: Indira Gandhi National Centre for the Arts.
Singh, R. P. B., & Fukunaga, M. (2010). Kashi as cosmogram: The Panchakroshi route and complex structure of Varnasi (India). In J. M. Malville & B. Saraswati (Eds.), *Pilgrimage: Complexity and cosmos*. New Delhi: D. K. Printworld.
Sinha, A. (2010). Landscapes and Ramayana legends. In J. M. Malville & B. Saraswati (Eds.), *Pilgrimage: Complexity and cosmos* (pp. 138–149). New Delhi: D. K. Printworld.

Architecture in Africa, with Special Reference to Indigenous Akan Building Construction

Tarikhu Farrar

The hall itself was the chief object that attracted my attention. It was at least a 100 ft in length, 40 ft high, and 50 broad. It had been quite recently completed, and the fresh bright look of the materials gave it an enlivening aspect, the natural brown polish of the wood-work looking as though it were gleaming with the lustre of new varnish. Close by was a second and more spacious hall, which in height was only surpassed by the loftiest of the surrounding oil palms; but this, although it had only been erected 5 years previously, had already begun to show symptoms of decay... Considering the part of Africa in which these halls were found, one might truly be justified in calling them wonders of the world; I hardly know with all our building resources what material we could have employed, except it were whalebone, of sufficient lightness and durability to erect structures like these royal halls of Munza, capable of withstanding the tropical storms and hurricanes. The bold arch of the vaulted roof was supported on three long rows of pillars formed from perfectly straight tree stems; the countless spars and rafters as well as the other parts of the building being composed entirely of the leaf-stalks of the wine-palm (Raphia vinifera). The floor was covered with a dark red clay plaster, as firm and smooth as asphalt. The sides were enclosed by a low breastwork, and the space between this and the arching roof, which at the sides sloped nearly to the ground, allowed light and air to pass into the building. (Schweinfurth, 1874, Vol. II, pp. 42–3)

Famed nineteenth century botanist, Dr. Georg Schweinfurth, here writes of one of tropical Africa's most remarkable achievements in indigenous architecture and building technology, what he calls the "royal halls" of the Mangbetu kingdom. In the last years of the 1860s, Schweinfurth, traveling with Sudanese merchants, made his way southward along the Nile corridor toward the African interior. Ultimately, he reached the northeast quadrant of central Africa.

Schweinfurth would go on to write voluminously about this central African world. He also produced illustrations in quantity and of considerable quality. From his writings and illustrations we can gain some appreciation of the technological prowess of this region's cultures in the late precolonial era. The grandeur and elegance of the "royal halls" certainly captured Schweinfurth's imagination. So too did the considerable building skills embodied in their construction.

The "royal halls" were merely the grandest expression of the architectural and building skills of the peoples of this part of Africa. Of the more ordinary buildings, dwellings, storage structures, etc., we can also learn something from Schweinfurth's writings and illustrations. He was encountering traditions of architecture and building technology that were indigenous to tropical Africa. Nor should we imagine that the Mangbetu, in this instance, represent some sort of unusual or atypical culture.

The building materials identified by Schweinfurth are familiar from elsewhere in tropical/sub-Saharan Africa. These include types of clay, particularly those deriving from forest and savanna ochrosols and oxysols, and tropical black earths. Also included are various hardwood tree species. Of great importance is the raphia palm. Virtually every part of this useful tree was employed in the building process.

The trunk provided posts; the fronds, laths and rafters; and the leaves, roofing or thatch. Rope and twine for binding purposes (binding laths to posts, for example) were also made from the woven fibers of the leaves. These materials were readily available, abundant, and admirably suited to the task of building. As elsewhere in tropical Africa, the peoples of this region mastered their use. This is evident in the way that the materials were processed, in the techniques of building developed in conjunction with their use, and in the final product of the building process. Here, as elsewhere in tropical/sub-Saharan Africa, people constructed houses that were durable, comfortable, and, in today's jargon, "ecologically sound."

The study of African architecture, at least in an academic setting, did not truly develop until the second half of the twentieth century. A small, but determined and dedicated body of scholars, not a few of them from Africa, had taken up the challenge to the orthodoxy. Africa (i.e., sub-Saharan/tropical, or Black Africa), they insisted, was indeed a part of the *historical* world and worthy of study as such. Within this group was body of architects, folklorists, a few historians, and others who began to pay serious attention to indigenous African architecture, or what was termed "African traditional architecture." (See, for example, Denyer 1978; Dmochowski 1988 [1958–1965]; Gardi 1973; Gluck 1973 (1956); Hull 1976; Oliver 1971; Prussin 1969).

Their work, in conjunction with the written accounts of earlier travelers to Africa like Schweinfurth, provides us with a solid foundation on which to continue to piece together something of a coherent picture of the technologies of building developed by the peoples of tropical Africa at earlier periods in their histories. Also useful are recent ethnoarchaeological/material culture studies of "traditional" building where and to the degree that it continues to be practiced. The writer conducted this type of research in southern Ghana, primarily in the Akan region, in the mid-1980s. The information yielded by this research is useful in developing a broader understanding of indigenous building technologies in tropical Africa based on the use of clay, wood, and other plant materials.

The Akan peoples inhabit roughly the southern half of the modern country of Ghana, and spill over into the eastern borderlands of Cote d'Ivoire. They constitute almost half of the population of Ghana, and in terms of history and culture are among the better known of West Africa's peoples. While the so-called "traditional" architecture of the Asante has been studied and is reasonably well known, that of other Akan groups has not received comparable attention, in some cases none at all. The study of Asante architecture has, in general, focused on the products of the building process rather then the raw materials and the building process itself. Considerable attention has been paid to the esthetics of architectural forms, and the uses and meanings that the various forms of enclosed space (e.g., shrine houses, palaces, etc.) were and continue to be imbued with. The focus here is different. Consideration will be given to the materials used in building construction.

In the mid-twentieth century, the Akan peoples were practicing a number of different building technologies, as were Ghanaians generally. Of these, only two can be described as being "indigenous." The two are *timber frame construction* and *coursed clay construction*. Both types, by the way, were observed by Schweinfurth in the Upper Nile region and northern central Africa, and are widespread throughout tropical Africa. The Akan and other Ghanaian peoples recognize these building technologies as being of considerable antiquity, long predating the colonial era. They have an existence in local oral history, as the writer was to discover to his surprise. Moreover, historical documents (i.e., written documents from the period of early European contact, or ca. 1500–1750) and archaeological evidence firmly support the idea of great antiquity.

Coursed clay construction is related technologically to the building methods known in other parts of the world as pise, tapia, rammed earth, and tauf. The product of this method is a structure with freestanding, solid clay walls. *Timber frame construction* is historically the more widely practiced of the two by the Akan peoples. It starts with a timber framework, which may then be closed in with a panelling of palm-fronds (this is the case with the Mangbetu "royal halls") or ► bamboo, or with a structure of clay and wood. The two techniques and resulting built forms are distinguished in local terminology. Timber frame construction finished with clay and wood is often referred to by the archaic "wattle and daub" by English speakers, although some more accurately call it "frame and plaster." In southern Africa it is known as "pole and daga."

Of the range of building materials employed in indigenous building construction, plant materials constitute the most varied group. These include a staggering number of hard and soft wood species, including several species of palm, and other woody plants, notably shrubs and lianes. Many of the tree species, especially the palms, provide not only useful timber, but leaves and bark. The leaves are used for thatch and in the manufacture of binding material. Sometimes, fibers, also used in the manufacture of binding material, are derived from the bark. Also included in this group are various species of grass, particularly bamboo and elephant grass.

Earthen materials consist primarily of clays. Most of the soil types of southern Ghana are characterized by strata classified as light to medium clays. These strata lie immediately beneath a layer of sandy to silty topsoil at depths of 20–2 m (Brammer, 1962, pp. 101–20). Light to medium clays are locally described as being "soft." What this means is that they are easily workable. With little difficulty, they can be trodden or mixed with a hoe into the proper consistency for building. The only thing required is the addition of water.

By contrast, those clays that are described as being "hard" are the types that are more suitable for pottery manufacture. Unlike some of the neighboring peoples, notably the Anlo Ewe and the Se (Shai) Dangme who occasionally use such clays for wall construction, the Akan have never used them for this purpose. Kaolin, *hyire* in the Akan language, is a "hard" clay that was used extensively by the Akan, but for the manufacture of white, yellow, or gray wall finish or plaster. At the time of the earliest European contact (the late fifteenth century), such plasters were a nearly universal feature of buildings in Akan towns.

As mentioned above, the earthen material used in wall construction is found nearly everywhere in the region inhabited by the Akan, lying just beneath the topsoil. The predominant soil types in southern Ghana are savanna and forest ochrosols, and to a lesser extent, oxysols. Tropical black earths are found, but are of limited distribution. From the point of view of agricultural potential, these differences in soil type have significance. In terms of use as building material, they do not. All contain light to medium clay strata.

Color is the primary characteristic by which the Akan distinguish soil types, but always in combination with other characteristics, for example, viscosity. *Notia/dotia*, or *netia/detia* is the generic term for soil. The different soil types are *notia tumtum*, *notia koko*, and *ntwuma*. Ntwuma is a sub-type of notia koko. Notia tumtum, literally, "black soil," refers to two different types of soil, both black in color. No terminological distinction between the two is made, although people are quite clear on the differences in terms of physical properties in general, and specifically with reference to use for building purposes.

One type of notia tumtum derives from the predominant soil type, notia koko (savanna/forest ochrosols). This type results from the decomposition of organic matter, in particular "kitchen" refuse, into the upper strata of notia koko. Thus, it is typical of the soil found under and around middens and other places of refuse deposit, and is also found near habitations. This type of soil is not at all suitable for building purposes, although excellent for kitchen gardens.

The principal type of notia tumtum is a tropical black earth. It is characterized by light to medium clay strata immediately below the topsoil and is thus appropriate for any type of construction. It has never been widely used by the Akan simply because its distribution in those parts of Ghana where they live is limited. In Ghana, tropical black earths are found principally in the coastal savanna (Brammer, 1962, pp. 116–117). They do constitute a good part of the soils of the Accra Plains where they are known as *Akuse clays*. There, they are extensively used for building by the Ga and Se Dangme peoples.

Notia koko, literally, “red soil,” is the predominant soil type and the most widely used earthen building material. It is used in both timber and clay (wooden frame with clay plaster) construction, and in coursed clay (free-standing, solid clay wall) construction. It is used for walls, floors, courtyards, and hearths.

Ntwuma is described as a distinct type of notia koko. “Ntwuma” has been translated as “hematite” because it is used as a source of red ochre. The quality that makes ntwuma the building material par excellence for construction of solid, free-standing clay walls is its near ideal balance between clay, sand, and silt. It is widely distributed and is often found beneath the more ubiquitous notia koko by digging down to a depth of about a meter where the red earth matrix begins to reveal traces of yellow clay. The type of ntwuma used for plastering floors, courtyards, hearths, and wall bases, on the other hand, is of more limited distribution. It is quarried from special sites. It is distinguished by its deeper red color, presumably reflective of a higher iron content.

As mentioned above, the number of different species of plants that constitute building materials is extensive. F. R. Irvine (1962), in his *Woody Plants of Ghana*, lists 124 species of trees, shrubs, and lianes used throughout Ghana for building purposes, and this is not likely to be a complete listing.

Through several interviews conducted in the Brong-Ahafo region of Ghana, in the settlements of the Nkoransa Traditional Area and in the town of Nkoransa itself during the dry season of 1986–1987, the writer was able to compile a list of nearly 50 plant species used in building construction. Some 35 of these are species of trees and shrubs used to provide timber. An additional 13 species of trees, shrubs, and vines are used in the manufacture of binding material (rope, twine, etc.), plaster, and thatch. The trees that were identified as the main sources for the timber framework were mostly hardwood species. Some softwoods can be used for elements of the framework that do not come into contact with the ground, for example, thatch poles and rafters. But posts and studs require decay and insect resistant hardwoods (For a complete listing of plant species used in building construction along with their scientific names, see Appendix).

Each tree, shrub, vine, and cane was thoroughly described in terms of its physical properties and its uses. Trees, for example, had the color and texture of their bark, sapwood, and heartwood described, whether or not the wood was soft, medium, or hard, and how resistant to insect attack and to decay. Discussions always went beyond uses in building construction to include information about uses in woodworking, of medicinal properties of bark, roots, fruits, etc., and uses for food, if any. Some species were said to have specific useful “spiritual” (for lack of a more accurate term) properties, and these, too, were described (For a detailed description of the collection and processing of building materials see Farrar, 1996, pp. 95–154.).

This vast range of building materials, earthen and plant, is the stuff of indigenous Akan building. In the past, the materials constituted the universe of Akan building materials and were used in the construction of two timber frame architectural forms and one of coursed clay. Of the two timber frame building types, one, the *mpapa-dan* structure, is built entirely of plant materials. The other, the *tare-dan* structure, consists of a timber framework with an infilling and final plastering of clay. The former is normally a type of temporary dwelling, while the latter is designed to have much greater longevity, or at least was so in the past.

The considerable skill that once characterized indigenous building construction was the product of centuries of technological growth. This process involved the acquisition of a profound knowledge of the environment and the multitude of resources therein, and the result was the evolution of architectural forms that were attractive, comfortable, and reasonably durable. The materials used in this type of building construction were widely available and easily accessible to most people. The tools used in their collection and processing were widely possessed. The skills associated with indigenous building were virtually universal, although some builders attained a level of building skill that earned them the status of "masters" in a way that separated them from others. And finally, the pressures placed on precious resources were minimal. These architectural/building traditions of tropical Africa thus represent an intelligent, rational, and efficient use of the local environment. They are yet another reminder of a largely ignored indigenous African technological ingenuity.

Appendix: Timber Used in Building Construction

Unless otherwise stated, the below-listed trees were described by Akan builders as having hard wood. Finer distinctions between hardwoods were made with respect to degree of hardness, resistance to insects and decay, etc., but are not indicated below because of limited space. Some of the characterizations of the hardness of the wood of various species are at variance with those of F. R. Irvine. The writer, in those cases, has stuck with the descriptions given by builders.

Abisiwa – *Vitex Doniana*.

Adobe – *Raphia* spp. The part of the tree that is used in the framework is the midrib of the frond. The leaves are used for thatch and in the making of a strong but soft fiber.

Asesea – *Trema Guineensis*. A fiber is also produced from the bark.

Atoaa – *Spondias Monbin*. A softwood timber that is not resistant to insects or decay. It is nevertheless occasionally used in the Bono region by "a lazy man who cannot find a hardwood tree," in the words of one Bono builder.

Babadua – *Thalia Geniculata*.

Dodowa – *Sterculia Tragacantha*.

Dwini – *Baphia Nitida*.

Fihankra – *Tetrorchidium Didymostemon*. F. R. Irvine claims that the wood is "soft and perishable," but Bono and Asante builders maintain that the wood is hard and insect resistant.

Kane – *Anogeissus Leiocarpus*.

Kokoaa – Identification uncertain. Possibly *Parinari Robusta*.

Kokobata – *Pileostigma Thonningii*.

Kranku – *Butyrospermum Parkii*. This is the well-known Shea butter tree.

Krayie – *Pterocarpus Erinaceus*.

Kwabedua – *Dacryodes Klaineana*.

Kyiribente – *Lophira Alata*.

Mmaa Kube – *Borassus Aethiopum*. Borassus palm.

Moto – *Neuropeltis Acuminata*.

Mpampuro/mkanpuro – *Oxythenantera Abyssinica*. Savanna ► bamboo. Although technically a grass, bamboo is used like timber in the construction of a house framework.

Mpapa – *Elaeis Guineensis*. Mpapa are the oil palm-frond midribs. The tree is called Abe.

Ngo ne nkyene – *Cleistopholis Patens*.

Nwoo – Identification uncertain. Possibly *Terminalia Glaucescens*.

Nyame Dua – *Alstonia Congensis*.

Odum – *Chlorophora Excelsa*. The leaves are also used for sandpaper.

Odwuma – *Musanga Cercopiodes*. A softwood timber used only for rafters.

Ofram – *Terminalia Superba*. A timber of moderate hardness, but not resistant to insects or decay. Used extensively for building purposes in the areas of dense forest.

Opesiakwa – *Morinda Lucida*.

Pam – *Trichilia Heudelotii*.

Pampani – *Albizia Adianthifolia*.

Pepaa/mpepea – *Antidesma venosum*.

Pinimu – Unable to identify.

Potorodom – *Sterculia Rhinopetala*.

Prekese – *Tetrapleura Tetrapleura*; also, *Prosopis Africana*.

Sisi – Identification uncertain. Possibly *Erythrophleum Africanum*.

Wama/awama – *Vitex Mesozygia*.

Fiber/Rope/Cordage Sources

Asense – *Urera* spp. A vine. Fiber is derived from the fibrous, woody interior.

Batatwene – Unable to identify. A vine. Cut and used as is.

Firaye – Unable to identify. A shrub. An extremely soft fiber is derived from the leaves.

Mfun/mfo – *Triumfetta Cordifolia*. A shrub. Fiber is derived from the stems.

Muto – *Neostachyanthus Occidentalis*. A vine. Cut and used as is.

Nem – *Ancistrophyllum Opacum* and *Calumas Deeratus*. The rattan palms. Fiber is derived from the split stems.

Notuo – *Hippocratea Africana*. A vine. Fiber is derived from the fibrous, woody interior.

Ntwea – *Hippocratea Rowlandii*. A vine. Cut and used as is.

Sibre – *Corchorus Aestuans*. A grass. Fiber is derived from the outer skin of the cane.

Sofo – *Christiana Africana*. A tree. Fiber is derived from the bark.

Toa-ntini – *Paullinia Pinnata*. A vine. Cut and used as is.

Sources of Thatch, Plaster, etc

Asakoo – *Cissus Populnea*. A liane. The root – bark and stems are used in the manufacture of plaster.

Awuromo – Unable to identify. A shrub. The leaves are used for thatch.

Etoo – *Pennisetum Purpureum*. Elephant grass. The blades are used as thatch. The stalks, "hyiridie" (the Akan term), resemble small bamboo stalks and are used to build doors, gates, fences, "bamboo curtains," etc.

Sapotoro – *Grewa Mollis*. A tree. The bark is used in the manufacture of plaster.

Identifications were made with the aid of F. R. Irvine's Woody Plants of Ghana.

References

Brammer, H. (1962). Soils. In J. B. Wills (Ed.), *Agriculture and land use in Ghana* (pp. 88–126). London, UK: Oxford University Press.

Denyer, S. (1978). *African traditional architecture*. New York: Africana Publishers.

Dmochowski, Z. R. (1988). In J. C. Moughtin (Ed.), *The work of Z. R. Dmochowski: Nigerian traditional architecture. [1958–1965]*. London, UK: Ethnographica Publishers.

Farrar, T. (1996). *Building technology and settlement planning in a West African civilization*. Lewiston, NY: Mellen University Press.

Gardi, R. (1973). *Indigenous African architecture*. New York: Van Nostrand Reinhold Publishers.

Gluck, J. F. (1973). African architecture (1956). In E. P. Skinner (Ed.), *Peoples and cultures of Africa* (pp. 230–244). Garden City, NY: Natural History Press.

Hull, R. W. (1976). *African cities and towns before the European conquest*. New York: W. W. Norton and Company.

Irvine, F. R. (1962). *Woody plants of Ghana*. London, UK: Oxford University Press.

Oliver, P. (1971). *Shelter in Africa*. New York: Praeger Publishers.

Prussin, L. (1969). *Architecture in Northern Ghana*. Berkeley, CA: University of California Press.

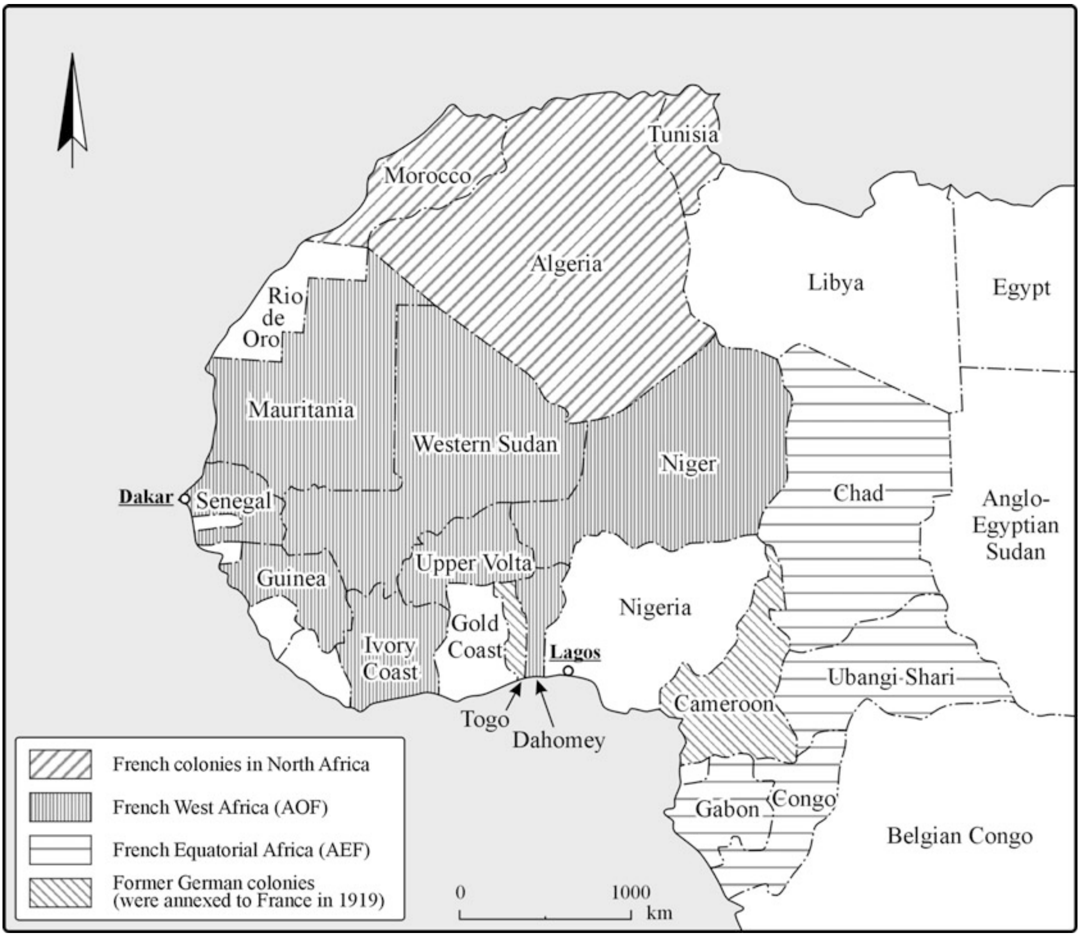
Schweinfurth, G. (1874). *The heart of Africa*. New York: Harper and Brothers.

Architecture in French West Africa

Liora Bigon
European Studies, The Hebrew University of Jerusalem, Jerusalem, Israel

The great variety of architecture in question – mainly indigenous, European, and in-between creations in terms of structure and form – is limited in space and time due to our use of the term "French West Africa." As an invented politico-administrative unit, French West Africa (AOF for *Afrique Occidentale Française*) was a federation established by the Ministry of the Colonies in Paris (1895–1956). Created alongside the neighboring federation of French Equatorial Africa (AEF, 1910–1956), the aim of the AOF was to facilitate the centralist decision-making process in the home country and the economic exploitation of this vast territory. It consisted of 4,633, 985 km^2 with the government general's headquarters, from 1902, in Dakar. The federation included eight colonies: Senegal, French Sudan (today's Mali), French Guinea, Ivory Coast, Dahomey (Benin), Upper Volta (Burkina Faso), Niger, and Mauritania (Conklin, 1997; Suret-Canale, 1971) (see Fig. 1).

There is little space here to expand on the architecture that accompanied the French expatriate community – the white civil and private sectors stood, in the so-called golden age of the interwar period, at only 4,200 persons spread over a territory 14 times larger than France



Architecture in French West Africa, Fig. 1 Colonial West Africa (Map drawn by the author)

(Brunschwig, 1986). Nor is there enough space to depict the medieval roots of the architectural vernacular traditions, i.e., of the Berbers, the Tuaregs, the Fulani (Fulbe or Peuls), Wolof (Oulouf), Serer, Tukulor (Toucouleur), Malinke (Mandingue), Soninke, Bambara, Dyula (Diola or Juula), Songhay, Hausa, Bobo, Senufo, Mossi, Kpelle, Loma, Kissi, Agni, Baule, Fon, Adja, Yoruba, and Bariba – all of whom, among others, fell within the physical borders of the AOF (Elleh, 1996; Oliver, 1997).

Moreover, some of the colonial-*cum*-indigenous architectural traditions stretched far beyond the physical space and time-span delimited by the AOF. We would rather treat this subject through a few selected examples of certain reciprocal influences between colonial and indigenous architectures, representing the two main sides of the colonial equation. This is because the colonial situation, encapsulated in the term French West Africa, could be primarily characterized as a moment of encounter. The classic definition of the colonial situation by the French sociologist Georges Balandier supports this point of view, especially when translated from the sociopolitical realm to the spatio-aesthetic one. According to Balandier (1966), this situation can be understood as the overall influences of the foreign regime on the local (African) societies, the expatriate communities, and other involved groups, in most aspects of life – political, economic, social, religious, institutional, and psychological – from individual everyday lives to the public level.

Our focus on the formalistic correspondence in the built form between the colonizer and the colonized and vice versa is also valuable in bringing together their two architectural historiographies, each of which is normally considered separately. Moreover, it is valuable in transforming the orientation of each historiography, admittedly Eurocentric. That is, African architecture has been classified until recently as technologically unsophisticated material culture, no more than a temporary shelter (Oliver, 1971; Skinner, 1973). While some of its monumental expressions, such as the Sudanese style in West Africa, were the subject of scholastic attention, these were always assigned to exogenous inspirational models: an Egyptian heritage, Andalusian, or Moroccan (Prussin, 1986). Contemporary Sufi urban design in West Africa, nurtured on regional historical precedents in terms of configuration and semiosis, has even been attributed to Haussmann's Paris (Ross, 2006).

Colonial architecture suffers from a bad image: putting aside its ambivalent associations from the subaltern point of view, from a metropolitan perspective, it is associated with standardization, formalistic unity, and bureaucratic planning (King, 1992; Soulillou, 1993). Colonial architecture has been regarded as a simplistic reproduction of its occidental counterpart, provincial at best; until recently, the way western models spread in the colonial setting – adapted to the tropical climate and the interests of the ruling powers – was hardly treated (see, for instance, Bigon & Katz, 2014; Njoh, 2007).

Among the earliest indigenous examples that provided prototypes for colonial style in the AOF-to-be is the distinctive architecture of the Luso-Africans, or Portuguese as they identified themselves. Established in coastal trading centers from the Petite Côte in Senegal south to Sierra Leone from the sixteenth to the early nineteenth century, these Portuguese emigrants – some of them Jews who escaped from the Inquisition – married local African women. Their rectangular houses had a vestibule at the entrance or were surrounded by a porch or veranda, and their outside walls were whitewashed with lime. Suited to both the climate and the owner's occupation, the latter could negotiate with other traveling merchants in the vestibule. These elements spread among the neighboring populations and gradually became the contemporary vernacular (Mark, 2002). The veranda was prevalent in West Africa in the precolonial period and also, since the mid-nineteenth century, became a symbol of European colonial architecture in the tropics. Research is ambiguous as to the history of this architectural element in this part of the continent.

The old French settlements in Senegal, particular testimony to the European presence in this part of the continent as early as the mid-seventeenth century, featured similar elements made of more permanent materials, such as stone. First in Saint-Louis and Gorée and then in Rufisque and Dakar, the houses of the *métis* community (descendants of a French merchant forefather and an African *signara*) inspired both the indigenous and later colonial building styles. Their rectangular units were built around an internal courtyard, usually with a second floor used for living quarters, enhanced with an internal colonnade and external terrace, and a ground floor which served for storage and business negotiations. Their distinctive features, known as the Saint-Louisian style, also introduced a rich imagery of social prestige, status, and stratification among the autochthonous population, based on built form and materials (Sinou, 1993; see also Sinou, 1995; Sinou & Oloudé, 1988) (see Figs. 2 and 3). This sociopolitical stratification was backed by AOF legislation, which, particularly from the early twentieth century, promoted residential segregation on a racial basis between locals and expatriates, based on similar criteria of building materials and forms (Bigon, 2009).

The second half of the nineteenth century was marked by military occupation of the vast hinterland, launched by the French from along the Senegal River, where a series of fortified posts was erected by the Engineering Corps to house

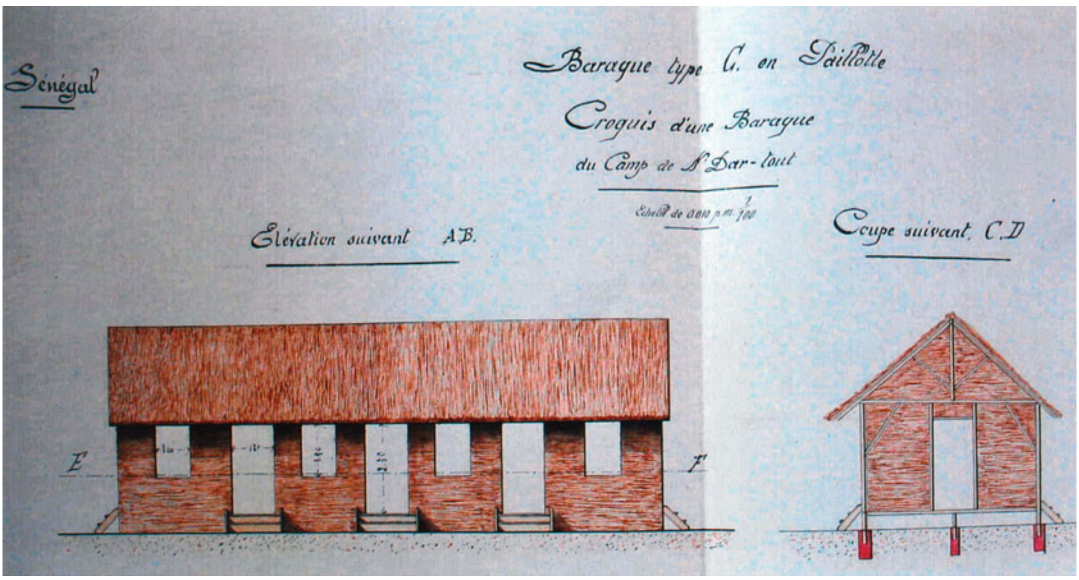
Architecture in French West Africa, Fig. 2 Saint-Louis, Senegal. An old renovated façade of an eighteenth-century house of a European merchant/*métis*, its form adapted to the climate and original function (Author's photo)

Architecture in French West Africa, Fig. 3 Dakar, Senegal. The old commercial city center. An inside view from the courtyard of a Saint-Louisian style house dated to the late nineteenth century (Author's photo)

the garrison. These posts, such as those of Podor, Médine, Bakel, Kayes, and Kita, were configured as a square, rectangle, or star, usually surrounded by a ditch. Due to the practical hardships in transporting permanent materials such as stone from the coast inland or the cost of their import from Europe, the use of local building materials was maximized by the Corps. The use of sun-dried mud bricks – already familiar to these engineers from the French conquest of North Africa – evokes some similarity with the Sudanese fortified complexes, employing this technique for at least several hundred years. In both cases a monumental building is involved, well defined by thick walls and surrounded by ditches. Moreover, because of the employment of local natural building materials by the Corps in the western Sudan and in spite of the contemporary image of the colonial army as an island of civility inside a barbaric sphere, some barracks in certain military outposts actually resembled the African straw huts! The latter were generally condemned by colonial civil servants, seeing them as precarious, unsophisticated, and primitive structures (see Figs. 4 and 5).

There is abundant literature about the vernacular mud building of the western Sudan and the Islamic medieval towns of Timbuktu,

Architecture in French West Africa, Fig. 4 French Guinea. Indigenous rectangular huts made of mud bricks and mortar and roofed with palm tree thatch (Postcard, private collection)



Architecture in French West Africa, Fig. 5 Drawing of the façade of one of the straw barracks erected in the military camp of N'Dar Tout, Saint-Louis (Courtesy of the Archives Nationales du Sénégal)

Djenné, and Gao, which are considered its archetypal models (Brunet-Jailly, 1999; Maas & Mommersteeg, 1992; Prussin, 1986; Takezawa & Cisse, 2012). Often labeled as *style Sudanese*, its formal features include a base that gradually becomes narrower towards the upper part of the structure, blind columns with rocket-shaped heads, a few small openings, and projecting wood beams that are decorative but over which the builders also climb after the short wet season in order to renew the mud patina (see Figs. 6 and 7). Indeed, most of the research literature has been preoccupied almost exclusively with residential buildings and mosques. A reason for this might be because a great portion of the fortified complexes was

Architecture in French West Africa, Fig. 6 Mali (French Sudan). Residential house in Djenné, exemplifying the Sudanese architectural style (Photo taken in the 1960s, courtesy of Marli Shamir)

Architecture in French West Africa, Fig. 7 Mali (French Sudan). Friday Mosque, Mopti (Photo taken in the 1960s, courtesy of Marli Shamir)

completely destroyed by the *pax colonial* and the following pacification process; and the rest is in ruinous state. The study of the *tata* – the historical fortified mud-brick complexes of the Sudan, can teach us about the extent of indigenous spatial control, political and military command until the early colonial period (Bah, 1985).

In the country of Senegal, for instance, there are only a few examples of the *style Sudanese*, most especially in the northern region of Futa Toro. These examples of monumental mud mosques with thick semi-fortress walls are assigned by local oral traditions to the mid-nineteenth century, with the return of Hajj Omar from the pilgrimage to Mecca. Other traditions assign them to the Toucouleur warriors during their withdrawal to Futa Toro at the end of the same century, following the destruction of Omar's empire by the French (Boulègue, 1972). It is possible that these traditions are not contradictory but complementary. However, in the Senegalese coastal strip of Cayor, one of the four districts of the Wolof precolonial kingdom, the plain ground, consisting of dunes of moving sands, made *tata* building impossible. This point is particularly ironic as in the interwar period, colonial Dakar which is situated in the Cayor region was the preferred location by the French for the realization of their neo-Sudanese architectural style. The latter invented colonial style had been inspired by the indigenous forms of the *tata* and the *style Sudanese*.

More than any other architectural style in West Africa, the *style Sudanese* became a French national symbol for the whole colonial endeavor in the AOF in the interwar years. The adherence to this style was both transnational and

Architecture in French West Africa, Fig. 8 Dakar, Senegal. The neo-Sudanese façade of the Polyclinique of the Médina, built in 1932 (Author's photo)

multilateral in its character from a very early stage of the French colonial occupation. Against the background of the exoticist and romanticist literature in France at the end of the nineteenth century, the visual documentation that accompanied the French explorative missions into Africa's hinterland contributed to the fossilization of the vernacular vocabulary in the metropolitan mind. This in turn influenced the visual representation of the AOF's pavilions at a series of Universal and Colonial Exhibitions held in France (and in Europe) from 1855 to 1937 – an imaginative construct that argued for a fictive authenticity. Through these exhibitions, the metropolitan archetypes found their way back to the Sudan, where several French reconstructions were created. Examples include *La Residence* at Ségou in 1893 – this renewed version of the original Palace of Ahmadu was now symmetrically arranged into a three-part, neoclassical composition in the Beaux-Arts style – or the 1911 renewal of the mosque at Djenné, carried out with the support of French administration funds and military advice (Morton, 2000; Prussin, 1985).

Moreover, the latter reconstruction became a prototype for a neo-Sudanese style. That is, a selective choice, designated for a series of colonial public buildings from the regional formalistic repertoire, is to be executed in concrete, ochre color, and Art Deco style. Ideologically, this *style AOF* was in line with the French colonial doctrine of *association*, which displayed a seemingly softened approach towards the autochthonous societies by comparison to the previous one of *assimilation* (Betts, 1961, 1985; Johnson, 1971). In the French colonial empire up to the early twentieth century, assimilation was identified with transplanting the neoclassical style into the colonized regions, hence known as the conqueror style (Çelik, 1997; Wright, 1991). Situated in a variety of AOF capitals, the neo-Sudanese works were, however, few and somewhat uncrystallized – this rather temporary style faded out after the interwar period (Bigon & Sinou, 2013) (see Fig. 8).

With the developmental impulse of the post-Second World War order, accompanied by winds of decolonization, such historicist architectural approaches were replaced by less exclusive and less segregationist urban vocabularies. During the 1940s until the 1960s, International Modernism could be noticed in certain commercial and administrative complexes of urban centers such as Dakar and Abidjan, as well as in other Francophone and Anglophone contexts such as Kinshasa, Douala, and Lagos (see Figs. 9 and 10).

Architecture in French West Africa, Fig. 9 Dakar, Senegal. The governmental *building administratif*, the 1950s (Author's photo)

This architectural optimist wave for the future of the newly independent states was followed by the brutality of the 1970s, stressing public services and facilities, as well as by more eclectic and varied trends in built forms. However, these styles and built projects, whether backed by internal governmental or other external bodies, were always increasingly limited in terms of actual space and target population. Moving at this point from French West Africa into postcolonial French-speaking Africa and West Africa in general, it is more and more difficult to speak about architecture per se in this subregion. With a total population of 312.2 million in 2011, of whom 44.9 % lived in urban areas, it is projected that an urban majority of 65.7 % will be reached by 2050 in one of the world's poorest regions (UN-Habitat, 2014). This massive population growth in the face of widespread poverty produces a complexity of threats, vulnerabilities, and risks to the African populations and their habitats (see Fig. 11). The emerging urban spatial and aesthetic configurations call for the development of creative ways of thinking and analyzing West African architectural trajectories and imagined futures, together with a reexamination of western paradigms.

Architecture in French West Africa, Fig. 10 Douala, Cameroon. Residential building in the old commercial center, a melange of Bauhaus and Art Deco (Author's photo)

Architecture in French West Africa, Fig. 11 Limbé, Cameroon. Houses made all of corrugated iron, built on a cement platform (Author's photo)

References

Bah, T. M. (1985). *Architecture militaire traditionnelle et poliorcétique dans le Soudan occidential*. Yaoundé, Cameroon: Clé.

Balandier, G. (1966). The colonial situation: A theoretical approach. In I. Wallerstein (Ed.), *Social change: The colonial situation* (pp. 34–61). New York: Wiley.

Betts, R. (1961). *Assimilation and association in French colonial theory, 1890–1914*. New York: Columbia University Press.

Betts, R. (1985). *Uncertain dimensions: Western overseas empires in the twentieth century*. Oxford, UK: Oxford University Press.

Bigon, L. (2009). *A history of urban planning in two West African colonial capitals: Residential segregation in British Lagos and French Dakar (1850–1930)*. Lewiston, NY: The Edwin Mellen Press.

Bigon, L., & Katz, Y. (Eds.). (2014). *Garden cities and colonial planning: Transnationality and urban ideas in Africa and Palestine*. Manchester, UK: Manchester University Press.

Bigon, L., & Sinou, A. (2013). The quest for colonial style in French West Africa: Prefabricating Marché Kermel and Sandaga. *Urban History, 39*(4), 709–725.

Boulègue, J. (1972). Mosquées de style soudanais au Fuuta Tooro (Sénégal). *Notes africaines, 136*, 117–119.

Brunet-Jailly, J. (1999). *Djenné: d'hier à demain*. Bamako, Mali: Editions Donniya.

Brunschwig, H. (1986). The decolonization of French Black Africa. In P. Gifford & R. Louis (Eds.), *The transfer of power in Africa, decolonization, 1940–1960* (pp. 211–224). New Haven, CT: Yale University Press.

Çelik, Z. (1997). *Urban forms and colonial confrontations: Algiers under French rule*. Berkeley, LA: University of California Press.

Conklin, A. L. (1997). *A mission to civilize: The Republican idea of empire in France and West Africa, 1895–1930*. Stanford, CA: Stanford University Press.

Elleh, N. (1996). *African architecture: Evolution and transformation*. New York: McGraw-Hill.

Johnson, W. (1971). *The emergence of black politics in Senegal: The struggle for power in the four communes, 1900–1920*. Stanford, CA: Stanford University Press.

King, A. (1992). Rethinking colonialism: An epilogue. In N. Al-Sayyad (Ed.), *Forms of dominance: On the architecture and urbanism of the colonial enterprise* (pp. 339–356). Brookfield, WI: Avebury.

Maas, P., & Mommersteeg, G. (1992). *Djenné: Chef-d'œuvre architectural*. Eindhoven, The Netherlands: Université de Technologie.

Mark, P. (2002). *'Portuguese' style and Luso-African identity: Precolonial Senegambia, sixteenth-nineteenth centuries*. Bloomington, IN: Indiana University Press.

Morton, P. (2000). *Hybrid modernities: Architecture and representation at the 1931 colonial exposition, Paris*. Cambridge, MA: MIT Press.

Njoh, A. (2007). *Planning power: Social control and planning in colonial Africa*. London: UCL Press.

Oliver, P. (Ed.). (1971). *Shelter in Africa*. New York: Praeger.

Oliver, P. (Ed.). (1997). *Encyclopedia of vernacular architecture of the world* (3 Vols.). Cambridge, MA: Cambridge University Press.

Prussin, L. (1985). The image of African architecture in France. In W. Johnson (Ed.), *Double impact: France and Africa in the age of imperialism* (pp. 209–235). London: Greenwood Press.

Prussin, L. (1986). *Hatumere: Islamic design in West Africa*. Berkeley, CA: University of California Press.
Ross, E. (2006). *Sufi city: Urban design and archetypes in Touba*. Rochester, NY: University of Rochester Press.
Sinou, A. (1993). *Comptoirs et villes coloniales du Séné gal: Saint-Louis, Gorée, Dakar*. Paris: Karthala, ORSTOM.
Sinou, A. (1995). *Le comptoir de Ouidah*. Paris: Karthala.
Sinou, A., & Oloudé, B. (1988). *Porto-Novo: Ville d'Afrique noire*. Paris: ORSTOM.
Skinner, E. (Ed.). (1973). *Peoples and cultures of Africa*. Garden City, NY: Natural History Press.
Soulillou, J. (Ed.). (1993). *Rives coloniales: Architectures de Saint-Louis à Douala*. Paris: ORSTOM, Parenthèses.
Suret-Canale, J. (1971). *French colonialism in tropical Africa, 1900–1945* (T. Gottheiner, Trans.). London: Hurst.
Takezawa, S., & Cisse, M. (2012). Découverte du premier palais royal à Gao et ses implications pour l'histoire de l'Afrique de l'Ouest. *Cahiers d'études africaines, 208*, 813–844.
UN-Habitat. (2014). *The state of African cities, 2014: Re-imagining sustainable urban Transitions*. Nairobi, Kenya: UN-Habitat. Also available online http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3528
Wright, G. (1991). *The politics of design in French colonial urbanism*. Chicago: The University of Chicago Press.

Useful Website Links

ArchiAfrika Foundation/Accra. http://www.archiafrika.org/
EU COST Action IS0904: Architecture beyond. http://www.architecturebeyond.eu/
Institut de Recherche pour le développment (IRD), France. http://www.orstom.fr/
The Tombouctou Manuscripts Project. http://www.tombouctoumanuscripts.org/
UN-Habitat for a better urban future. http://mirror.unhabitat.org/categories.asp?catid=9

Architecture in Hanoi

Dinh Quoc Phuong
Swinburne University, Hawthorn, VIC, Australia

Historical Context

Architecture in Hanoi is influenced by the city's dynamic transformation as a result of more than 1,000 years of Chinese occupation, almost 100 years of French colonization, and several decades of post-independence with support and assistance from the former Soviet Union. Almost 30 years of *Doi Moi* (economic reform) and opening up to global markets have led to rapid transformation of the built environments yet bring another architectural coating to Hanoi.

The street names in Hanoi represent the city's turbulent history. Several of Hanoi's main streets were named after local heroes, such as Ngo Quyen and Tran Hung Dao, who led the city against Chinese and Mongolian invaders in the tenth and thirteenth centuries respectively. To mark the end of French colonization in Hanoi, one of the most important streets is named Dien Bien Phu, after the place in northern Vietnam where French troops officially withdrew from the country in 1954. The main road to southern Vietnam is named Giai Phong (liberation), to celebrate the North–South reunification at the end of the war against America in 1975. Street names are also significant in Hanoi's Ancient Quarter, since they reveal the street's specializations and traditions. Hang Bac (silver) Street, for example, is where tin products are made and sold by silversmiths who came from the same village and craft guild near Hanoi.

In recent decades, Hanoi has changed a lot due to globalization. This has weakened the cohesiveness of the craft guild system in Hanoi's Ancient Quarter. One can buy not only local silver products on Hang Bac Street, but also Italian-style clothes, for example. Young people now love to sit in global fast food and coffee shops, such as KFC, or in universal-style food courts in shopping malls that are mushrooming in the city. Hanoi's layered history and recent changes provide some context for the following discussions about the city's architecture and urbanism.

Village Architecture

Hanoi can be seen as the city of villages (Phuong 2010). The establishment of Hanoi was connected to village settlement, which resulted in the city having some important elements of Vietnamese village culture, including village

Architecture in Hanoi, Fig. 1 Communal house in Bat Trang village

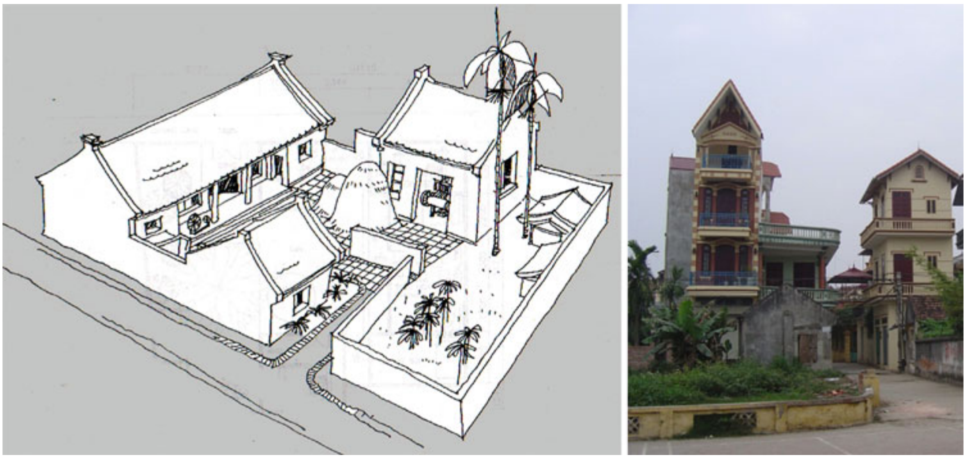
architecture in its inner-city villages. Village culture, including the village sense of community, is represented by traditional public buildings, such as the *dinh* (communal house), *chua* (village pagodas), *den* (village temple), and village gates. Village domestic life is represented by village houses, local craft production with the *phuong* or guild system, building rites and customs, and everyday activities within the houses.

For example, Bat Trang is a ceramic village in Long Bien District in Hanoi, where there are a number of public buildings constructed and maintained by villagers. The most important building is the *dinh*, an open structure for public use. What makes the *dinh* important is not only its impressive structure, but also its essential social and cultural values to the community. The main functions of the *dinh* are administrative, cultural, and religious, demonstrating some patterns of life including village festivals and local ceremonial activities. Despite many changes, the *dinh* is always the place for keeping and developing the village traditional values (Fig. 1).

Along with the *dinh*, the *chua*, the village pagoda, has been an important building that enhances the village's built form as well as the village's social and spiritual life. Each village often has a pagoda that villagers regard as a Buddhist ground, which provides them with spiritual support during the course of daily life. While the traditional role and use of the *chua* were disregarded during the war effort, the economic reform that started in 1986 has resulted in the need for a better cultural and spiritual life, which encourages people to renovate and recover the *chua* and its social position in the village.

From the village center, the village roads lead to the village houses, which share similar features created by building styles and techniques, rites, and folk beliefs. There are L-shape, U-shape, and H-shape house layouts in plans that reflected the owners' economic condition, social ranking, and feudal government rules. A typical village house has a main building and one or two side buildings for kitchen, storage, and craft production. The house construction and related customs are crucial for guaranteeing the inhabitants' spiritual comfort, which sometimes is more important to consider than physical convenience. Despite many common characteristics, the village dwellings are varied. Craft production has an impact on the use of space in a village house. The force of the market economy, urbanization, and tourism increases the demand for craft products that transform the spatial arrangement in the house compound. The changes of production techniques and increase in population also lead to spatial transformations inside the houses (Fig. 2).

Shophouses, an urban housing typology, have also been built in the village in the last few decades. The new market economy results in major shifts in the house layout, and attracting tourists and customers seems to be the key driving force that transforms the shophouse's compositions and façades. The uses of new architectural elements such as front yards in Bat Trang, as well as the imitation of the so-called French-style architecture, indicate people's perception of



Architecture in Hanoi, Fig. 2 *Left*, a village house in Van Phuc village; *right*, new tall houses in Phu Thu village, Hanoi

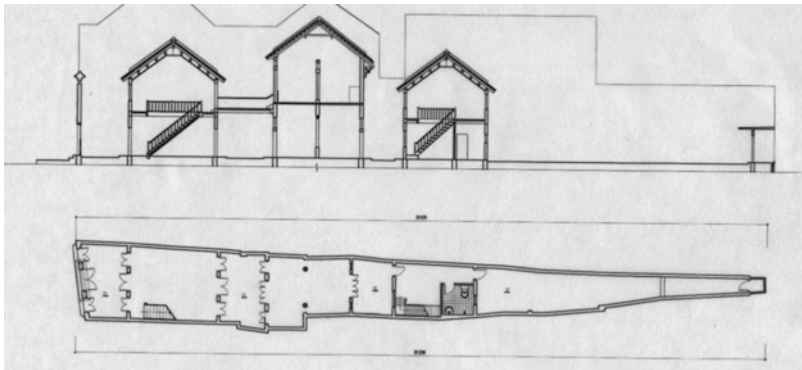
architectural changes. Tourist tastes and commercial activities also bring more abstract styles of house designs and result in the exploitation of the traditional features in new shophouse designs.

Most aspects of village culture were maintained almost at the same time as when village craftsmen migrated to the central of Hanoi in the fifteenth century (Le Van Lan, 1977, p. 196). People from the same village often lived and worked in a street, where they set up craft guilds and built communal houses to worship the village gods, who often were the founders of their professions. Since then, Hanoi's Ancient Quarter has been known as the area of 36 streets and guilds, which, up to now, are characterized by rows of shophouses.

Hanoi's Ancient Quarters and Shophouses

Hanoi's Ancient Quarter has been a shopping area since it was founded almost 1,000 years ago (Nguyen Vinh Phuc, 1994; Logan, 2000). The streets of the area are characterized by *phuong* or guilds, a village system of trade and production, so that each street is named after a particular product which was once locally made and merchandized in that street. The practice remains today even though many streets have changed their specializations. The streets' identity is strongly influenced by *nha ong* (tube houses) or shophouses which normally have front shops or workshops with narrow façades and prolonged and deep living quarters behind. Rows of narrow shophouses that maximize the use of shop fronts for retail are the key feature of Hanoi's Ancient Quarter. This area has experienced significant changes spatially, socially, and physically as a result of its adaptation to the influences from external forces, including recent globalization.

The formation and development of the area were not the result of formal planning strategies but were directly linked to the (re)settlement of villages. Local historians, such as Nguyen Van Uan (1995), also suggested that streets in this area were first established by rows of market stalls built by craftsmen, and traders came from nearby villages. Living rooms were added to the back of each stall as the village craftsmen decided to stay and work in the area. Narrow streets with rows of market stalls on two sides were established. As the population grew the stall owners kept adding living rooms and space to the back of their properties until the empty spaces, including the small lakes, in the center of the blocks were closed. The village craftsmen then built permanent shophouses on the land they occupied. As a result, most blocks are fully occupied by long and narrow shophouses, which are 3–4 m in width



Architecture in Hanoi, Fig. 3 Section and floor plan of 38 Hang Dao (silk) Street

Architecture in Hanoi, Fig. 4 *Left*, old shophouse; *right*, new tall shophouses in Hanoi

and 30–60 m in length. Some houses can be as narrow as 2 m and as long as 100 m (Fig. 3).

There are several types of shophouses in Hanoi's Ancient Quarter. The first one is *nha chong diem* or shophouses with a *chong diem* style roof generally dating from the nineteenth century (Dang Thai Hoang, 1999, p. 19). The upper level, which is set back, has a double roof, while the first level has a single roof. The upper level of the house looks approximately half the height of the lower level, and therefore the shophouse is seen to have one and a half levels. The second levels have small windows. At present, *nha chong diem* remain in several streets in Hanoi's Ancient Quarter, such as Hang Bac Street, Hang Bo (basket) Street, and Hang Duong (sugar) Street.

The second type of shophouse, which is normally taller than *nha chong diem*, were popular at the beginning of the French colonial period in the early twentieth century (Dang Thai Hoang, 1999, p. 28). Wealthy shop owners often renovated their *nha chong diem* to be bigger and taller, altering the second levels to make them similar in height to those of the first levels. The building façades were also renovated by adding some French-style elements, such as louver windows opening on to the balconies. This type of shophouse, therefore, presented a mixed style of architecture created by the earlier *nha chong diem* and the latter larger building with French architectural elements (Fig. 4).

Hanoi's Ancient Quarter is significantly marked by private housing constructions, which flourished after *Doi Moi* since the late 1980s. Having the right to run private businesses and to own private property has enabled Hanoi's residents to improve their lives and change the area. Consequently, many people have become wealthier and spent their money buying property and building houses, in particular the tall shophouses that perhaps best represent the characteristics of Hanoi's everyday architecture and streetscape in post *Doi Moi*. The shift of property ownership from government to private has significantly changed Hanoi's street blocks. Many old timber shophouses, which were previously owned by the government, were sold to wealthy businessmen. The old shophouses were replaced by much taller ones with five or six levels to be used as shops, small budget hotels, bars, and offices for the increasing number of both Vietnamese and foreign tourists coming to Hanoi. Architecturally, many of these new shophouses present French-style facades, which represent a revival of the French colonial experience in Hanoi.

French-Style Architecture

With almost a hundred years of colonizing Vietnam (1858–1954), the French strongly influenced Hanoi's architecture and urban characteristics. After establishing Hanoi as the capital of northern Vietnam and the larger region of Indochina, the French built new French-style buildings and a new French-style urban quarter, popularly called *khu pho Phap*. Alfred de Pouvourville described the area in 1888 as "now featuring broad, well-cut boulevards, and the execution of recent projects by the municipality which makes this, without doubt, the most beautiful city of the Far East." This urban vision for Hanoi also showed the power of French culture and a significant link to the prestige of Paris (Wright, 1991).

One of the earliest and most significant French influences on the city was probably the establishment of a commercial and cultural axis on Paul Bert Street during the 1880s. This street, which now consists of Trang Tien Street and Hang Khay Street, was widened by demolishing all of the thatched houses built by the Vietnamese. Andre Masson (1929, p. 130) added that Paul Bert Street was characterized by an increasing number of French-style coffee shops, such as *Café de Paris* and *Café de Beira*, which were popular places for many French traders, officials, and soldiers. Also located in the street were a number of important buildings, such as Hanoi's central department store *Grands Magasins Reunis* and the cinema *Cinema Palace*.

In 1911, an opera house called *Nha Hat Lon* was erected at one end of Paul Bert Street marking another French influence on Hanoi's architecture. According to William Logan, "it was characteristically French both in its architecture and its siting. It seems to have been inspired by Charles Garnier's opera house in Paris. . .It was sited in baroque town planning fashion on Foch Square at the convergence of important roads and closing off a key vista along fashionable Rue Paul Bert" (Logan, 2000, pp. 93–94) (Fig. 5).

There were a number of other public buildings and hotels designed and built by French colonial experts in Hanoi including the Indochinese Bank, Hotel Metropole Hanoi, Hanoi University, and the Presidential Palace. Many of these buildings were designed by Ernest Hebrard, the head of the Hanoi Town Planning and Architecture Service, who was also famous for his unique Indochinese style that integrates French architectural elements and local tradition as shown in the design of Hanoi Historical Museum and Hanoi University (Fig. 6).

Together with other aspects of French influences, the French colonial villas represented the modernized lifestyle in Hanoi for both local residents and French migrants. During the late 1880s and early 1890s, the French Quarter was developed to the south of Hanoi's Ancient Quarter. Similar to those in Paris, the boulevards in Hanoi had wide tree-lined pavements. French-style villas were gradually built to provide homes for an increasing number of French newcomers. Most villas were detached houses; each was built on a large lot of land ranging from 300 m^2 to 1,000 m^2. Tramlines and a number of Paris-style sidewalk cafés were established in

A

Architecture in Hanoi, Fig. 5 Hanoi Opera House marks the end of formerly Paul Bert Street, Hanoi

Architecture in Hanoi, Fig. 6 Front façade and doorway of Hanoi University, Hanoi

the quarter. The development of the French Quarter with different style villas in Hanoi represented Indochina's French urban image, which provided nostalgic feelings for the French living in the city.

French villas built between 1880s and 1940s in Hanoi are diverse in style. Local architects, such as Tran Quoc Bao (2009), categorize them into several main styles: neoclassical villas, regional French villas, art-deco villas, villas with Indochinese styles, and French-Chinese villas. Older villas were often built and owned by the first French colonial officials, and businessmen worked in Hanoi. According to Dang Thai Hoang (1999), with solemn and highly decorative looks, these villas represented the wealth and pride of their owners who were successful in business and politics while settling in the new colony. With simplified architectural details and flat roofs, Hanoi's art-deco villas were most preferred by Vietnamese middle class families who wanted to express their appreciation of modern living and the status as a modernized and civilized population. A villa often has three levels: level one includes a garage, a kitchen, storage, and rooms for servants. Level two provides rooms for a foyer leading to a guest room and sitting rooms and a dining room. Level three includes bedrooms with toilets and bathrooms, balconies, and open space for plants and drying clothes (Fig. 7).

Architecture in Hanoi, Fig. 7 French colonial villas, Hanoi

Another style of colonial villa is a "regional style villa," because villas of this style resembled those from different regions in France. They were erected in Hanoi between the end of the nineteenth century and early twentieth century. These villas were built and owned by colonial officials, military officials, and businessmen who came to reside in Hanoi from different regions in France. As a nostalgic expression, they wanted their villas to have similar architecture to those in their hometowns in northern, central, and southern France. As a result, old villas in Hanoi are diverse in style, which present similar architectural feature to their French counterparts. For example, to represent architectural characteristics of villas in northern or northwestern France, some villas in Hanoi have steeper roofs compared to those that resemble the southern French villas. While steeper roofs would help draining winter snow in northern France, they do not have this role in Hanoi because there is no snow in the city.

Due to economic and political changes after the end of colonialism in 1945, Hanoi's French architecture has been changed together with a shift to socialist-style architecture under the post-colonial government.

Soviet-Style Architecture

Several decades of support and assistance from the former Soviet Union had an impact on Hanoi's built environment. While South Vietnam had American support, the North followed the socialist ideology, popularly practiced in the countries of the Soviet bloc. During the American/Vietnam War, and after the 1975 reunification of the country, Hanoi received great economic and technological aid from the Soviet Union. This also applied to the field of architecture and urban planning. Architects and urban planners from Russia were sent to Hanoi, while many Vietnamese were sent to universities in Soviet bloc countries to study architecture and construction (Fig. 8).

The influence of the Soviet Union and socialist ideology on Hanoi's architecture was probably most recognizable in the area of housing. After 1954, the government strictly controlled houses and land. Private ownership of property was illegal. In Hanoi, the government implemented subsidized public housing developments called *khu tap the* (KTT), which were modeled after the Soviet housing architecture called "microrayon" by Bater (1980, p. 102). This housing scheme was implemented in Hanoi by leading Russian experts, such as S.I. Sokolov (Hung & Thong, 1995, pp. 144–145; Logan, 2000, p. 206). Each KTT was a self-contained residential community that consisted of a number of four- or five-level apartment blocks with attached basic services, such as medical centers, schools, and kindergartens. Each apartment block had standard units for different-sized families with shared bathrooms and kitchens. They were often

Architecture in Hanoi, Fig. 8 Plan of KTT Nguyen Cong Tru and a typical floor plan of an apartment block

managed by a government company to provide homes for its employees and staff.

The impact of the Soviet Union on Hanoi's architecture can also be seen through the design and construction of many of its major public buildings and monuments, such as the Ho Chi Minh Museum and Mausoleum Complex and the Cultural Palace of Labour (formerly called the Soviet-Vietnamese Friendship Cultural Palace). Even though most of the projects attempted to reflect the traditional architectural character of Vietnam, they also "made use of architectural models established previously in the Soviet Union" (Logan, 2000, p. 196). The Cultural Palace of Labour is possibly the best example to illustrate this point. The building was given by the Soviet's Central Union of Labour to its Vietnamese counterpart, the General Vietnamese Union of Labour, under a friendship agreement (Nguyen Vinh Phuc, 2000, p.304). It was designed by a Soviet-funded architectural team led by G. Isakovitch (Dang Thai Hoang, 1999, p. 113) and consisted of a number of theaters, cinemas, lecture halls, conference rooms, and exhibition spaces, which provided decent facilities for cultural and social events in Hanoi. It is a reinforced concrete structure with solid pillars tiled with white marble panels (Fig. 9).

Like many cities in the Soviet Union, Hanoi wanted to have a statue of Lenin to symbolize its socialist ideology and fellowship with other Soviet bloc countries. The Lenin Statue, which was jointly designed by G. Isakovitch and the Russian sculptor A. Tyurenkov, was built in 1985 on a site formerly occupied by a French statue opposite Hanoi's historical flag tower (Nguyen Vinh Phuc, 2000, pp. 277–278; Logan, 2000, p. 198). While most Lenin statues around the world were removed after the collapse of the Soviet Union in 1991, Hanoi's still remains as a reminder of Vietnam's socialist links despite the fast changing city under *Doi Moi*.

Architecture in Hanoi, Fig. 9 *Left*, Ho Chi Minh Museum; *right*, the Cultural Palace of Labour, Hanoi

Architecture in Hanoi, Fig. 10 *Left*, New Hanoi Museum; *right*, National Convention Centre by GMP

New Architecture under *Doi Moi*

In 1986, *Doi Moi*, an economic reform program, which encouraged Vietnam to establish a market economy and global integration, was officially launched. Hanoi has changed significantly since this reform, and this is particularly true of its architectural practices.

Hanoi's urban and architectural changes under globalization might be most obvious in the construction of a number of high rises and new residential areas designed and planned by international consultants since the late 1990s. Buildings, such as the Hanoi Nikko Hotel on Tran Nhan Tong Street, built by the Japanese hotel group Nikko, present an international appearance and standard interior designs that can also be experienced in many other places around the world. The development of several new residential areas, such as Ciputra Hanoi International City by Ciputra, an Indonesian group of developers, which is like a "gated community," has been developed in western countries for several decades and more recently in Southeast Asia (Fig. 10).

The impact of global integration on Hanoi's built environment is more significant in recent years as more urban and architectural projects at a national level have been entrusted to foreign consultants and experts, especially those from

Architecture in Hanoi, Fig. 11 Times City Development by Vingroup

western countries. The design competitions and subsequent construction of the country's major projects, such as the new Parliament House Complex, the National Conference Centre, and the National Museum of History, have attracted well-known international architectural firms, including Von Gerkan, Marg and Partners (GMP) from Germany, Denton Corker Marshall (DCM) from Australia, Renzo Piano Building Workshop, and Norman Foster Associates, as evidence that after decades of wars and isolation from the West, Hanoi's architecture is more open to international participation and subsequent influences.

Moreover, Hanoi's People Committee and its Korean partner from Seoul recently launched an urban planning and design scheme to build a new city center, called Hanoi Red River North, along the northern side of the Red River in Hanoi. The new city together with the old city center, which has been developed to the south of the Red River, will create a new Hanoi city region with Seoul as a model for urban development. According to the authorities, the two cities have similarities: for example, the Han River in Seoul and the Red River in Hanoi share natural and geographical characteristics; therefore, the development of Seoul along the Han River is a good model for Hanoi (Trang An Nguyen, 2007).

Local developers, such as Vingroup, one of the Vietnamese largest private corporations, are also active in residential and commercial developments in Hanoi. Vingroup recently opened two of its ambitious inner-city developments called Royal City and Times City built on large areas of land, which formerly were state-owned factories. Both estates show global characteristics architecturally and functionally. Each contains a number of apartment towers and shopping and entertainment complexes with international-style food courts, global brands, and cinema and amusement facilities. The estates also contain some school and hospital buildings that provide educational and health-care services claimed to be at international standard. Most buildings present global design features, which include several underground and aboveground levels for retails, services, and entertainments following up by towers of apartments. Such global characteristics make them hard to differentiate from new developments in any other cities such as Singapore or Shanghai (Fig. 11).

Hanoi's built environment is increasingly dependent on global designs and international planning standards. Many parts of the city have been homogenized so that it is now not easy to differentiate them from other places in Vietnam or elsewhere. Perhaps globalization is inevitable, but it is still important for place makers to search for Hanoi's distinctive characteristics and to integrate them into the new developments so that some aspects of the city's unique architecture will be maintained.

References

Bater, J. H. (1980). *The Soviet cities: Idea and reality*. London, England: Edward Arnold.

Hoang, D. T. (1999). *Hanoi's architecture in the 19th and 20th centuries*. Hanoi, Vietnam: Hanoi Publishing House (in Vietnamese).

Hung, T., & Thong, N. Q. (1995). *Thang Long – Hanoi: Ten centuries of urbanization*. Hanoi, Vietnam: Construction Publishing House (in Vietnamese).

Le Van Lan. (1977). The influences of rural character on Vietnamese cities in history. In *Rural Vietnam in history* (Vol. 1, published by the Vietnam Institute of History). Hanoi, Vietnam: Social Science Publishing House (in Vietnamese).

Logan, W. (2000). *Hanoi: A bibliography of a city*. Sydney, ACT: UNSW Press.

Masson, A. (1929). *History of Hanoi between 1873 and 1888* [translated from *Hanoi Pendant La Periode Heroique (1873–1888)*]. Hai Phong, Vietnam: Hai Phong Publishing House (in Vietnamese).

Nguyen Van Uan. (1995). *Hanoi in the first half of the 20th century* (Vols. 1, 2, 3). Hanoi, Vietnam: Hanoi Publishing House (in Vietnamese).

Nguyen Vinh Phuc. (1994). *Hanoi through the years*. Ho Chi Minh City, Vietnam: Tre Publishing House (in Vietnamese).

Nguyen Vinh Phuc. (2000). *Pho va Duong Hanoi* [Streets and roads in Hanoi]. Hanoi, Vietnam: Transportation Publishing House (in Vietnamese).

Phuong, D. Q. (2010). *Village architecture in Hanoi: Patterns and changes*. Hanoi, Vietnam: Science and Technics Publishing House.

Tran Quoc Bao. (2009). French villas in Hanoi. *Ashui Online Magazine*, 9 March 2010. Retrieved from http://ashui.com/mag/index.php/chuyenmuc/kientruc/67-kientruc/2363-d (in Vietnamese)

Trang An Nguyen. (2007). Will Hanoi be similar to Seoul: Red river and Han river? *VietnamNet* online News. Retrieved from http://vietnamnet.vn/xahoi/dothi/2007/04/679859 (in Vietnamese)

Wright, G. (1991). *Politics of designs in French colonial urbanism*. Chicago, IL: University of Chicago Press.

Architecture in Java

Gunawan Tjahjono

This article focuses mainly on the architectural objects of the Javanese people whose worldviews are closely related to the court society of Central Java, Jogjakarta and Surakarta. As architecture concerns ideas of making meaningful space, this article will discuss the spread of ideas represented by various building types.

Throughout their cultural history, the Javanese interacted with five major religions and cultures: Hinduism, Buddhism, and Islam, China and the West (Europe). The most significant influences are from Hinduism and Buddhism, followed by Islam. Chinese carpentry affected East Java and some parts of Central Java. Western culture introduced modern town planning and new building types.

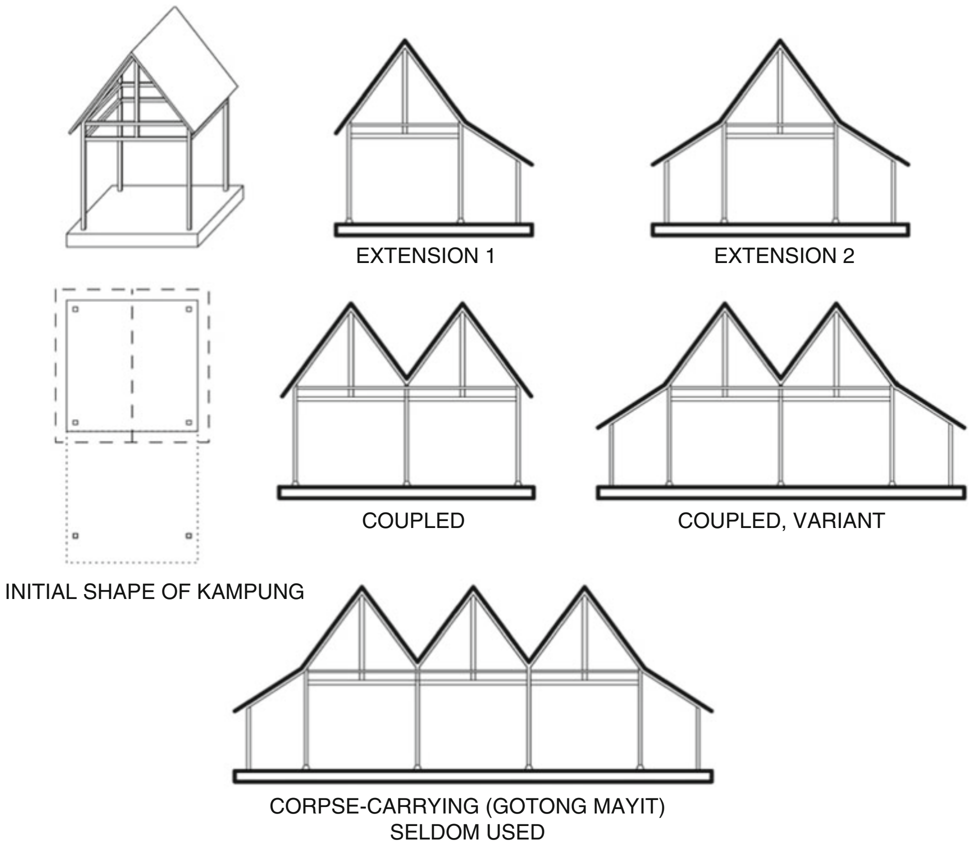
The Javanese House: An Architectural Type

The house is perhaps the first structure human beings constructed to seek shelter. The inherent ideas in a house can thus serve as the architectural basis for other building types, such as temples, cemeteries, and cities. Although there are no remains of ancient houses, as they were constructed with perishable materials, one can trace the tradition of building houses from such remains as palaces and well maintained houses in two Javanese cultural cores around Jogjakarta and Surakarta; and also from the bas-reliefs of temples.

The temples' bas-reliefs illustrate the probable built environment of the Javanese past when stone and wood were the major building materials. Stone appeared in sacred structures, while wood appeared in residential structures. Buildings depicted there are on stilts. Tall pile structures as shown on the bas-reliefs of Central Java's temples can seldom be found in Java now. Low pile structures, as shown on the bas-reliefs of East Java's temples, can still be found in Bali. Thus people in Java probably lived on stilts.

Javanese houses differ in roof shapes but agree in plans. Roof shapes were connected to the social and economic status of the owners. There are three major roof shapes for houses; *Kampung*, *Limasan*, and *Joglo*.

- *Kampung*, also known as *Serotong*, is the simplest shape and is used by the common people.



Architecture in Java, Fig. 1 The Kampung (Schematic drawing. Illustrator: Paulus)

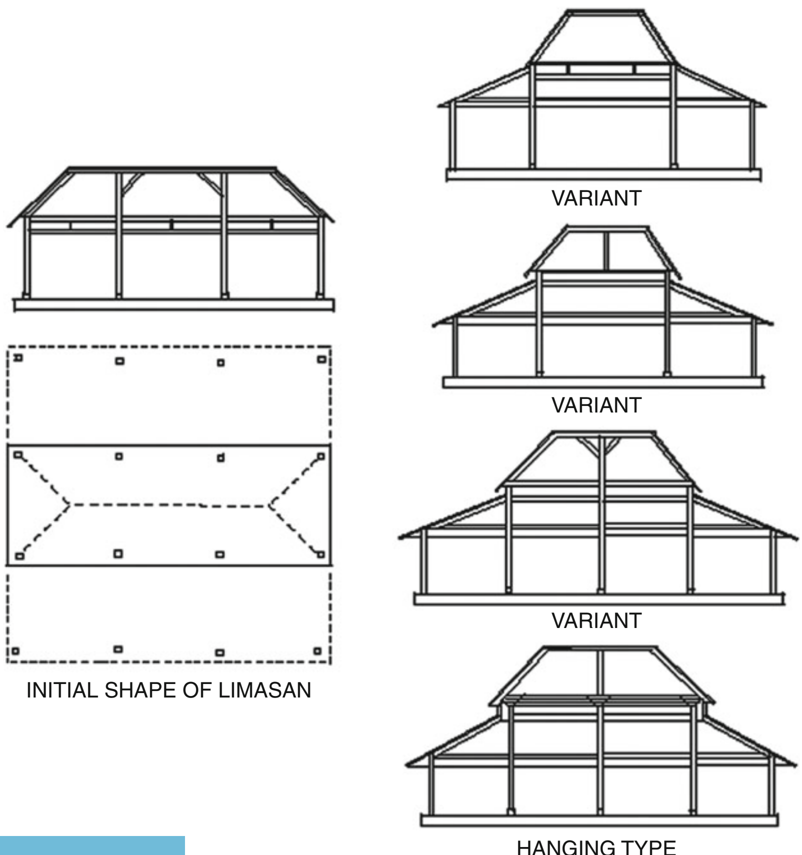
  It consists of four main posts braced by a double ring of beams. Two upper posts stand at the middle of one pairs of beams, usually those parallel to the north-south direction, to support the roof ridge beam. Two roof sheets meet at this line and fall away on either side of the beam. The roof can extend in one or two directions at different angles (Figs. 1 and 2).
- *Limasan* is a more elaborate *kampung*. It requires more materials and effort to build and is associated with a higher socioeconomic status. It contains eight posts to support its trapezoidal roof. Two transitional posts rise at the middle of the beams that span the interior space between the middle posts. The main roof extends evenly to four sides (Figs. 3 and 4).
- *Joglo* looks like a more developed *limasan*. It is more difficult to construct and was the most favorable shape for the nobility. It embodies several distinct features. These include a steeper main roof which resembles a pyramid that comes to two points and four main posts hold layers of wooden blocks which step back in several directions. The outer layer of these blocks holds the roof, while the inner, *Tumpang Sari*, the "essential piling up," divides the ceiling into two inverted pyramids (Figs. 5 and 6).

A house consists of at least a basic unit containing essential spatial patterns that all social strata share. All houses have a sanctuary and two storerooms, a clear boundary between the inner and outer domain, and are patterned according to the hierarchy of sacredness of place. The house plan is independent of the roof shape, especially for *kampung* and *limasan*, and to some extent, for *joglo* which has a more elaborate spatial division.

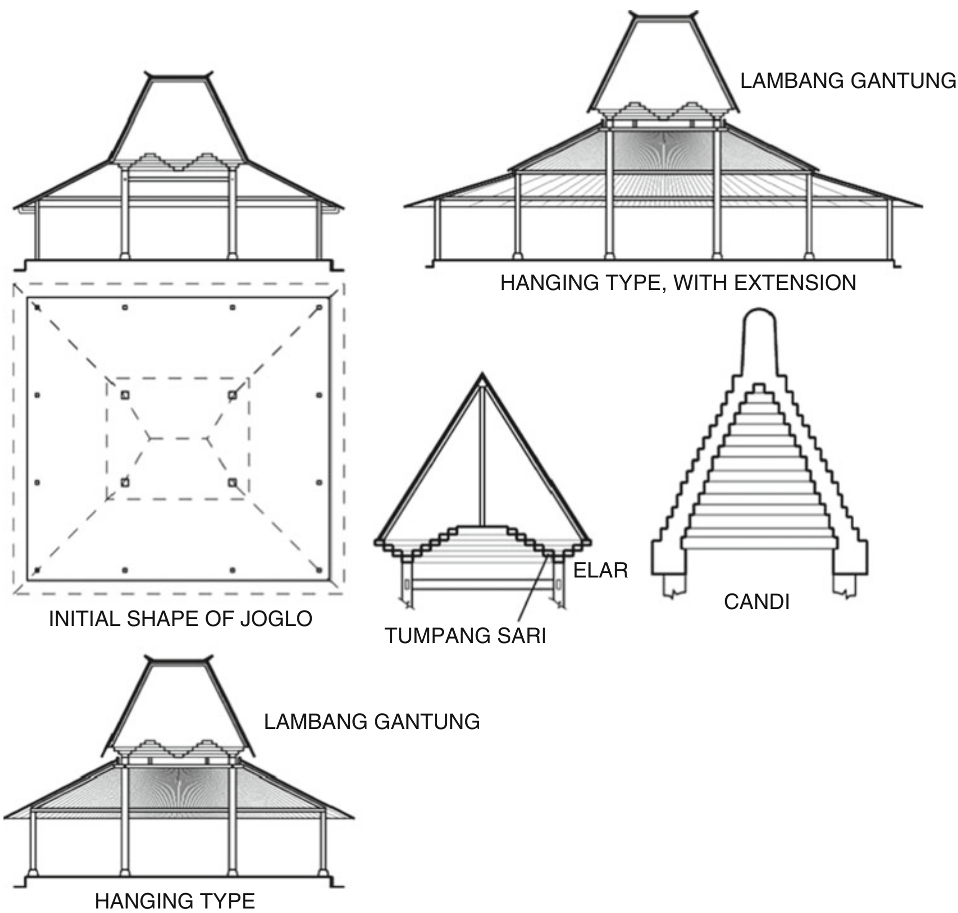
A

Architecture in Java, Fig. 2 (Photograph: author's collection)

Architecture in Java, Fig. 3 Limasan (Schematic drawing. Illustrator: Ary Dananjaya Cahyono)



Architecture in Java, Fig. 4 Photo image of a limasan roof (Author's collection)



Architecture in Java, Fig. 5 Joglo (Schematic drawing. Illustrator: Paulus)

Architecture in Java, Fig. 6 Photo image of Jogo (Author's collection)

The basic unit of a house is *omah*, which employs a rectangular plan emphasized by a raised floor. It encompasses an inner and an outer domain defined by wall panels. The outer, *emperan* or porch, is about 2 m wide to accommodate the family's more public activities. There is a wide bamboo bench for sitting, lying or sleeping. A wide door at the middle of the front wall connects this domain to the inner part.

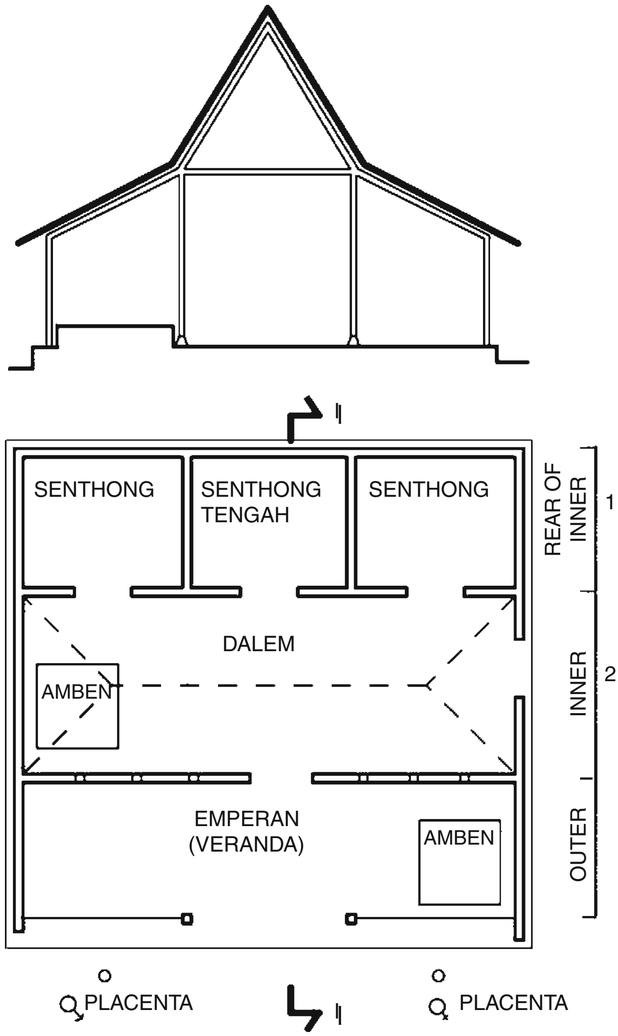
The inner, *dalem*, is an enclosed structure which is subdivided into either two: front-rear, or three: front-middle-rear sections along a north-south axis. Each section suggests three spatial domains along the east-west axis. A two-section *dalem* applies usually to a *kampung* or a *limasan* roof, while a three-section one is for a *joglo*.

The middle section, if any, which is defined by four main posts at its center, has no exact usage. The central part was where the incense was burned once a week in honor of the rice goddess Sri, who occupied a permanent place in the house at the center of the rear section.

The rear section encompasses three enclosed rooms called *senthong*. The west senthong stored agricultural products. The east one stored other equipment or was sometimes empty. The middle senthong was the most lavishly decorated but the least used part of the house. It was the sanctuary of the rice goddess Sri and thus took the form of a fully equipped bed. The function of this room would be fully revealed during the most celebrated ritual, the wedding ceremony. In this ritual the bride and bridegroom sit at the front of the *senthong tengah*, underneath the house ridge. Now many Central Javanese have transformed the once sacred *senthong tengah* for prayer. Many new houses now do not follow concepts from the recent past but from examples of new models in the big cities (Fig. 7).

An ideal house should have at least two, and if possible, three main structures: an *omah*, a *pendapa*, and a *peringgitan*. Pendapa is a roofed open hall located at the front yard of an omah. Its shape, size and position of posts are often akin to those of the omah. It displays a different spatial quality from that of an omah. It is open, accessible and lighted, while omah is opaque, forbidden and dark. Pendapa is the public domain of a house, a place for gathering and ritual performance and informal entertainment. Peringgitan, which employs a *kampung* or a *limasan* shape, connects pendapa to omah. It is a place for the performance of the shadow puppet play *wayang*, the ritual in Javanese culture that predicted life cycles, harvest, and higher rank career promotions.

The kitchen stays outside an omah, separately built near the well. A well should be the first to be



Architecture in Java, Fig. 7 Plan of a two section Omah (Illustrator: Paulus)

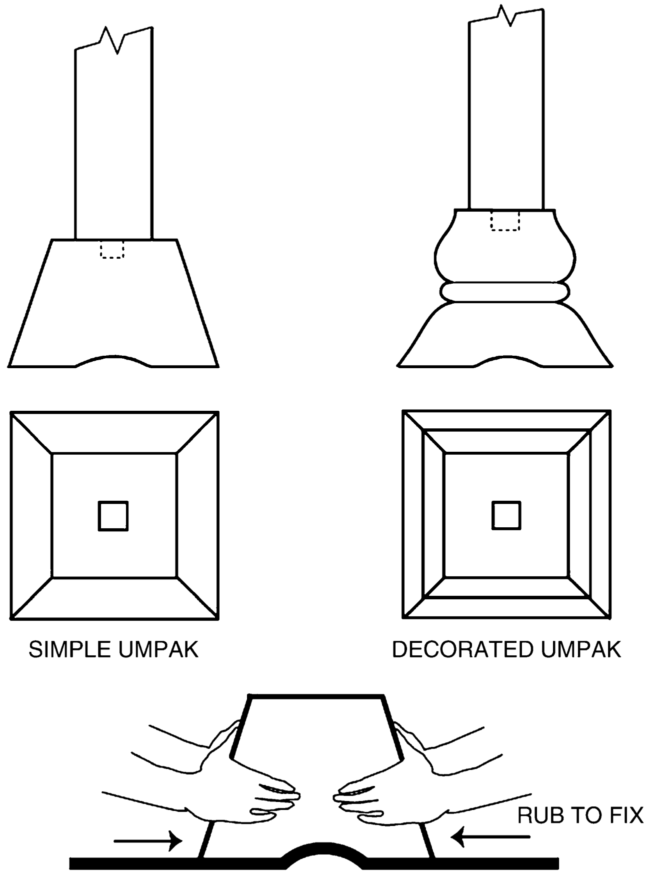
dug out prior to the construction of any erected structure. The well also serves a later developed lavatory which has its own structure at the left and the back of a house compound. As the number of families and income grew, new structures expanded first to the east or to the north, then to the south for pendapa, and next, as needed, to the west to complete the symmetry. In an expanded house, the family lived in the wings and the omah became a real sanctuary.

Most houses in Central Java whose entries were facing south have front, sides, or back yards within a clear boundary marked by a brick wall or low fence. The enclosed wall often has a roofed or unroofed gate, which connects the inner world of family to the outer universe of community. After selecting and purifying a site and after digging out a well, the next step is to determine the location of the omah, as it should always be built first. After setting the omah's position, the team of community volunteers led by a carpenter starts the construction. The basic house plan is a matter of measurement and house shape of affordability. The carpenter will adjust the dimensions derived from the dweller's body to determine the size of the house.

The construction follows this sequence:

1. Dig the well
2. Erect the omah

Architecture in Java, Fig. 8



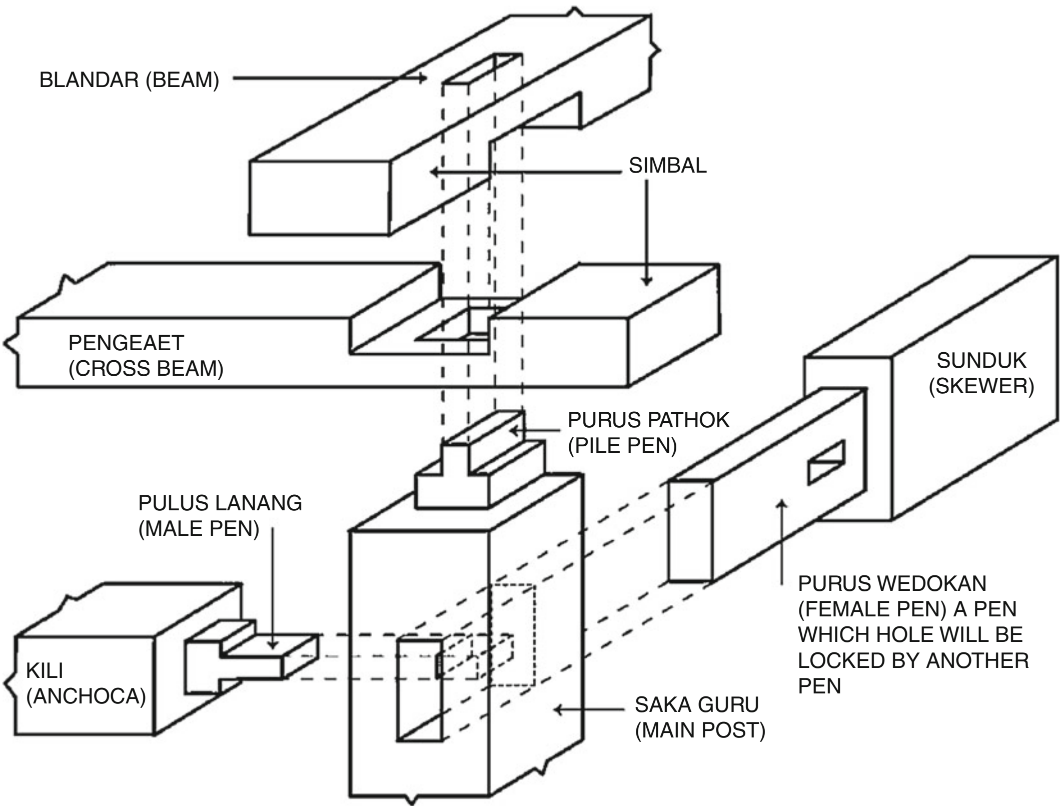
3. Build the east *gandok* or kitchen
4. Construct the pendapa
5. Finally set up the west gandok
6. Fencing is the last, if needed, to be done

Construction proceeds by leveling the site and improving the strength of the soil by piling ▶ bamboo or stones around the edge of the main building. Its floor is often elevated to help drainage. The main posts are usually on *umpaks*, the three dimensional trapezoidal stones which act as transitions between the posts and foundations. The size of the umpak varies, from 20 × 20 cm^2 to more than a square meter, dependent upon the dimension of the post, which commonly ranges between 12 × 12 and 40 × 40 cm^2. Umpak is a structural device which reduces horizontal forces caused by earthquakes. It prevents the posts from the infiltration of ground water. The wooden posts always stand according to the direction of tree growth (Fig. 8).

Two or three parallel beams join the post at its top. The posts may directly support roof trusses or roof beams. In the case of joglo, the main posts are usually topped by two sets of inward stepped wooden piles, *tumpang sari*, and outward stepped piles, *elar*. The number of tumpang sari steps reveals the status of the owner. The roof sheet is framed by wood blocks or bamboo sticks (split in half); the smaller blocks or sticks are laid parallel in a horizontal position with some distance between each other. All blocks are in a horizontal position rather than upright which, as seen individually, is more appropriate to the law of force of material (Fig. 9).

The post has pens at both ends; the lower fixes the umpak and the upper plugs in the hole

Architecture in Java, Fig. 9 Tumpang Sari (Author's collection)



Architecture in Java, Fig. 10 Construction join (Illustrator: Paulus)

of the main beam, which represents females. At the upper position of the main post, a hole is cut out to be filled by the pen of a secondary beam which acts as a stabilizer, as opposed to the beam above it. The basic structure is stable upon the completion of all plug-in procedures. The term for pen is *purus* meaning the male sex organ (Fig. 10).

Modular Coordination and Mobility

The Javanese book of carpenter Kawruh Kalang mentions the basic measurement unit *dim* which is determined by either the length of a foot or the width of a fist. The length of beams and the interval between posts apply the formula $5 \times n \times \text{dim} + m$. The m should be within one to three because four or five dim is considered an inauspicious number for the initial structure, and n is any number defined by a special event such as a wedding. In it a fourfold modular grid based on serving devices is applied. Under such a practice, the interval between the main posts averages 2.5 m, being approximately the width of two floor mats. Plug-in construction join and the application of modular coordination have the flexibility to mobilize the house. A house can be moved after it has been torn down into construction parts and refabricated at other preferable places.

Although there is no concrete proof about the origin of Javanese houses, they can be traced back to agricultural tradition. Buildings for worship or commemoration altered as religion changed. However, the ideas that generate a house remain the source for the spatial arrangement of other buildings.

Buildings for Worship: The Hindu-Buddhist Legacy in Javanese Architecture

Hinduism and Buddhism, whose imprints in Java can be traced back to the fifth century, affected most forms of cultural expression, such as religion, art, (a certain degree of) social organization, technology, language, and statecraft. The intensive ceremonial life filled the interior Javanese landscape with *candis* (temples). Remains of habitats in the forms of foundation stones that spread around various candi complexes indicate that social organization was centered on religious ceremony at the state and, to some extent, the village level.

In prehistoric Java, mountains were the places where the ancestral spirit could be contacted for protection and prevented from their wrath by offerings. *Lingga*, an upright stone and *yoni*, a flat stone plate, were possibly the first erected effigies to consecrate the center of the universe symbolizing creation and fertility. Later on, Hindu Javanese candis were designed to replicate mountains at the high places where spirits of the gods could be induced to go down into a lingga in a cave-like hall. Candis were enclosed by walls to divide the sacred inner from the profane outer. In the inner zone the priests presented offerings, performed prayers, and contacted the gods when they descended to earth. Thus temples were not for holding large numbers of peoples.

As religious buildings, candis were built to last in stone or brick. Archaeologist Jacque Dumarçay observed that the Central Javanese stone candis developed the techniques of interlocking stones articulated with perspective effect to cast expected results. They cut the stones into several modular blocks and created stone courses by joining stones placing one on top of the other without mortar.

The early eighth century Hindu Javanese candi compound is located at the Dieng Plateau. The four major candis known as Arjuna group face west. Candi Arjuna comprises a square room constructed over a pit containing a foundation deposit for ritual. The stone blocks interlocked through tongue-and-groove connections by having cut a section out of each stone in horizontal and vertical directions. The eighth century Buddhist temple compound Candi Sewu's stone wedges were driven between the stone blocks, pushing adjacent sides outward toward the corner of building, strengthening the course and reducing the gap between joints. The ninth century's Candi Loro Jonggrang of central Java exemplifies the greater stone technology achievement in Hindu Javanese candis. Here, according to Dumarçay, the technique of double-leaf walls was adopted by establishing a pair of parallel walls, then filling the gap between them with rubble or unshaped stones by using mud or lime.

The Buddhist legacy Borobudur of the ninth century exemplified such techniques with an adjusted ten-layer *mandala* (Mandalas are geometric designs intended to symbolize the

A

Architecture in Java, Fig. 11 Lorojonggrang of Prambanan (Author's collection)

universe) plan. The 113 m side long square plan base tells the story of a worldly sinful life through carved bas-relief. Ascending from the base are three layers of stepped enclosed roofless corridors with each wall relief describing the world of daily life. Up another three layers one finds on one side a slightly opened corridor which depicts the world of form as the intermediate experience of the last three layers. The last three layers represent the formless world without enclosure so one can also look out against the blank wall. At the top layer, whose center is a stupa, you could watch your surroundings as if the whole universe were under your eyes. To experience Borobudur, one ascends nine peripheries of adjusted squares whose size decreases gradually to the top. It brings visitors through a spiral labyrinth route to find nirvana.

Candi Loro Jonggrang exemplified the highest achievement of the Central Javanese Hindu legacy. Consecrated in 856, it was a complex dedicated to Siva and was possibly related to a town of the same size. It consists of three walled courtyards on ascending terraces. The inner two courtyards are concentric and facing east, while the outermost is aligned another way. The terraces are made of heaped-up earth. Eight major sanctuaries fill the upper terrace. Three cruciform plan structures are devoted to the trinity of Hinduism, Siva, Vishnu, and Brahma. Facing each is a smaller structure for vehicles or mounts of the god. Two accompanying candis stand at the south and north entrances of the complex. Two hundred and twenty-four smaller structures fill the four lower terraces of the middle courtyard; those at the corners have two doors and the rest have one door. Such an arrangement recalls the image of mandala (Fig. 11).

Dumarçay concluded from his research on the stone construction of temples in Southeast Asia that Borobudur and Loro Jonggrang applied a perspective principle to create special visual effects in their construction, so that visitors

Architecture in Java, Fig. 12 The Great Mosque of Jogjakarta (Author's collection)

could experience the glory of their existence from various angles. For Borobudur it is at its base that this effect was applied so that its upper terraces would be visible. In Loro Jonggrang it is through the manipulation of the form which enhances the feeling of height.

Buildings for Worship: The Islamic Legacy in Javanese Architecture

Islam spread gradually from the twelfth century on. It began with trade around the ports and then infiltrated the interior of Java. The earlier Islamic buildings retained references from Hindu architectural elements such as ceremonial gateways, split portals and multilayered roofs.

The concept of early mosques in the interior cultural core of Central Java around the sixteenth century resembled that of a house. Dutch scholar de Graaf identified seven distinctive features of these mosques as (1) a square plan, (2) a raised solid floor, (3) a multilevel roof that peaks to one point, (4) a roofed veranda called *serambi* at the front, (5) a *mihrab* – an annex or niche on its western or northwestern edge to indicate the direction of Mecca, (6) encircling by water, which in turn is surrounded by open spaces, and (7) a wall that encloses the whole complex. In addition to those features, the door of early Javanese mosques faced east, with the prayer direction oriented toward the west rather than Mecca.

Of these features, the square plan, raised floor, and walled enclosure can be found in the structure of the remaining Hindu Javanese temples, while the one-point multilevel roof is a common element of the Balinese Meru that existed in East Java before the domination of Islamic culture. The niche, *mihrab*, is a common element in mosques elsewhere in the world; perhaps each regional culture incorporates it differently. The encircling water is an adaptation of a moat appropriated to Javanese cosmology which can be found in old Javanese palaces. *Serambi* is a typical Javanese creation. Separating the sacred domain from other domains is parallel to the division of activity zones in a house. An ideal complete house exemplified such an idea by separating other daily activities from omah, especially the senthong tengah. The spatial quality of a sacred domain, which was usually governed by darkness, as in the main mosque and in the dalem, appeared to dominate Javanese thought (Fig. 12).

The great mosque of Demak of Central Java exemplified all the principles and became the model for the subsequent mosque around coastal Java. Its influence continues, as can be seen by the reproduction of its basic shape in the mosques built around Indonesia sponsored by former President Suharto. The four main posts that support the upper roof were originally made by tying pieces of timbers with iron strips.

The additional element in many recently built mosques is the crown, which is now in the shape of a small dome, a result of native adaptation of an outside idea. The onion shaped dome has been associated with Islamic architecture in many parts of the world. However, such a dome has seldom become the main body of the roof in the Javanese mosques. A dome reduced in size is employed as a crown to top the roof. It is interesting to note that any new mosque, whose construction is funded by a special presidential grant, must follow the traditional Javanese two-layer *tajug* roof shape.

The House Extended: Settlement, Palace and City

Settlement patterns in the cultural center of central Java follow the north-south axis. Almost all traditional houses located in this district face south. Some coastal settlements are linearly aligned facing east for the north coast of East Java. The linear arrangement appears in many coastal zones. This is the most practical arrangement considering coastal conditions. Rural houses seldom have pendapa. Housing in the Cilacap, southern Central Java coastal area, has a common hall as a collective pendapa. This instance raises questions as to when the pendapa became the exclusive property of the urban elite.

A concentric settlement called *mager sari*, or fencing the essence, applies in urban Central Java. In it the houses of the wealthy were enclosed by the servants' houses. It is a reflection of a feudal society which illustrates the master-servant relation. The master is the center and the servants are represented by the fence. The palace or *kraton* compound exemplifies these relations.

Kraton refers to the seat of a ruler at a level of king or prince. The term is widely used in many Indonesian Islands such as Sumatra, Java, Kalimantan, Sumbawa, Sulawesi, and Maluku; it is applied not only to an Islamic kingdom, but also a pre-Islamic one. Kraton was a dynasty's center of power, and usually generated an urban environment around it. In Java, e.g., it was the kraton, rather than the territory that identified a kingdom's geographical image.

Most kratons are located on a plain served by a river and its tributaries. In Java, the seat of a kraton was usually backed by a single coned sacred mountain. The Javanese kratons manifest these relations even stronger through axial positioning of the building complex toward the sacred mountain. A kraton comprises several buildings within a clear boundary. Descriptions of such boundaries of older kratons have not been supported by archaeological findings; possibly the materials for the palisades could not survive the tropical climate. The fence can be easily found in more recent kratons. Large kratons, such as those at Banten in West Java, Cirebon in Central Java, Jogjakarta, and Surakarta, had stone-walled boundaries. The wall was a defense device as well as a representation of hierarchical segregation based on status or sacredness.

As an ideal center, the alignment of a kraton reflects the ruler's views on the universe. The kratons of both Jogjakarta and Surakarta expose these images through a series of courtyards and gates lined up on a north-south axis. The axis replicates the directions of the mountain and sea and of cardinal points in Hindu cosmology. The Sultan's residence contains the royal pleasure garden which is located on the outskirts of the inner wall. The main pendapa, where the Sultan held audience, is the only building that faces east. This pendapa created a new east-west axis.

The main pendapa exemplified the most refined construction of a joglo. Timber blocks and rafts frame its roof sheet. The rafts are laid parallel in a horizontal position with some distance between each one. They are tied onto the layers of larger blocks and are arranged in a sun ray or centrally organized pattern. All the blocks are horizontal rather than upright. Dutch architect Maclaine Pont suggested that the Javanese treated their roof as an entity rather than the sum of individual elements (Fig. 13).

Architecture in Java, Fig. 13 The Great Pendopo of Jogjakarta Kraton (Author's collection)

The *alun-alun* or town square is related to the seat of power. Two banyan trees stand at the alun-alun's center to symbolize harmony. The alun-alun was the meeting place of the Sultan and his people. It held major state rituals, festivals, games, and in the past was a place for punishment. The north alun-alun of Jogjakarta still hosts major cultural events today. It is encircled by several important buildings – the state mosque at its west, the main market and a prison at its north, with some other buildings around. The mosque was usually followed by a compound of the *kaum* – the religious experts who initiated religious rites and ceremonies – called the *Kauman*.

The kraton determined the conceptual layout of the city associated with it. From the toponyms one can trace this order in such old towns as Kuta Gede near Jogjakarta and Banten. According to sociologist Selo Soemardjan, the city of Jogjakarta exemplifies the social strata through several rings, which started with the Sultan at the center, with his family around him, and other nobility within the walled compound. Around the wall is the ring of town community surrounded by the rural community. The town community comprises those who have frequent contact with the ruler such as the smiths, the slaughterers, the carpenters, the kaum, and the merchants. The rural community is in charge of cultivating agricultural land.

The layout of both Jogjakarta and Surakarta suggests a Javadvipa, the central continent of the whole cosmos which consists of seven rings of continents separated by seven rings of ocean. Javadvipa contains seven mountains and six plains along a north-south axis, and four mountains and plains along the east-west axis. At the center is the *Mahameru*, the sacred mountain. Both kratons have six courtyards and seven gates with the seat of the sultan at the center to represent this inner cosmos.

This pattern, to some extent, can also be found in a coastal Javanese kraton and its cities. Since the coastal areas had many foreign traders, the ruler also provided a special zone for foreigners which served the same function as a kampung.

Kraton, square, state mosque, and market are the basic features for most Javanese towns. Their appearance set guidelines for building shapes around them. The other governmental centers followed such patterns during the period of Dutch control. The square accommodates recreational activity for the citizen. The mosque also serves as a religious court. The markets have peak activity once a week. There are coastal markets, littoral markets and agrarian town markets. Their location defines the character of the town economy. Such patterns also appeared in other towns, with the office of the ruler at the center and a town square which connected the mosque, marketplace and prison.

References

Anderson, B. R. O. G. (1972). The idea of power in Javanese culture. In C. Holt (Ed.), *Culture and politic in Indonesia* (pp. 1–69). Ithaca, NY: Cornell University Press.

Atmadi, P. (1980). *Beberapa Patokan dalam Perencanaan Candi*. Jakarta, Indonesia: Departemen Pendidikan Dan Kebudayaan.

Behrend, T. (1984). *Kraton and cosmos in traditional java*. Unpublished Master's Thesis. University of Wisconsin-Madison.

Bernet-Kempers, A. J. (1976). *Ageless Borobudur*. Wassenaar, Netherlands: Servire.

de Graaf, H. J. (1963). The origin of the Javanese mosque. *Journal of Southeast Asian History, 4*(1), 1–5.

Dumarçay, J. (1998). Perspective effects in Javanese Temple architecture. In G. Tjahjono (Ed.), *Architecture. Vol. 6: Indonesian heritage series* (pp. 58–59). Singapore: Archipelago Press.

Hamzuri, P. S. (1982). *Rumah traditional jawa*. Jakarta, Indonesia: Departemen Pendidikan dan Kebudayaan.

Horgronje, S. (1983). *Islam di Indonesia*. Jakarta, Indonesia: Bhratara.

Ismunandar, R. K. (1986). *Joglo: Arsitektur Rumah Jawa* [Joglo: The Architecture of Javanese Traditional Houses]. Semarang, Indonesia: Dahara Prize.

Miksic, J. (1998). Architecture of the early Islamic period. In G. Tjahjono (Ed.), *Architecture. Vol. 6: Indonesian heritage series* (pp. 86–87). Singapore: Archipelago Press.

Pigeaud, T. G. (1977). Th. Javanese divination and classification. In P. E. J. de Joselin de Jong (Ed.), *Structural anthropology in the Netherlands – A reader* (pp. 63–82). The Hague, Netherlands: Martinus Nijhoff.

Pijper, G. F. (1947). The minaret in java. In F. D. K. Bosch et al. (Eds.), *India Antiqua* (pp. 274–283). Leyden, MA: E. J. Brill.

Pont, M. (1923). Javaansche Architektuur. *Djawa, 3*, 112–127. and 4 (1924): 44–73.

Priotomo, J. (1984). *Ideas and forms of Javanese architecture*. Jogjakarta, Indonesia: University of Gajah Mada Press.

Santosa, R. B. (2000). *Omah: Membaca Makna di Rumah Jawa*. Yogyakarta, Indonesia: Yayasan Bentang Budaya.

Sedyawati, E. (1979). Ikonografi Hindu dari Sumber-Sumber Kitab Jawa Kuna dan Jawa Tengahan. *Seri Penerbitan Ilmiah, 3*, 102–135.

Sumardjan, S. (1978). The Kraton in the Javanese social structure. In H. Soebadio, C. A. Du Marchie, & Sarvaas (Eds.), *Dynamics of Indonesian history* (pp. 221–236). Amsterdam: North Holland.

Swellengrebel, J. L. (1977). Classsification in Korawasrama. In P. E. J. de Josselin de Jong (Ed.), *Structural anthropology in the Netherlands – A reader* (pp. 94–95). The Hague, Netherlands: Martinus Nijhof.

Tjahjono, G. (1990). Center and duality in the Javanese house. In N. AlSayyad & J. P. Bourdier (Eds.), *Dwellings, settlements, and tradition: A cross cultural perspective* (pp. 213–236). New York: University Press of America.

Tjahjono, G. (1989). *Cosmos, center, and duality in Javanese architectural tradition: The symbolic dimensions of house shapes in Kota Gede and surroundings*. Unpublished Ph.D. Dissertation, University of California at Berkeley.

van Ossenbruggen, F. D. E. (1977). Java's Manca Pat: Origin of a primitive classification system. In P. E. J. de Joselin de Jong (Ed.), *Structural anthropology in the Netherlands: A reader* (pp. 30–60). The Hague, Netherlands: Martinus Nijhoff. (Original work published in Dutch in 1916).

Architecture in Mesoamerica

Phil C. Weigand

The Mesoamerican world system was composed of a number of closely connected and related but distinct civilizations. The peripheries of the system extended from the southwestern United States of America, in the north, to the borders of Nicaragua, in the south. Each of these component civilizations, while sharing with the larger whole series of cosmological and iconographic concerns, had an unambiguously regional architectural style. The distinct civilizations usually considered, from south to north, are the highland Mayan area (Guatemala), the lowland Maya (the Petén of Guatemala and the Mexican states of Yucatán, Quintana Roo, and Campeche), the Gulf Coast lowlands (Veracrúz and Tabasco), southern Pacific coast (Chiapas and Guerrero), Oaxaca, Central Mexico (the states of Puebla, Tlaxcala, México, and Hidalgo), the Huaxteca (northern Veracrúz and southern Tamaulipas), western Mexico (Jalisco, Michoacán, Nayarit, Colima, and Sinaloa), and northern Mexico (Zacatecas, Durango, Chihuahua, and Sonora, with extensions into New Mexico and Arizona). The architectural styles represented within each region were original and innovative traditions which in some cases lasted for centuries with only cosmetic changes. To speak simply of the existence of pyramids in Mesoamerica is to miss the point: while pyramids of one type or another indeed were pan-Mesoamerican, accompanying them was a remarkable diversity of other building forms, representing styles that still remain difficult to classify. Some areas, such as western Mexico, had a number of radically different architectural traditions through time, while other zones, such as Central Mexico, displayed much more conservatism. Of course, anything approaching a comprehensive survey is not possible in this summary. Important sites, even regions, have been omitted.

Reference and Bibliographical Considerations

There have been many descriptive architectural studies within Mesoamerica. Over the last century of research this orientation has produced a wealth of detail that has never been completely synthesized. The study by Marquina (1951) is a classic of the descriptive school, though there are major area omissions in his text and very little in terms of comparative or integrative commentary. Never-the-less, his text remains the most useful and encyclopedic source available in the Spanish language. In English, other overviews, though also limited in area coverage, have been published by Kubler (1975) and Gendrop and Heyden (1993). Useful general summaries concerning architecture within specific regions of Mesoamerica are in the *Handbook of Middle American Indians* (Wauchope, various dates). In the *Handbook*, surveys on regional architectural traditions include Smith (1965) on the Guatemalan highlands, Acosta (1965) on Oaxaca, and Margain (1971) on Central Mexico.

One of the best sources for specific site details is the journal, *Cuadernos de Arquitectura Mesoamericana*, published by the Facultad de Arquitectura of the Universidad Nacional Autónoma de México. Early numbers of the journal basically followed the Marquina descriptive tradition, though in recent years interest has broadened to include spatial relationships, cultural symbolism, and astronomical considerations. Excellent and more specialized books and monographs on those topics also exist. As examples, for spatial relationships: Mangino Tazar (1990); for cultural symbolism: Kowalski (1999); and for ancient astronomy as viewed through architecture: Aveni (1977). A useful dictionary for architectural terms and terminology pertaining to Mesoamerica has been compiled by Gendrop (1997).

A number of site studies, emphasizing spatial relationships, describe architectural specifics in addition to the character of community settlements patterns. Three representative studies are Millon (1973) on Teotihuacan in Central Mexico, Blanton (1978) on Monte Albán in Oaxaca, and Folan et al. (1983) on Cobá in the lowland Mayan area. Researchers in the lowland Mayan area have produced some of the most detailed descriptive studies. This is no doubt due to the spectacular nature of the soft limestone building tradition in that region, wherein architectural ornamentation and elaboration, often baroque in character, reached a peak of development unequaled in any other area of Mesoamerica. An example is the study of the Río Bec, Chenes and Puuc styles, by Gendrop et al. (1998). In western Mexico, due to the highly geometric character of the early monumental architecture (Weigand, 1996), the approach of Chippindale (1986) and Stiny (1976) has been utilized to determine the rules of formal design employed there.

Architectural Types

The typology employed *infra* is far from complete, but represents a sampling of building types found throughout pre-Hispanic Mesoamerica.

Pyramids

Urban precincts, as spaces, and the buildings within, are almost universally well organized and formal. Within them are found the most monumental buildings in Mesoamerica, usually pyramids which are often of considerable size.

Among the earliest monumental pyramids is the structure found at La Venta, Tabasco. Located in a tropical rain forest and made from earth, it is badly eroded. Hence, its original shape has generated controversy. Its original shape may have been like a fluted cone, with ten alternating ridges and valleys at regular intervals around the oval base (Heizer, 1968). Its original height cannot be determined, but it towered over the flat flood plain that surrounds the site. Apparently, there existed no access ramp or stairway. This structure dates to around 900–400 BCE.

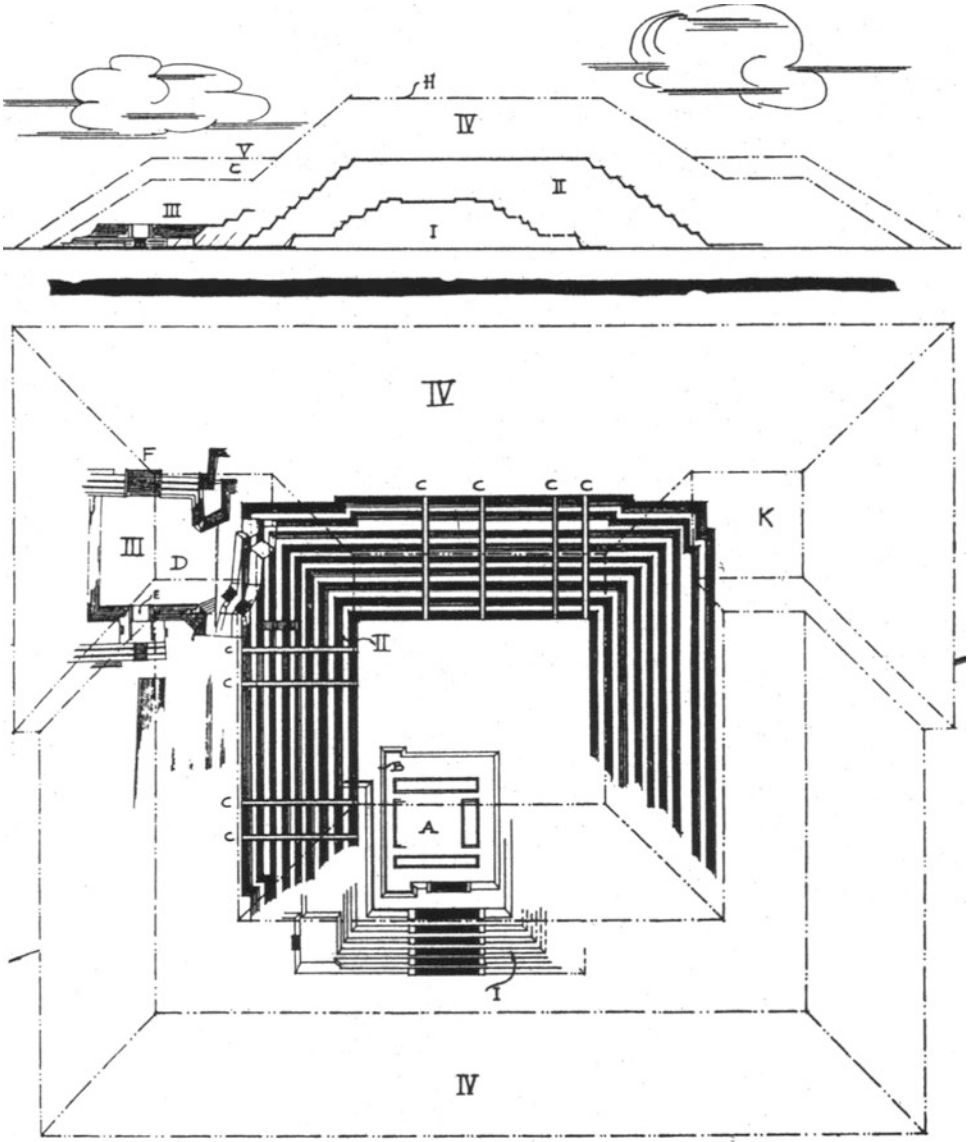
For the Classic period (AD 150–700), while the Pyramid of the Sun at Teotihuacan is the best known, it is not the largest. That distinction belongs to great pyramid at Cholula (Puebla), considered by some to be the largest single structure (by volume) in the Americas. While the pyramid is the greatest single building of the Mesoamerica architectural tradition, it is poorly preserved and understood. This structure eventually covered over 16 ha of surface, and was 55 m high. Some of the 16 ha represent poorly preserved platforms attached to the main body of the pyramid. The basic form is shared with the monumental pyramids at Teotihuacan: square to rectangular and terraced, culminating in a flat surface atop of which was placed a rather small temple (Marquina, 1951, pp. 115–125; Fig. 1). The pyramid at Cholula was constructed over a very long period of time, apparently in constant use from around AD 100 to the Spanish conquest in the early sixteenth century. As such, it represents one of the monumental buildings in longest continuous use within the overall area. The material used in construction varied from well-prepared adobe brick to rock and clay fill. The decorative finish, usually described as variations on the *talud-tablero* technique, was painted and highly sophisticated. The *talud-tablero* technique is usually ascribed to influence from Teotihuacan, but in most cases throughout Mesoamerica, including Cholula, this is doubtful. This architectural decorative technique was pan-Mesoamerican, though, very prominent at Teotihuacan.

The pyramids at Teotihuacan, dating from the Classic period (AD 100–850), as well as adjoining and neighboring structures, have been extensively studied for over a century. The site, while huge (22.5 km^2 – Millon, 1973), is still the focus of intensive research. George Cowgill's ongoing project at the Pyramid of the Moon has shown an extremely complex construction history, including prestige burials with sacrifices for this structure, thus supplying documentation equivalent at Teotihuacan for Cholula. The Pyramid of the Sun covered just under 5 ha of surface, and is 61 m high. The restoration of this structure, begun over a century ago, is controversial (Fig. 2). A natural, but improved, cave underneath this pyramid may represent the famed *chicomostoc*, or emergence tunnel through which people of this world originated. A tunnel dug through the Pyramid shows what may be a much earlier structure, perhaps representing a tomb (Millon & Drewitt, 1961).

Perhaps one of the best examples of baroque architecture in Mesoamerica is the Pyramid of the Niches at Tajín, Veracrúz. While the substructure as such is comparable to pyramids elsewhere, it is the decorative elements that set it aside (García Payón, 1957). Its fine decorative masonry is unique in the non-Mayan regions of Mesoamerica. The niches, 365 in number, set into the ornamental *talud-tablero* facing, probably housed figurines (Fig. 3).

The double pyramid at Tenochitlan, destroyed by the Spanish after they conquered the city in 1521, is the most famous of this architectural type. The building has been extensively excavated and restored, and its history and utilization is fairly well understood (Matos Moctezuma, 2003). The pyramid was associated with a multiplicity of rooms and adjoining shrines, containing painted murals, rich offerings, and statuary. The "double" term refers to the peak of the pyramid. There, twin temples, each reached by a separate stairway, sat atop a common base. In architectural models and illustrations, this structure is often portrayed as being far more monumental than it actually is. This is apparently due to the centrality given to the Aztecs in the official histories of the Republic.

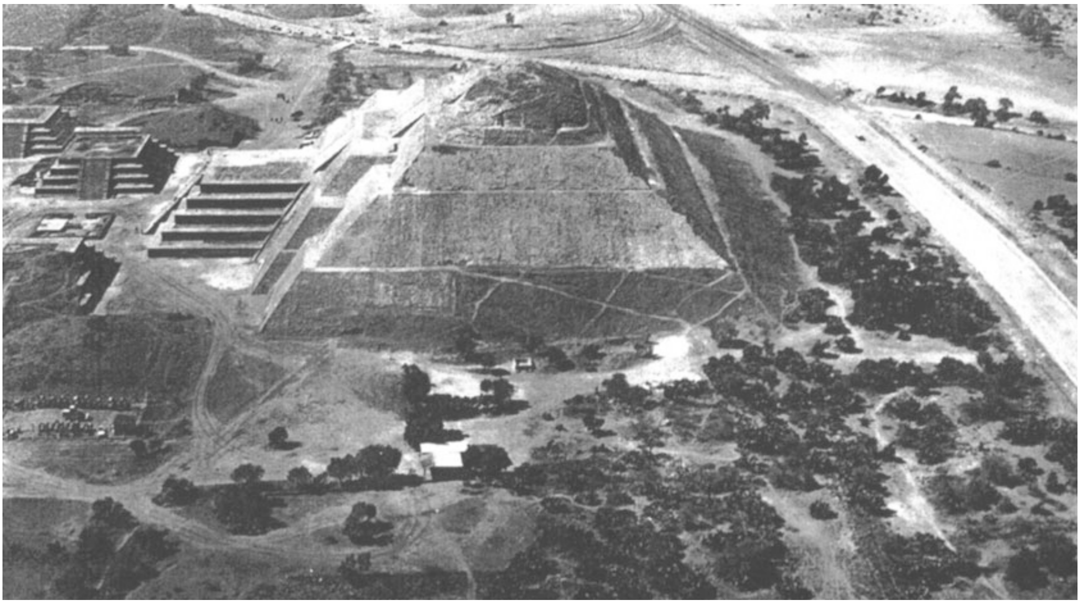
The small pyramid complex at Tula, Hidalgo, while not impressive if viewed as isolated



Architecture in Mesoamerica, Fig. 1 Map of the Cholula pyramid, Puebla, showing plan and profile (Taken from Marquina, 1951, p. 119)

structures, had extremely complex sculpture and appended buildings. The "atlantean" statues, originally placed atop one of the main pyramids, and the Halls of Columns adjoining that same structure, are unique in Central Mexico (Mastache et al., 2002; Fig. 4).

Pyramids in the Mayan area are unusual for their steepness and height in relation to their bases. The Temple of the Giant Jaguar (also called Temple #1) at Tikal, in the Petén district of Guatemala, is one of the best examples. It had nine terraces, and three rooms at the summit. The rooms' vaults were supported by beams from the sapodilla tree. A large vaulted tomb was excavated in the plaza before this pyramid was finished. On the upper terrace of the pyramid is a limestone temple which has a two-level roof comb. This comb, while adding a decorative element to the building, also increased significantly its overall height. This structure was finished

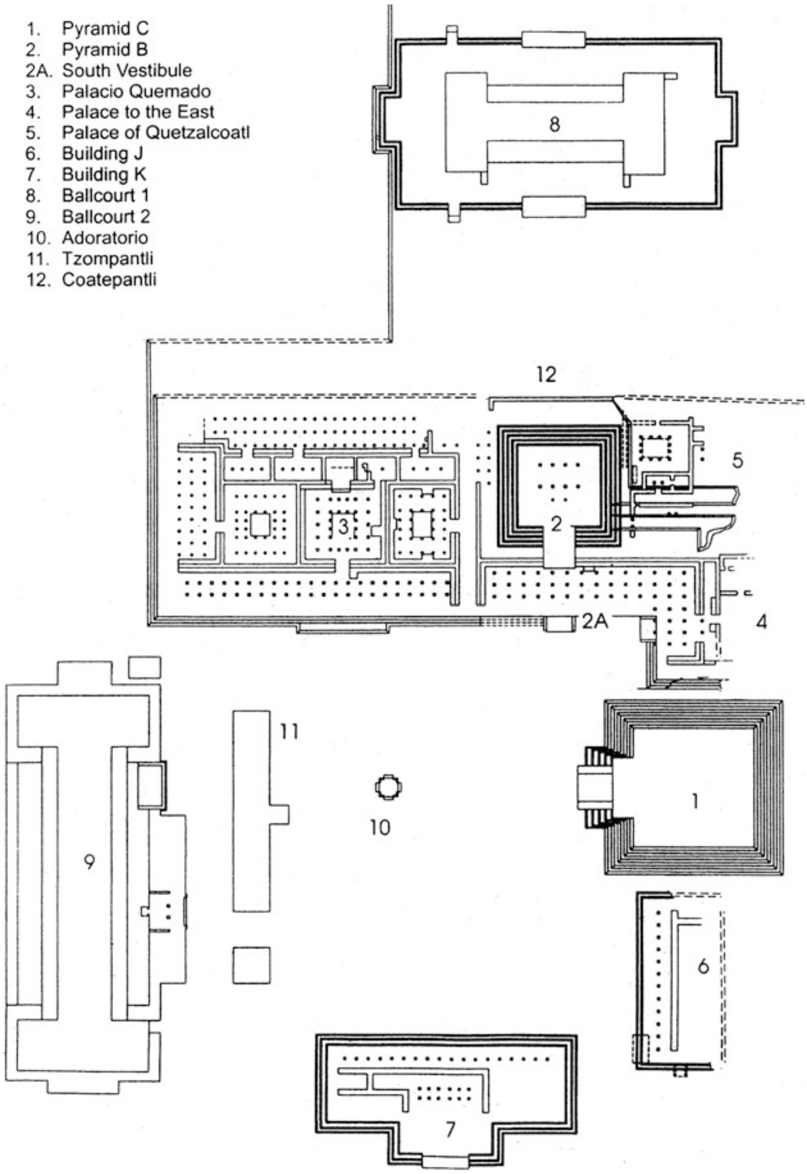


Architecture in Mesoamerica, Fig. 2 The Pyramid of the Sun, Teotihuacan, State of México (Taken from Millon, 1973, Plate 24a)

Architecture in Mesoamerica, Fig. 3 Pyramid of the Niches, Tajín, Veracrúz (Taken from Porter-Weaver, 1981, p. 244)

around AD 700 (Coe, 1967). Other pyramidal buildings of note are found at Piedras Negras (Houston et al., 2000); Palenque, and its great subpyramid tomb of King Pacál (Ruz Lhuillier, 1963); Chichén Itzá (Ruppert, 1952); as well as those mentioned in Gendrop et al. (1998). Aside from the decorative sculptures and friezes, some Mayan buildings had elaborate wall murals. The best preserved of these are at the Temple of the Paintings at Bonampác, Chiapas (Ruppert et al., 1955).

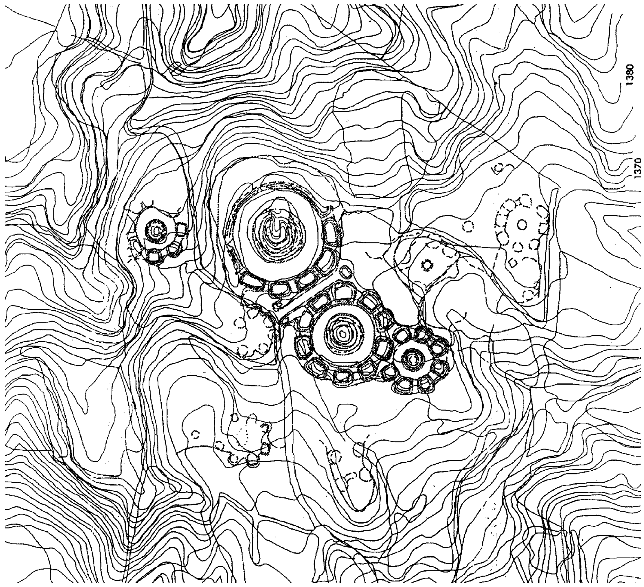
In western Mexico, three sites deserve special note. The Guachimontón precinct, at Teuchitlán, Jalisco, has ten concentric circular structures, each having central circular pyramids, surrounded by elevated circular patios, which in



Architecture in Mesoamerica, Fig. 4 Plan of the Halls of Columns, and associated buildings, Tula, Hidalgo (Taken from Mastache et al., 2002, p. 92)

turn are surrounded by circular banquettes. While some 400 of these precincts have been located to date, this type of architecture morphology is unique in the world repertoire. The largest circle is 128 m in diameter, and 405 m in circumference. The precinct covers 19 ha. The pyramids in these complexes are only attributes of the overall structure. The highest one is 20 m. The outer banquette served as the base for between 8 and 16 platforms, atop of which were large temples. Beneath the platforms are the shaft-tombs, which are full of the figurines that have given the region its fame in the antiquities market. The deepest shaft-tombs are 14–20 m, with between three and five large rooms. These structures date from the late Formative and early Classic period (350 BCE–AD 450; Weigand, 1996, 2005; Fig. 5).

Ihuatzio and Tzintzuntzan, Michoacán, are both sites associated with the Tarascan empire of the late post-Classic period (1300-Spanish conquest). Ihuatzio is the earlier site. It has a



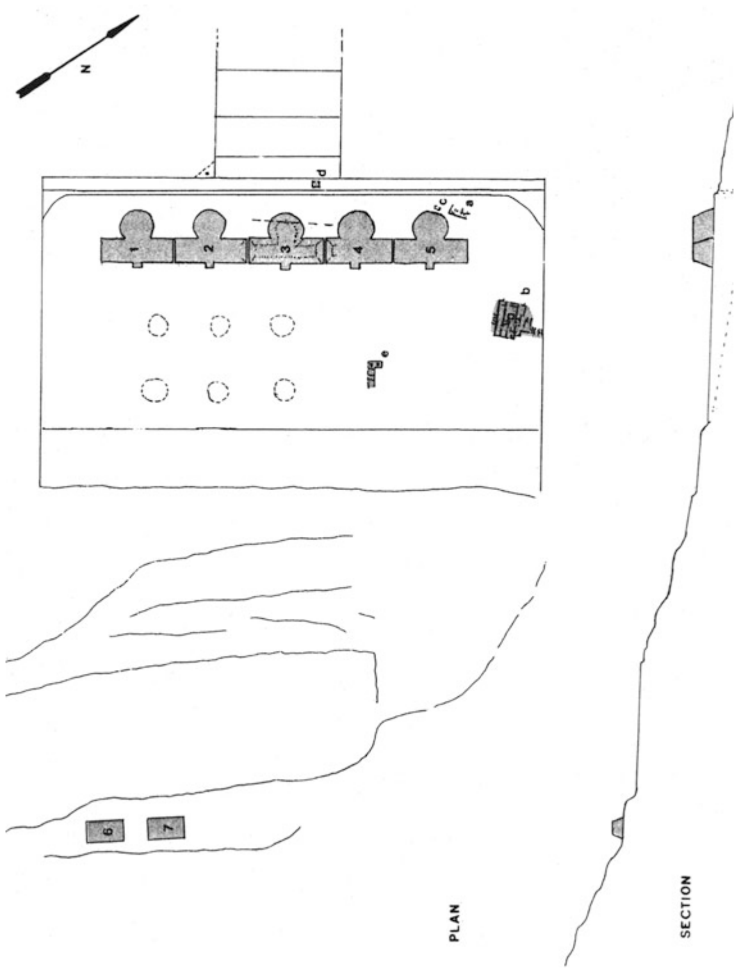
Architecture in Mesoamerica, Fig. 5 The Guachimontón precinct at Teuchitlán, Jalisco (Taken from Weigand, 1996, p. 95)

large double pyramid complex which is partially surrounded by huge walls that clearly limited access to them. The *yácata* style building is also present. *Yácatas* are another unique building form found only in western Mesoamerica. They are large circular altars appended to rectangular platforms. Stairways are at the rear of the structures. The site with the most impressive array of *yácatas* is Tzintzuntzan. Five *yácatas* are lined up atop a huge rectangular platform (Cabrera Castro, 1987; Pollard, 1993; Fig. 6). Clearly, the *yácatas* and their base platform form a single structure, one of the most monumental of Mesoamerica.

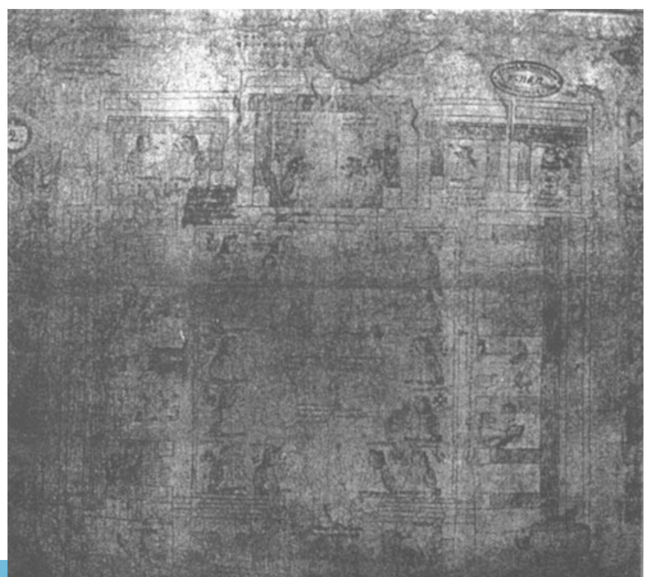
Palaces

These structures, commonly called *tecpan*, abound within the complex sites of Mesoamerica. Although the identification is not certain, the Ciudadela at Teotihuacan is often identified as a *tecpan* (Millon, 1973). It is a huge, square structure measuring 400 m to a side. Its interior plaza is a large open space facing a small pyramid complex with complex serpent and rain god heads protruding from its surface (Drucker, 1974). It was probably completed around AD 300, if not earlier. Also at Teotihuacan, many sunken patio structures aligning the Street of the Dead have been identified as palaces, or at least as residences of the elite elements that ran the urban complex. Many of these buildings were elaborately decorated with murals and low relief carvings. The Quetzalpapalotl Palace is one of the best examples of this type of building (Acosta, 1964). It is a stunning example of a highly complex structure which apparently combined public administrative functions with residential quarters. A magnificent courtyard is bordered by porches. This type of structure is commonly called a *patio hundido*, or a sunken plazuela complex. The palace apparently dates to around AD 500.

The studies by Evans (1998, 2001) constitute the most comprehensive comparative research concerning palace structures in Central Mexico. Since so many of the late palaces in Central Mexico are covered by Colonial and contemporary buildings, including that of the last Aztec emperor, Moctezuma II, in Tenochitlan, she has made ample use of ethnohistorical descriptions. In general, the Central Mexican *tecpan* is defined as an open court surrounded by a high banquette on at least three sides and open on one side to community plazas. The Codice of Quinatzín, portraying a Texcoco palace (State of México) clearly shows this type of structure (Fig. 7). Moctezuma's palace is said to have been 200 m



Architecture in Mesoamerica, Fig. 6 Map of the *yácatas* at Tzintzuntzan, Michoacan (Taken from Pollard, 1993, p. 48)



Architecture in Mesoamerica, Fig. 7 The *tecpan* represented in the Codice of Quinatzín (Taken from Weigand & García, 1996, p. 183) to a side, though this structure, buried beneath Mexico City, is no longer visible. The average, however, is considerably smaller: between 60 and 80 m to a side.

Several structures at Monte Albán have been identified as possible palaces (Winter, 1974). These structures face the large, rectangular plaza that forms the central feature of the citadel. While they somewhat resemble palace structures at Teotihuacan, and date to approximately the same period, they are much more compact, and with fewer decorative elements. The plazuelas are quite small. Tombs, most probably lineage crypts, are often associated with these structures, and open directly onto the plaza.

At Yagúl, in Oaxaca, a different type of palace structure has been identified. Apparently, six side-by-side structures existed, built during the post-Classic period. Each is characterized by a series of fairly small rectangular patios surrounded by long, narrow rooms. The overall effect is cramped and crowded. The core of these buildings was rough stone and earth, but the exterior decorations were careful and sophisticated, usually plaster or cut stone. Facades and door frames were decorated with small cut stones formed into geometric mosaic patterns (Bernal, 1965). This decorative appliqué is similar to that found at Mitla, though the functions of the structures there have not been identified with certainty.

Buildings identified as palaces abound in the Mayan area. Perhaps the best known of these is the Tower Palace at Palenque. This square, four story structure was constructed from finely cut limestone blocks. The floors were supported by wooden beams, instead of corbelled arches so often employed in other palaces and temples throughout the zone. While attached to a palace-like structure, the tower is unusual for its height. A variety of functions have been suggested for the tower per se (Carlson, 1976).

From the post-Classic period, the largest visible *tecpan* is found within the village of Oconahua, Jalisco. At 125 m to a side, it conforms rather exactly to the arrangement set out in the aforementioned Codice of Quinatzín. An internal plazuela is surrounded by high platforms, the northern one of which is out-sized at 125 × 50 m. Outside this building is an external plaza measuring 180 × 55 m. Within this plaza were small platforms which served as bases for large stelae. The core of the structure is clay and earth, with some rock. It was finished with cut stone slabs, almost all of which have been looted (Weigand et al., 2005).

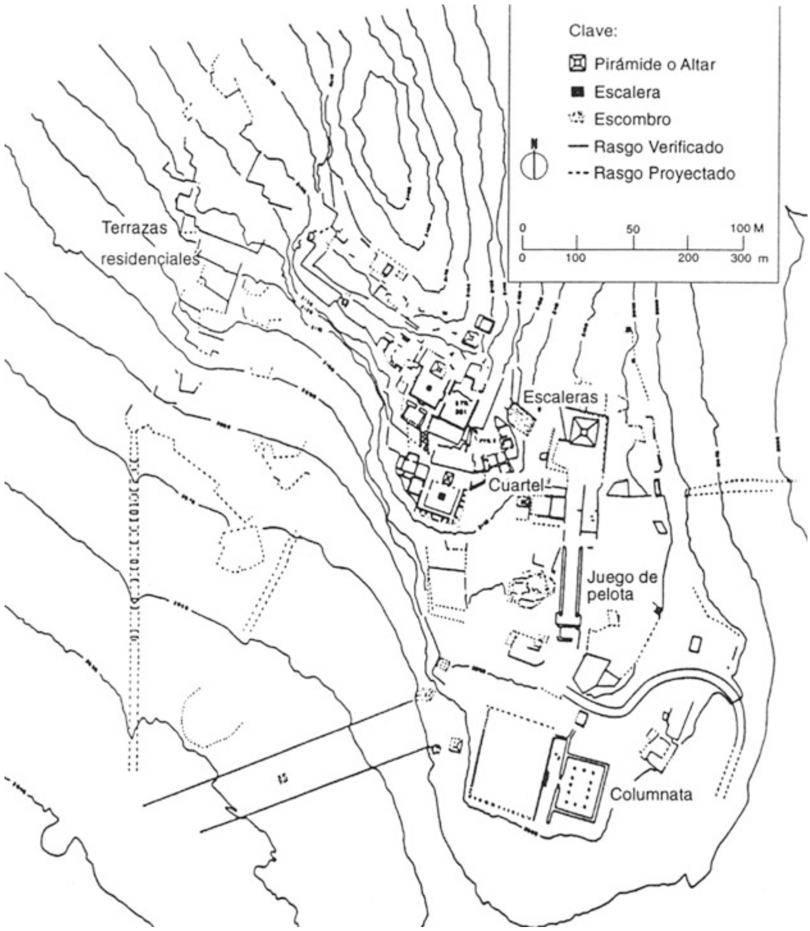
Market Places

These spaces were frequent features within Mesoamerican urban spaces. Often, they are hard to identify, and frequently are labeled as just plazas. One of the largest and earliest such spaces has been identified at Teotihuacan (Millon, 1973). Across the Street of the Dead from the aforementioned Ciudadela, this open space measures approximately 125 × 250 m. It is surrounded by streets and buildings, some of which are directly associated with the market. Stalls, some of which dealt in obsidian artifacts, were arranged within the plaza of the market. Unfortunately, this space was chosen to house the site museum and a restaurant, and is therefore difficult to appreciate today.

Places identified as markets have been located in the Oaxaca valley, as well, such as at Xaachila. The best information, though, comes from the Spanish sources from the conquest period. These attest to great markets at Cholula and Tlatelolco, in addition to other sites.

Ball-Courts

Fortunately, for this type of structure, excellent comparative studies are available. The studies by Taladoire (1981, 1998) are unparalleled in detail, classification, and chronological considerations. A few more recent studies from western Mexico have added detail to his overview (Weigand & García, 2005). Taladoire associates the architecture of ball-courts in different areas quite logically with the types of games performed there. Basically, two types of games dominated the Mesoamerican ball-court traditions. One type was the game played off the forearm (*antebrazo*), which required a court that had a hoop and a tall banquette. This is the type of game played at the monumental court at Chichén Itzá, for example. At 135 m in overall length, this



Architecture in Mesoamerica, Fig. 8 The fortified citadel at La Quemada, Zacatecas (Taken from Weigand & García, 1996, p. 170)

court is one of the largest within all of Mesoamerica. The site of Tajín has perhaps the largest quantity of ball-courts, and the decorative elaboration of several is unsurpassed anywhere else. Elsewhere, the game played is called the *cadera*, or hip game. No hoop is required and thus the lateral banquettes are lower than in the *antebrazo* variety. The earliest monumental ball-courts of this type are found in Jalisco, where five buildings have been located and studied. The one at Santa Quitería is 135 m long, and the other four average 110–115 m in total length. The court at the Guachimontones has been restored, and dates to 150 BCE–AD 150 (Weigand & García, 2005).

Fortifications

Fortified or defendable sites abound within Mesoamerica. Three strongly fortified sites stand out as excellent examples of military architecture: Tepexi el Viejo in Puebla (Gorenstein, 1973), Oztuma in Guerrero (Armillas, 1944), and La Quemada in Zacatecas (Armillas, 1948; Fig. 8). All three forts share several basic features: located on high, difficult terrain, they are terraced with walls and *revetments*? to make access almost impossible. All have specialized buildings and apparent gateway areas. Ceremonial architecture, while present, is modest and rather inconspicuous. La Quemada is the earliest of these three examples, dating to the AD 600–1100 period, while the other two belong to the Aztec polity. Smaller, but still impressive and earlier forts, can be found at the Peñol de Santa Rosalía, Jalisco (Weigand, 1996). Some areas, such as the Caxcan zone of southern Zacatecas, have fortified sites literally on every hill top.

Architectural diversity characterizes the many traditions of ancient Mesoamerica. This diversity is both temporal and spatial in nature. Some types have not been considered in this survey: specialized shrine sites, such as Malinalco in the State of México; mining complexes, such as those at the Sierra de Navajas in Hidalgo, and Chalchihuites in Zacatecas; ports of trade, such as Xicalanco, between Tabasco and Campeche; elegant burial chambers, such as the monumental shaft-tombs of Jalisco; and the great agricultural field systems such as the chinampas of Jalisco and Central Mexico.

References

Acosta, J. (1964). *El Palacio del Quetzalpapalótl*. Mexico City, Mexico: Instituto Nacional de Antropología e Historia.

Acosta, J. (1965). Preclassic and classic architecture of Oaxaca. *Handbook of Middle American Indians* (pp. 837–848, Vol. 3. Pt. 2). Austin, TX: University of Texas Press.

Armillas, P. (1944). Oztuma, Gro., fortaleza de los mexicanos en la frontera de Michoacán. *Revista Mexicana de Estudios Antropológicos, 6*(3), 165–175.

Armillas, P. (1948). Fortalezas mexicanas. *Cuadernos Americanos, 7*(5), 143–163.

Aveni, A. (Ed.). (1977). *Native American astronomy*. Austin, TX: University of Texas Press.

Bernal, I. (1965) Archaeological synthesis of Oaxaca. *Handbook of middle American Indians* (pp. 788–813). Austin, TX: University of Texas Press.

Blanton, R. (1978). *Monte Alban: Settlement patterns at the ancient Zapotec capital*. New York: Academic Press.

Cabrera Castro, R. (1987). Tzintzuntzan: decima temporada de excavaciones. *Homenaje a Roman Piña Chán* (pp. 531–565). Mexico City, Mexico: Instituto de Investigaciones Antropológicas, Universidad Nacional Autónoma de México.

Carlson, J. B. (1976). Astronomical investigations and site orientation influences at Palenque. In M. Roberston (Ed.), *Segunda Mesa Redonda de Palenque* (pp. 107–122). Peeble Beach, CA: Robert Lewis Stevenson School.

Chippindale, C. (1986). Archaeology, design theory, and the reconstruction of prehistoric design systems. *Environment and Planning, B, Planning and Design, 13*, 445–485.

Coe, W. (1967). *Tikal: A handbook of the ancient Maya ruins*. Philadelphia: University of Pennsylvania Press.

Drucker, R. D. (1974). *Renovating a reconstruction: The Ciudadela at Teotihuacan, Mexico*. Ph.D. Dissertation in Anthropology, University of Rochester, Rochester.

Evans, S. (1998). *Aztec palaces and other elite residential architecture. ms*. Department of Anthropology, Pennsylvania State University.

Evans, S. (2001). Aztec noble courts. In C. Jessica & S. Patricia (Eds.), *Maya royal courts* (pp. 237–273). Boulder, CO: Westview Press.

Folan, W., Kintz, E., & Fletcher, L. (1983). *Cobá: A classic Maya Metropolis*. New York: Academic Press.

García Payón, J. (1957). *El Tajín*. Mexico City, Mexico: Instituto Nacional de Antropología e Historia.

Gendrop, P. (1997). *Diccionario de Arguitectura Mesoamericana*. Mexico City, Mexico: Editorial Trillas.

Gendrop, P., Andrews, G., & Wood, R. (1998). *Río Bec, Chenes, and Puuc Styles in Maya architecture*. New York: Labyrinthos Books.

Gendrop, P., & Heyden, D. (1993). *Architecture Mesoamericaine*. Paris: Gallimard.

Gorenstein, S. (1973). *Tepexi el Viejo: A post-classic fortified site in the Mixteca-Puebla region of Mexico* (Vol. 63.1, pp. 1–75). Philadelphia: American Philosophical Society Transactions.

Heizer, R. (1968). New observations on La Venta. *Dumbarton Oaks Conference on the Olmec* (pp. 9–36). Washington, DC: Trusteies for Harvard University.

Houston, S., Hector, E., Richard, T., David, W., George, V., & Kitty, E. (2000). Among the River Kings: Archaeological research at Piedras Negras, Guatemala. *Mexicon, 22*, 8–17.

Kowalski, J. (Ed.). (1999). *Mesoamerican architecture as a cultural symbol*. London: Oxford University Press.

Kubler, G. (1975). *The art and architecture of ancient America*. Harmondsworth, UK: Penguin Books.

Margain, C. (1971). Pre-Columbian architecture in Central Mexico. *Handbook of Middle American Indians* (pp. 45–91, Vol. 10. Pt. 1). Austin, TX: University of Texas Press.

Marquina, I. (1951). *Arguitectura Prehispánica*. Mexico City, Mexico: Instituto Nacional de Antropología e Historia.

Mastache, A. G., Cobean, R., & Healan, D. (2002). *Ancient Tollan: Tula and the Toltec Heartland*. Boulder, CO: University of Colorado Press.

Matos Moctezuma, E. (2003). Buildings in the sacred precinct of Tenochtitlan. In W. Sanders, A. G. Mastache, & R. Cobean (Eds.), *Urbanism in Mesoamerica* (pp. 119–147). Pittsburgh/Mexico: Pennsylvania State University/Instituto Nacional de Antropología e Historia.

Millon, R. (1973). *Urbanization at Teotihuacan, Mexico*. Austin, TX: University of Texas Press.

Millon, R., & Drewitt, B. (1961). Earlier structures within the pyramid of the sun at Teotihuacan. *American Anthropologist, 26*(3), 371–380.

Pollard, H. (1993). *Tariácuri's legacy: The prehispanic Tarascan State*. Norman, OK: University of Oklahoma Press.

Porter-Weaver, M. (1981). *The Aztecs, Maya, and their predecessors*. New York: Academic Press.

Ruppert, K., Thompson, J. E. S., & Proskouriakoff, T. (1955). *Bonampák, Chiapas, México. Carnegie Institution Publication No. 602*. Washington, DC: Carnegie Institution of Washington.

Ruz Lhuillier, A. (1963). *Palenque*. Mexico City, Mexico: Instituto Nacional de Antropología e Historia.

Smith, A. L. (1965). Architecture of the Guatemalan highlands. *Handbook of Middle American Indians* (pp. 76–94, Vol. 2. Pt. 1). Austin, TX: University of Texas Press.

Stiny, G. (1976). Two exercises in formal composition. *Environment and Planning, B, Planning and Design, 3*, 187–210.

Taladoire, E. (1981). *Les Terrains de Jeu de Balle: Mesoamerique et Sud-ouest des États-Unis*. Mexico City, Mexico: Études Mesoamericaines.

Taladoire, E. (1998). Los juegos de pelota en el occidente de México. In R. Avila (Ed.), *El Occidente de México: actas del IV Coloquio de Occidentalistas* (pp. 88–99). Guadalajara, Mexico: Editorial de la Universidad de Guadalajara.

Weigand, P. C. (1996). The Architecture of the Teuchitlán Tradition of the Occidente of Mesoamerica. *Ancient Mesoamerica, 7*(1), 91–101.

Weigand, P. C. (2005). La tradición Teuchitlán del Occidente de México. In E. Cárdenas (Ed.), *Tradiciones Arqueológicas* (pp. 217–41). Morelia, Mexico: El Colegio de Michoacán and the Gobierno del Estado de Michoacán.

Weigand, P. C., & García, A. (1996). *Tenamaxtli y Guaxicar: las raíces profundas de la Rebelión de Nueva Galicia*. Zamora, Spain: El Colegio de Michoacán and the Secretaría de Cultura del Estado de Jalisco.

Weigand, P. C., & García, A. (2005). El juego de pelota monumental de los Guachimontones, Teuchitlán, Jalisco. In E. Williams, P. C. Weigand, L. L. Mestas, & D. Grove (Eds.), *El antiguo Occidente de México* (pp. 45–72). Zamora, Spain: El Colegio de Michoacán.

Weigand, P. C., García, A., & Cach, E. (2005). *El Palacio de Ocomo: Tecpan monumental en el occidente de México* (Antropología en Jalisco, Vol. 13). Guadalajara, Mexico: Secretaría de Cultura del Estado de Jalisco.

Winter, M. (1974). Residential patterns at Monte Albán, Oaxaca, Mexico. *Science, 186*, 981–987.

Architecture in Palestine

Shadi Sami Ghadban

When talking about traditional architecture in this area of the Middle East, it is more correct to identify this architecture by the term "Palestinian Architecture" rather than by "Architecture in Palestine." The second term refers to all architectural styles found in Palestine throughout the different historical periods, from Hellenic, Roman, Byzantine, Umayyad, Abbasid, Fatimid, Crusades, Mamluk, Ottoman, and the British Mandate until today. These architectural styles were mainly popular in major cities like Jerusalem, Jaffa, Acre, and Nablus. In addition, these styles were commonly related to the architecture of the economic and political elite and the urban notables.

On the other hand, the first term "Palestinian Architecture" reflects what is known as "architecture without architects," which has flourished for several centuries in urban and rural areas. It maintained its characteristics until World War I because of the social, economic, and religious factors that reflected the needs and living habits of a particular time, and it directly reflects the interaction between human beings and their environment (Fig. 1).

Prior to the year 1839 (when Ottoman land reforms were applied), land in Palestine was the main source of livelihood and status, with very limited transactions with the regional or world market. The Palestinian community retained a system of agricultural subsistence, employing simple agricultural technology. The community as a whole was considered the unit of taxation by the state, and there were patriarchal households, where the extended family acted as the main unit of production and consumption, and labor was divided along clear gender lines.

The year of 1832 marked a critical turning point in the history of the region, when Mohammad ‘Ali, the Governor of Egypt from 1805 to 1848, occupied Great Syria, including the Palestinian territories, and implemented several land, administrative and economic reforms (Manna’, 1999, p. 161). He gained the support of the European superpowers for his military campaign when he said that he would take into consideration their vital interests in the area, treat the non-Moslem minorities in a better way than the Ottoman Authorities had, and even try to give them equal rights with the Moslems (Scholch, 1988, pp. 130–145). This Occupation brought

Samhan palace, village of Ras Karkar, Ramallah district.

Talamas house, Bethlehem city

Agha Tuqan house, Nablus city

Two-storey house with shops at the street level, Nablus city

Village courtyard house, Ramallah district

Two-storey house, Al-Bireh city

Architecture in Palestine, Fig. 1 Houses of the economic and political elite at different districts of the Palestinian territories during the eighteenth and nineteenth centuries (Photos are student works from the course "Local Architecture in Palestine", Birzeit University, 1998–2001)

Partial view of the old city of Ramallah, where the old fabric is scattered by the modern buildings constructed in the area.

Partial view of the old city of Nablus, surrounded by the new modern urban structure

Architecture in Palestine, Fig. 2 Images demonstrating the rapid construction growth outside and within the historical fabrics in Urban Areas (Photos by the author)

about several developments accompanied by the implementation of several administrative and economic reforms, but they were obstructed by different uprisings and disobediences that occurred in the area (Manna', 1999, pp. 137–138). The Egyptian policy in the Palestinian territories led to increasing European influence in these territories, mainly in Jerusalem. The activities of different missionary groups concentrated on constructing new churches and providing educational, social, and health services to the local population. The first European British Consulate in Jerusalem was inaugurated in this period, which was followed by other consulates during the period 1841–1858 (Spyridon, 1938).

In 1839, the Ottoman Sultan Abdul-Majeed came back to power in Great Syria, and this included the Palestinian territories. He was supported by the European coalition established by Great Britain, Russia, Austria, and Prussia (Scholch, 1988, pp. 458–475). In his decree, known as *Khat Golkhanah*, issued in November 1839, he expressed his readiness to apply new reforms that were known later as *Tanzimat Khairiah* (Davidson, 1973). In addition, the increasing European influence led to an economic amalgamation of the Palestinian territories with the world capital market, and produced an active involvement of the Palestinian local leadership in the continuously changing political circumstances. All these factors shaped the new socioeconomical interactions within Palestinian society.

By the end of the nineteenth century a new eclectic architecture with mixed styles witnessed the western influence that came through the activities of different missionary groups. This development was accelerated during the last three decades of the nineteenth century and continued intensely during the first two decades of the British Mandate (1920s and 1930s) when a rapid construction growth sprawled in both rural and urban areas (Fig. 2). Therefore, by the end of the 1930s, a new architectural fabric began to emerge which greatly affected Palestinian society since the middle of the nineteenth century.

The Tanzimat period represented one historical period of the Ottoman Empire, but for Palestine and other Arabic areas in the eastern coast of the Mediterranean, this period consisted of three major stages:

- *First stage* (*1840–1856 AC*). The Crimean war ended and a decree called *Khat Sharif Hamaion* was issued on 18th February 1856. This decree contained several reforms that Sultan Abdul-Majeed addressed to get the support of the European countries for his war against Russia. In this stage the Ottoman Authorities performed reforms similar to those applied by the Egyptian Government (1832–1840). However, the local leadership, mainly in the countryside, rejected them, arguing that they were contradicting with their interests (Izz-Elddine, 1928, pp. 95–96).

- *Second stage* (*1858–1878 AC*). The Ottoman land reforms (Tanzimat) started in 1858, which aimed to change the communal ownership of land to private ownership. This period, mainly in 1878, evidenced the first parliamentarian experience during Sultan Abdul-Hameed the Second's rule. New fundamental changes affected not only the relations between the state and the Palestinian local leadership, but also had an extensive effect on the socioeconomical, cultural, and living conditions of the Palestinian local society.
- *Third stage* (*1878–1919 AC*). During this stage the integration of the local economy into the world trade market and acceleration of the European influence in the area continued. However, there was a growing trend toward improving the infrastructure, mainly in the fields of transportation, communication, education, and governmental administration. It was also around this time that Palestinian immigration to both Americas increased and the immigrants started sending back money to their families in Palestine to build their future houses. In addition, this period included the expansion of Jewish emigration and construction of new settlements with imported architectural styles.

The 1840s was a decade rich with events assumed by several historians as indicators for the beginning of a new history in the Palestinian territories. As a result, new architectural systems, i.e., new building styles and forms, use of new materials and methods of construction were imported and implemented, but within the framework of the local knowledge in the area (Fig. 3).

Factors Influencing Palestinian Traditional Architecture

Several factors bear upon the development of Palestinian traditional architecture.

Geography

A distinguishing part of Palestine is its geographical location along the eastern Mediterranean coast. It has a key location between Asia and Africa, and has a specific character as a Holy Place for Judaism, Christianity, and Islam. Altitudes, which range from 394 m below sea level to 1,400 m on the mountainous chain parallel to the coast, allow the existence of a diverse landscape. The mountains shape the nature of the Palestinian territories and control climate and rainfall.

Many influences affected the Palestinian land, and large-scale architectural activities took place during the rule of foreign powers such as the Romans, Crusaders, Mamluks, or Ottomans. Despite the fact that these activities reveal strong local characteristics, they are of foreign origin. Therefore, independent Palestinian architecture was limited to housing structures and modest religious and public buildings. The influence of geography can be observed in the adoption of certain types of construction, architectural forms, orientation, and the arrangement of buildings. The articulation of plan, elevations, simplicity of masses, and the habit of one or two-story constructions are largely caused by the predominant conditions in the three main geographical zones of the country: the coastal area, the highlands and the Jordan valley (Fig. 4).

Natural Building Materials

Palestinian territories have an unusual geology because of their location between Great Syria and the Sinai Peninsula, where different geological formations produced a unique topography, diverse both in form and structure.

The mountainous area consists of hills, valleys, and gorges, where the geological strata are easily accessible. These strata usually consist of sandstone between limestone, and are cut up by various clefts, mainly in the Hebron, Bethlehem, and Nablus areas.

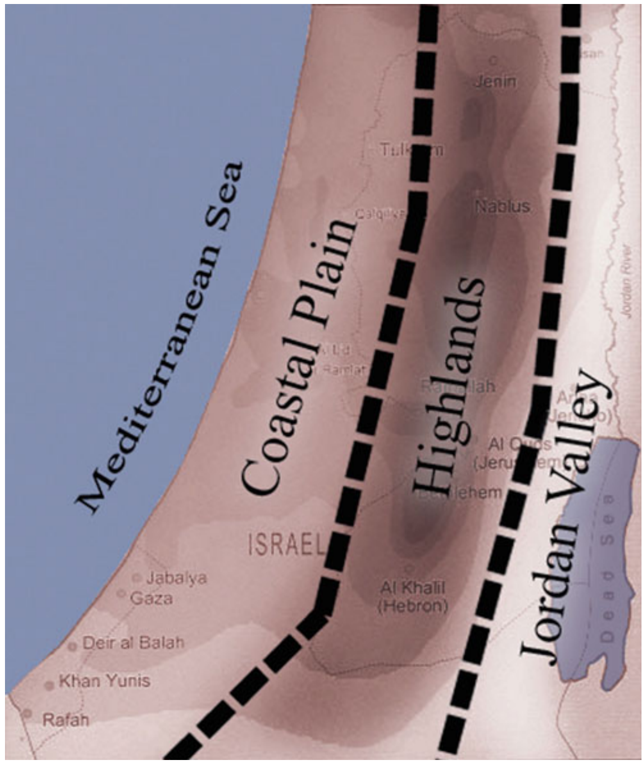
The abundance of stone in the country offers the opportunity for good masonry construction. The continuous use of stone has produced stonemason's families who passed on their accumulated skills from generation to generation, evolving a mastery and tradition of design in

Architecture in Palestine, Fig. 3 Houses and buildings with new architectural types, forms, new materials and methods of construction (Photos are student works from the course "Local Architecture in Palestine", Birzeit University, August 2000)

stone that is largely responsible for the homogeneous character of Palestinian architecture (Figs. 1 and 3).

Mud is limited to the Jordan valley and some coastal areas, mainly Gaza, because of their geological conditions. The fairly dry climate in these areas allows the application of mud brick (adobe) structures.

For many centuries, the use of wood for construction was limited to some kinds available in



Architecture in Palestine, Fig. 4 An illustration demonstrating the three geographical zones in historical Palestine (Adapted by the author, using as a base a map distributed by Applied Research Institute (ARIJ), http://www.arij.org)

the area, such as one-palm trees and olive trees and rarely poplar, willow, walnut, and maple. Wood is mainly used for doors, windows, some furniture, and for roof construction.

The Climate

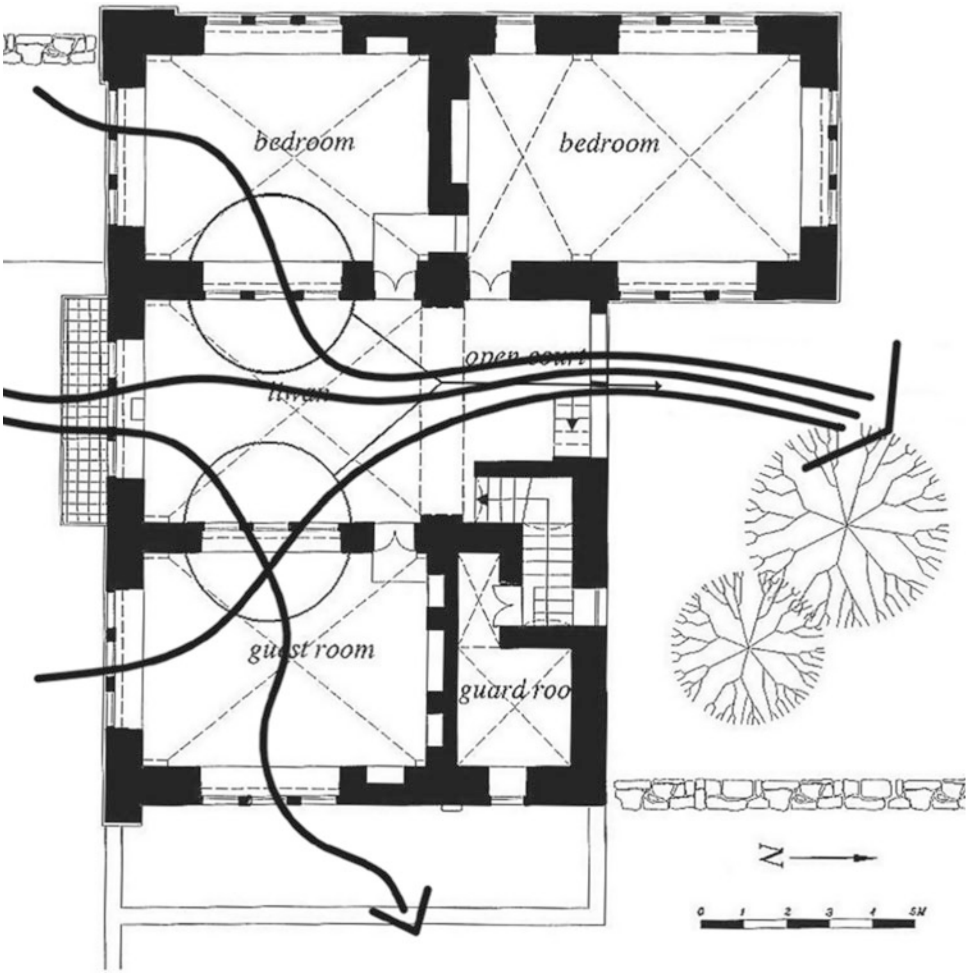
There are four climatic zones in the Palestinian area: the coast area, the western slopes of the mountainous area, the eastern slopes and the Jordan valley and the desert. The annual climatic cycle of the country consists of four hot dry summer months, a mild autumn with little rainfall, a rainy winter with snow down to 700 m and an early spring with the last rainfall in April.

The architecture of Palestine is a synthesis between local environmental conditions and the formulas of the philosophy of life, art and design prevailing in the entire Mediterranean region. The massive construction in stone or mud-brick in terms of a wall's thickness, height, texture, and verticality, satisfies to a large extent the exigencies of the climate. The roof structure, either flat surfaced from mud, wood, and straw or vaulted mainly from stone, guarantees appropriate temperature insulation and reduces the heat transfer process. Crossventilation is facilitated by openings placed high in the single-spaced structures or by internal windows between rooms and the central space, which is assumed to be the coolest space during the hot daytime (Fig. 5). The open ends of the central space are turned either to the north or to the south in order to avoid deep penetration of the sun's rays. Fortunately, the placement of the house parallel to the contour lines of the slope toward the valley makes its face toward the prevailing wind direction and ensures the desired ventilation.

Socioeconomic Factors

Palestinian traditional architecture has been the result of an experience between human beings and their environment. This dialog has two forms: action and reaction. The action of the

A



Architecture in Palestine, Fig. 5 A house plan showing the crossventilation system imposed by the central hall system used for functional organization of the internal spaces. A student work from the course "Local Architecture in Palestine", Birzeit University (1998–2001)

human being always produces a reaction in the environment, and vice versa. In both cases, the reaction has two levels: an unconscious reaction and a conscious reaction that needs to be reinforced and enhanced.

Palestinian traditional architecture has been very resonant in functional, constructional, and artistic approaches during the last 120 years. When the changeable living conditions of the Ottoman Reforms and the English Mandate caused some elements of traditions and values to loose their initial meaning, they had to be replaced by new ones with a function closer to the new requirements that still responded to certain sociohistorical conditions.

In this regard, there is a substantial importance to specific Palestinian local forms of production, religious customs, beliefs, traditions, mental adaptation, self-confidence, and spirit of people, because all of them are determined by local physical, geographical, and climatic conditions.

The religious affiliation of the Palestinian family did not affect the distribution of house types in Palestine. The conditions of living either in the mountains, valley, or in the coast areas were essentially the same for all religious

General view of Al-Lubban village, Nablus district. General view of Ras Karkar village, Ramallah district

Architecture in Palestine, Fig. 6 Images demonstrating the panoramic form and dimensional connection with the existing environment in rural areas (Photos by the author)

communities, and all families adhered to a strong paternalistic structure. Great class discrepancies were unknown and the social structure was egalitarian.

On the other hand, the Islamic influence has been very strong in artistic and architectural forms and details, but there is very little Islamic influence in the planning of the houses. They were simple and straightforward, and that includes the lack of specialized spaces as well as a lack of privacy for the individual.

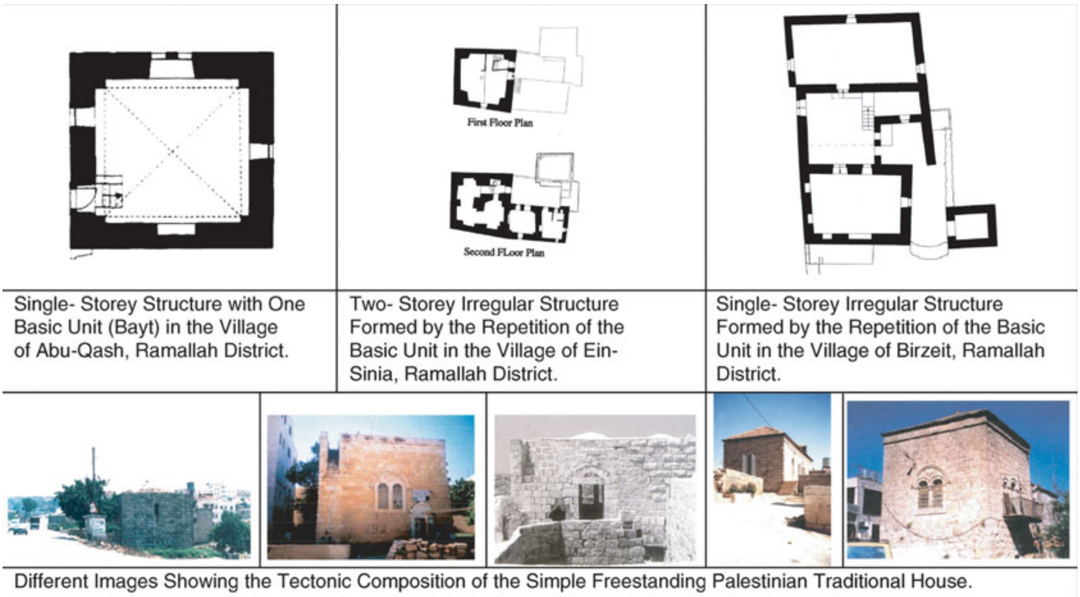
The House

Prior to the Ottoman Reforms (Tanzimat), land in Palestinian Territories was the main source of livelihood and status, and the Palestinian community employed simple agricultural technology. A system of agricultural subsistence was retained, with very limited transactions with the regional or world market. The village as a whole and not the individual was considered the unit of taxation by the state. The community had patriarchal households, the extended family acting as the main unit of production and consumption, and labor was divided along clear gender lines (A'miry & Tamari, 1989, pp. 11–15).

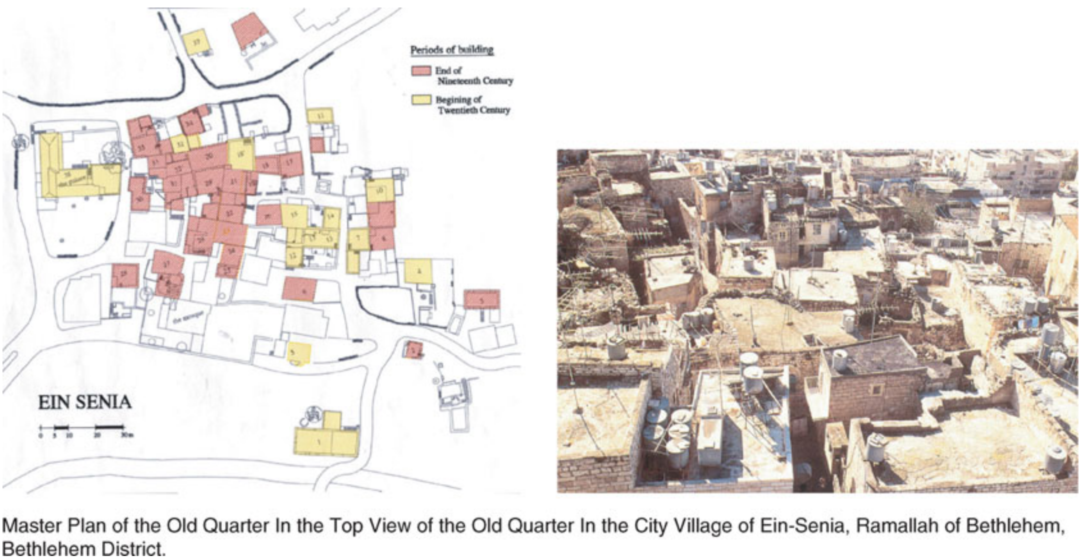
The Palestinian village has had an outstanding harmonic panoramic form and a dimensional connection with the existing environment where the built up area grew together with the land, but revealed its own main image (Fig. 6). This local rural process could be described as a classical expression of organizing the habitation process by spontaneity, intuition, and a connection with site topography. The socioeconomic organization of the built environment before 1832 evoked the implementation of one of two main systems:

- The single-storey freestanding structure, which consists of a square or rectangular space (*bayt*) with a low entrance (*bab*), ventilation opening below the roof (*taqat*), and one or a pair of two small windows (*mijwiz*) (Fig. 7).
- The clustered and concentric patterns of spatial organization, where houses and other structures have formed the traditional clustered fabric. The pattern was produced by repetition of the single-storey structure, as each house unit was adjacent to other house units at least from two sides, as the back of the structures formed a part of the periphery protecting the inner courtyard (Fig. 8).

Both systems were built either from natural stone and roofed by traditional crossvaults or with mud mixed with straw and roofed by a wooden flat structure. The free grounds between the structures mainly were used for agriculture, livestock, and/or for future expansion.



Architecture in Palestine, Fig. 7 Single and multi storey freestanding structures, consisting of a Square or Rectangular Space (Bayt), and a Pair of Two Small Windows (Mijwiz) (Student works within the Course "Local Architecture in Palestine", Birzeit University, 1999–2000)



Architecture in Palestine, Fig. 8 Two images showing the Clustered and Concentric Pattern of the Spatial Organization at the Urban and Rural Palestinian Areas. Student Works within the Course "Local Architecture in Palestine", Birzeit University, 1999–2000

Initial Forms of the Traditional House

Today, there are still some examples that demonstrate the initial forms of the Palestinian vernacular house before 1850, but most of them have been extensively restored that they can no longer belong to any specific period. Three original forms of this architecture are still used as spaces for living, agricultural, and stockbreeding activities. Mostly, they are located in the hilly areas, villages or within the large historical cities. The general characteristics of these forms are as follows:

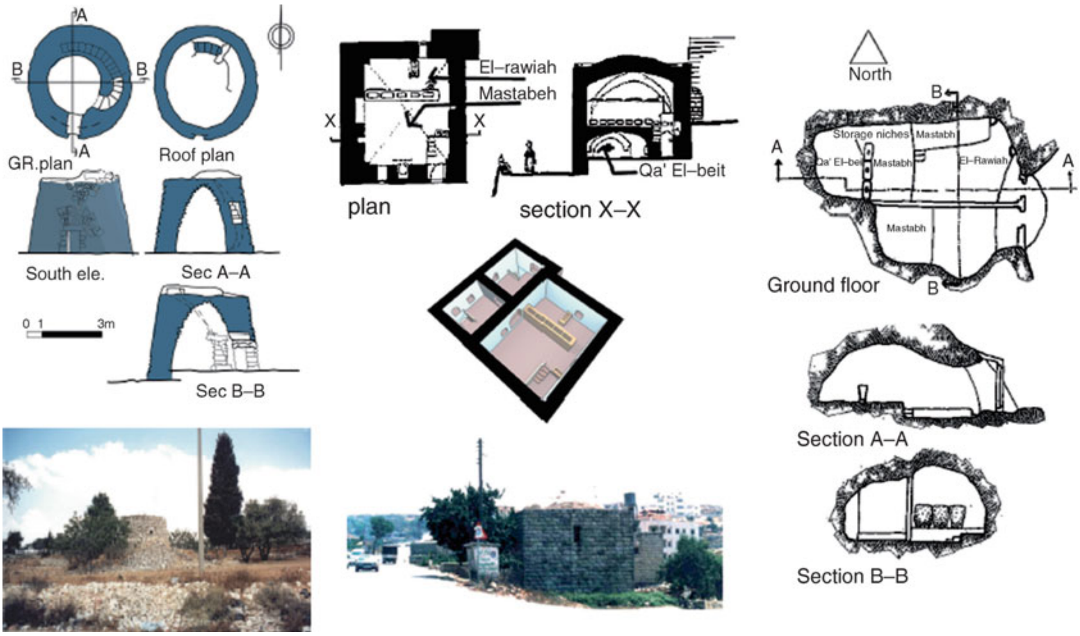
- *Caves*: they are considered the first habitation structure used by Palestinians for living purposes. Mostly, they are located at the eastern slopes of the Jordan Valley (winter pastures) and at the western mountains of the Palestinian territories (summer pastures). These caves are either natural, or have been rehabilitated to meet new living requirements (Fig. 9a). Each cave consists of one open space articulated into different zones by means of harmony between the various social, functional and aesthetic elements. Furthermore, some of these caves continue to host several living activities as a major element in the further extension of the living environment.
- *Watching Towers* (*Mantarah*): a freestanding stone structure that imitates tectonically the vernacular typical house, but with different function and details. Usually, they are located outside the rural or urban fabrics, on the top of hills between fig and olive trees and pastures. These structures had multifunctional purposes as places for watching and cultivating land, summer vacations, storage places and bases for winter agricultural activities. Each watching tower is divided vertically into two or three levels. It consists of a ground floor for livestock and storage, a first floor for living and a second floor in the form of an open terrace used for multipurpose activities. This structure exists in both rectangular and circular plans (Fig. 9b) and all levels are accessible by an internal staircase.
- *Shepherd's House*: this model represents the most popular form of the Palestinian vernacular house with a simple single-storey square structure, built from the limestone rock abundant in the surrounding areas, and has only one low arched entrance (Fig. 9c). Walls are massive, sometimes 1 m thick, in order to support the heavy stone crossvault of the roof. The elevations are free of any window openings apart from small ventilation holes. The three-dimensional development of the shepherd's house produced three well-defined and integrated domains (A'miry & Tamari, 1989; Hamdan, 1996): (a) the multipurpose space for living (*Mastabeh*), (b) the animals' space (*Qa' El-beit*), and (c) the food storage space (*El-rawieh*).

These three domains were available at all three forms, with certain discrepancies according with physical and environmental needs.

New Forms of Palestinian Traditional Architecture

Palestinian traditional architecture is a product of the cultural development of the East Coast of the Mediterranean basin. Historical events caused a great dislocation of ethnic groups and populations with different public systems, specific customs, and intertwined cultural traditions. Appropriate conditions for mutual influence were established during the formation, development and enrichment of traditions and values. Several new forms of the Palestinian traditional house were created. They reflect the sociopolitical changes, which took place after the Tanzimat (reforms) period in 1842 and brought about essential transformations in the traditional structural of the Palestinian society:

- Creation of modern state institutions, mainly in the large cities, that led to immigration toward the new urban centers. This phenomenon led to major growth in the population inside the boundaries of the Old City. As a result, the existing structure became incapable of assimilating the augmenting needs of the population, and people started moving outside the Old City, creating new urban centers that were in the beginning juxtaposed to the frontiers of the Old City.
- Decline in the power of the village sheikh (Ruler).
- Changes in land tenure due to the Ottoman land reforms (Tanzimat), and privatizations of the main means of production: the land. The new ownership policies allowed foreign



Architecture in Palestine, Fig. 9 Original initial forms of the Palestinian vernacular house (Photos and drawings by the author)

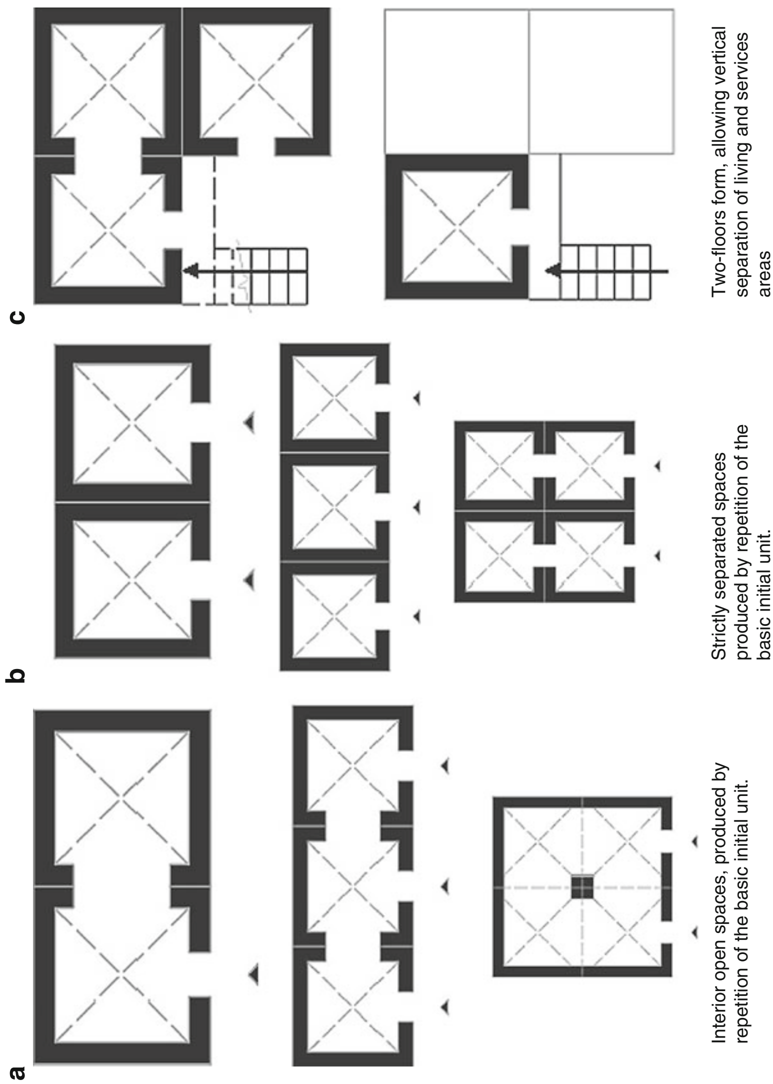
citizens to buy and register lands in their names. Foreign religious missions, relief agencies and consulates started their activities and gradually built up their religious, educational, health, and residential compounds.

- Growing integration of the local economy in the world trade market. This had an effect over all agricultural, trade and investment structures in Palestinian society.
- Formation and dissemination of a new culture in addition to the prevailing Islamic one.
- Changes in the occupational structure of the local population.
- Aggravation of social contradictions.
- Active emigration among the young Palestinian generation toward the American continent and Europe, in order to avoid the obligatory military service forced by the Ottoman authorities. Most of the immigrants started sending back their savings to invest them in Palestine by building mansions that reflected the new lifestyle of an affluent social class that was in formation in most Palestinian urban sites around that time.

Rectangular House with Repetitive Initial Units

The term "Repetitive Initial Units" is used here to express the way this type of traditional house was produced. It consists of a repetitive arrangement of the rectangular or square initial model in a horizontal or vertical direction producing a composite structure (Fig. 10). Further development of this system initiated other more advanced forms of this architecture:

- Enlarging the space by means of one or more interior supports producing large open spaces with an internal system of pillars or vaulted roofs and enclosed by bearing walls (Fig. 10a). Mud and stone were both used.
- Strict separated spaces with sharp rectangular corners and increased rigidity of forms. In this way the organic unity of the interior space is reduced (Fig. 10b). Roofing was implemented by barrel vault or crossvault structure, and both invited the addition of an upper floor. This form was mainly produced by stone material.



Architecture in Palestine, Fig. 10 Basic schemas of the rectangular traditional house. For existing examples refer to Figs. 7 and 9 (Drawings by the author)

- Adaptation of a two-floor form of stone construction, which was very significant since it allowed the vertical separation of the living and service areas. This system ended the cohabitation of people and animals, symbolizing their emancipation from unremitting toil (Fig. 10c). The connection between floors was always external.

The Court House

The court denotes an open space delimited by wings and connected to the surroundings or the main alley by a main door or gate. This schema was predominantly applied in the main villages and towns, because of the clustered character of the construction fabric (Fig. 11). In this case building units are arranged in an L or U shape and rarely in a closed square or rectangular shape.

The house built around a courtyard is fairly extensive and contains well-oriented wings that offer privacy and safety and form a reception space and daily activities area for the family. The courtyard was enriched by the addition of a covered terrace on one side called *Liwan*, which served as an extension toward a significant orientation like a valley, seashore or another nice view.

The Gallery House

The gallery (*Riwaq*) indicates a covered space, which opens to the outside through a series of supports such as colonnades or arcades. In the Mediterranean two forms of the gallery are popular. The first is a gallery that exists as an addition of a covered open space, mainly produced by ornamental plants or grapevines and therefore called a passive gallery. The second one is the active version of the gallery and is designed as an open corridor that functions as a traffic or transitional area linking different components of the building (Fig. 12). As a rule the gallery is greater in length than in depth. In general the gallery is reached either directly from the surroundings, if the terrain slope allows that, or by a courtyard in front. In contrast with the closed rectangular type the gallery building expresses three major trends (Ragette, 1974, p. 44): (a) appreciation of the gentle climate and the natural beauty of the region; (b) a feeling of confidence to the inhabitants, and (c) an increasing emphasis on life within the family.

In the majority of cases the gallery building has two floors, the lower of which is vaulted and the upper is flat-roofed or with tiled pitched roofs (imported from Europe in the nineteenth century). In its formal expression the gallery building presents the greatest possible contrast to the closed rectangular type. The continuous arcade or colonnade provides the feeling of openness and expresses the superior social standing of the building's owners.

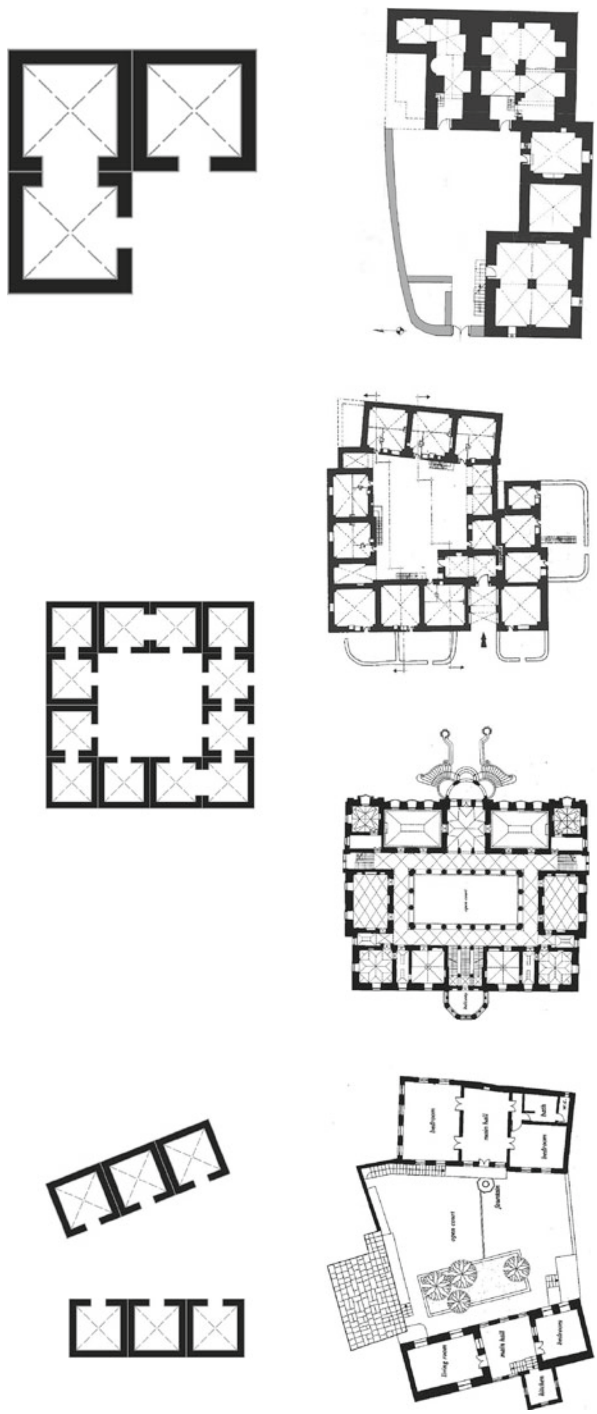
The Central Hall House

Although this type appears in Palestine at a later date than the other mentioned types, it became the most popular form of traditional house by the second half of the nineteenth century (Fig. 13). It has one, two, or three floors, and one or more entrances. In addition the central hall has a full depth, subdivided or surrounded by rooms from three sides. A symmetrical composition prevails when the entrance leads directly to the central hall, while the corridor to the central hall disturbs the symmetry when the entrance is lateral.

By the end of the nineteenth century, due to western influence, the central hall system was adopted widely and the design became increasingly formal. The houses turned into veritable villas that majestically dominated their surroundings outside the Old City walls. Often, the central hall house was built of stone. The lower floor was vaulted and the upper either vaulted, roofed with steel beams or timbered with red tiles.

This descriptive analysis of Palestinian traditional architecture shows that transformations in the structure of Palestinian society reflect not only the achievements of Palestinian ethnic groups, but also those realized by interaction with western identities. In this way both traditional creativity and "formal architecture" have been rationalized:

1. This architecture is a product of a simple and frugal society creating its habitat with elementary means, but also with an understanding of the functional requirements and the potential of the materials available.



U-Shape of the Court House-Tuqan Palace, Nablus, Nablus District.

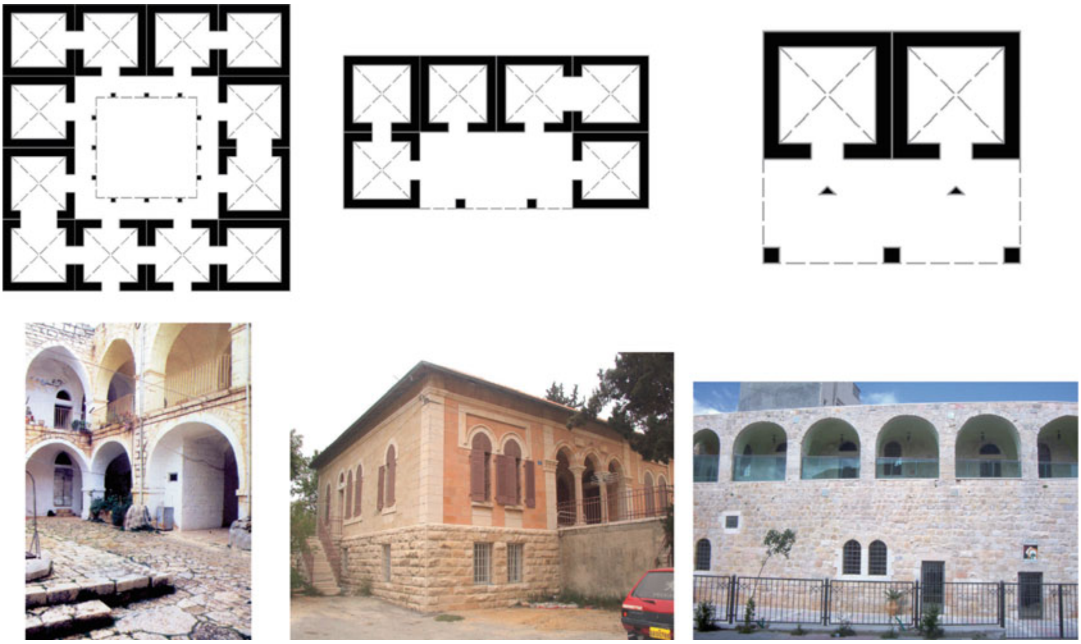
Closed Shape of the Court House-Jaser Palace, Bethlehem, Bethlehem District.

Closed Shape of the Court House-Suhweel Palace, A'bueen Village, Ramallah District.

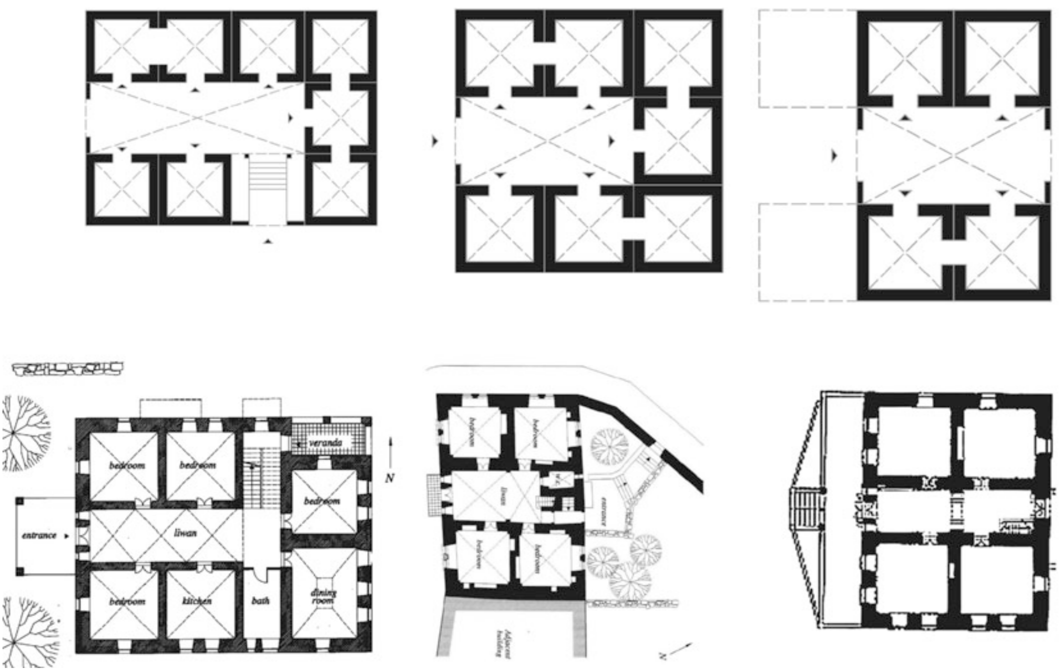
L-Shape of the Court House-Example from Ein-Senia Village, Ramallah District.

Architecture in Palestine, Fig. 11 Basic schemas of the court traditional house (Drawings by the author)

A



Architecture in Palestine, Fig. 12 Basic schemas of the gallery traditional house (Active Version) (Photos and drawings by the author)



Architecture in Palestine, Fig. 13 Basic schemas of the central hall traditional house (Drawings by the author)

2. The artistic quality of the buildings created in the second half of the nineteenth century was not totally dependent upon imported models. The stylistic self-sufficiency of the country's architecture has continued to be expressed through numerous variations of locally rooted traditions, as well as mastery of a craft.
   1. The color and texture of the natural stone contribute to the homogeneous and organic character of Palestinian architecture. The stone finishing reveals an intimate knowledge of the material acquired by generations of stonemasons. The use of color for decorative effects is limited to a few elements at entrances, windows, or arches. Palestinian architecture is more restrained in this regard than Arab architecture in general, where structural clarity is sometimes masked by decorations.
   2. The form's simplicity of the traditional building, the massing of single buildings as well as groups of buildings and the adherence to a uniform scale are the basic means of creating harmony between house and landscape, house and house or village and landscape. The juxtaposition of houses creates a repetitive rhythm of mass and void that covers the land without destroying its relief. The human scale is maintained in the traditional architecture, where the principal masses, as masonry works, automatically introduce a clear definition of scale. Yet each gate, door, window or arch dimension is in reasonable relation to necessity and importance.
   3. The shapes of walls and roofs normally adhere to the simple geometry of squares, rectangles and trapezoids. Spans and cantilevers are strictly limited. The repetitions of similarly shaped openings reinforce continuity and their irregular distributions within one elevation sometimes create pleasant diversity.
3. Palestinian traditional architecture occupies its place naturally and without pretension. It is imbedded in a landscape humanized by countless terraces, and built of the materials furnished by the environment. The balance of massing and the harmony of forms were exemplary, and the arrangement of the houses reflects deep understanding of the environment, and is indicative of a remarkable social balance.
4. However, by the end of the nineteenth century this architecture lost two of its most important qualities: the flexible inner space and public participation in the building process.

References

A'miry, S., & Vera, T. (1989). *The Palestinian village home*. London: The Trustees of the British Museum.

Davidson, R. (1973). *Reform in the ottoman empire, 1856–1876* (2nd ed.). New York: Gordian Press.

Hamdan, O. (1996). *Vernacular architecture in Palestine*. Al-Bireh: Center for Palestinian Folklore Heritage, Society for Family Welfare (In Arabic).

Izz-Eldine, A. (1928). Sulaiman. *Ibrahim Pasha in Syria*. Beirut, (In Arabic).

Manna', A. (1999). *The history of Palestine in the late ottoman period, 1700–1918: (a new reading)*. Beirut, Lebanon: Palestinian Studies Enterprise (In Arabic).

Ragette, F. (1974). *Architecture in Lebanon – The Lebanese house during the 18th and the 19th centuries*. Beirut, Lebanon: American University of Beirut.

Scholch, A. (1984). The decline of local power in Palestine after 1856: The case of aqil Aga. *Die Weltdes Islams, 23–24*, 458–475.

Spyridon, S. (1938). Annals of Palestine 1821–1841. Jerusalem: Manuscript of Monk Neophytes of Cyprus.

Additional Useful Literature

A'rraf, S. (1985). *The Arabic Palestinian village – Building and land use*. Jerusalem: Society of Arab Studies.

Abdulfattah, K. (1983). Geographical distribution of the Palestinians on both sides of the 1949 armistice line. In A. Scholch (Ed.), *Palestinians over the green line* (pp. 102–120). London: Ithaca Press.

Amiran, D.H.K. (1953). The pattern of settlements in Palestine. *Israel Exploration Journal* III.

Badawy, A. (1966). *Architecture in ancient Egypt and the near east*. Cambridge, MA: MIT Press.

Baldensberg, P. J. (1913). *The immovable east*. London: Pitman.

Canaan, T. (1932). The Palestinian Arab house: Its architecture and folklore. *Journal of the Palestine Oriental Society*, XII (1932) and III (1933).

Condor, C. R., & Kitchener, R. E. (1970). *The survey of western Palestine* (3 Vols.). Jerusalem: Kedem.

Dalman, G. (n.d.) *Arbeit und Sitte in Palastina*. Band VII. G. Olms: Hildesheim (In German).

Ghadban, S. (1998). Contemporary housing in Palestine – The potential for future adaptation. *Open House International, 23*(2), 37–49.

Khasawneh, D. (2001). *Memoirs engraved in stone: Palestinian urban mansions*. Ramallah, Jerusalem: RIWAQ-Center for Architectural Conservation.

Qamhieh, K. (1992). *Saving the old town of Nablus (a conservation study)*. Glasgow, UK: The Mackintosh School of Architecture, University of Glasgow.

Raheb, M., & Strickert, F. (1998). *Bethlehem 2000 – past and present*. Heidelberg, Germany: Palmyra Publishing House.

Rapoport, A. (1966). *House form and culture*. London: Prentice Hall.

Revault, P., et al. (1997). *Maisons de Bethlehem*. Paris: Maisonneuve & Larose (In French).

Robinson, E. (1841). *Biblical researches in Palestine Mount Sinai and Arabia Petra* (Journal of Travel in 1838, Vol. 3). London: R. Bentley.

Rogers, M. E. (1989). *Domestic life in Palestine*. London: Kegan Paul International.

Seger, K. (Ed.). (1981). *Portrait of a Palestinian village*. London: Third World Center for Research and Publishing.

Suad, A. (1987). *Kinship space, and gender: The social dimension of peasant architecture in Palestine*. Unpublished Ph.D. thesis, Edinburgh University.

Suad, A.(n.d.) *Throne village architecture – Palestinian rural mansions in the eighteenth and nineteenth centuries*. Ramallah: RIWAQ-Center for Architectural Conservation (In Arabic).

Volney, C.F. (n.d.) *Voyage en Syrie et en Égypte*. Paris: Mouton, (In French).

Wilson, C. T. (1906). *Peasant life in holy land*. London: Murray.

Websites

Arab Art Directory. http://www.arabsart.com/palestine

ArchNet. http://www.archnet.org/library/images

Conference on Vernacular Architecture/Alps Adria. http://www2.arnes.si/aa/index

George Eastman House. http://www.geh.org/ar/jericho

Google TM. http://www.google.com/architecture in palestine.

Hebron Rehabilitation Committee. http://www.hebronrc.org.

ICOMOS-PALESTINE. http://www.icomos-palestine.org

Jerusalem Media and Communication Centre. http://www.jmcc.org

Nablus City. http://www.nablus.org

Palestine 1948 Sites and Towns. http://www.prc.org.uk/palestine

Palestine Costume Archive, Canberra-Australia. http://www.palestinecostumearchive.org

Palestine Remembered. http://www.palestineremembered.com

Palestine: Sites and Sounds. http://www.palestine-net.com

Riwaq Center for Architectural Conservation. http://www.riwaq.org

Tel es Safa More than a Home, a Lifestyle. http://www.talessafa.com

The Adham Center for Television Journalism-The American University of Cairo. http://www.adhamonline.com

Welfare Association. http://www.welfareassociation.org

Architecture in South Africa: Domestic Architecture

Debbie Whelan
Department of Architecture, Durban University of Technology, Durban, KwaZulu-Natal, South Africa

South Africa is a large country with myriad cultures, ethnic groups both immigrant and aboriginal, and vastly differing climatic zones which in turn inform the natural landscape, and, by definition, the indigenous built environment. Furthermore, the more recent effects of modernism and modernization have had effect, removing the buildings from a static construct and situating them in an environment of innovation and change. This means that discussing the non-Western domestic architecture cannot be addressed simply or concisely due to its vastness and complexity. This broadcast exercise has been competently carried out in the past, by different authors such as James Walton (1956), Biermann (1971) and Franco Frescura (1981).

It is important to address the mercurial nature of this move from stasis to change, realizing that a rapidly changing world allows for new forms of domestic architectures such as informal dwellings, which house millions in contemporary South Africa. Thus, it is pertinent to focus more on a single region and a thread of architectures that are bound within a cultural and geographical framework.

The Zulu are southern Nguni people occupying the coastal littoral of the province of KwaZulu-Natal, on the eastern seaboard (see Krige (1962 [1936]) for a full, but dated, explanation as to the ethnography). Traditionally, they are polygamous pastoralists, relying on cattle keeping as a central focus of their lifeway, leading to authors such as Evers (1988) describing their settlement approach as the "Central Cattle Pattern." They have legendary status, having opposed colonial forces during the nineteenth-century British expansionism into the Colony of Natal.

Zulu architecture, and "architecture" that can be deemed in its potential complexity, is broad in its distribution stylistically as well as being open constantly to reinterpretation, change, and symbolic expression. The term "indigenous vernacular architecture" (see Oliver, 1997) would apply more fully, as the buildings that are produced act as products of a changing and mobile culture and are agglomerates of found and gathered materials. No static, representational "style" exists in the contemporary landscape, although an adherence to traditional planning can apply if economic stability and space allow.

It is important to describe the historically established norms comprising buildings to be able to understand how they formed part of the both large- and small-scale cultural and physical landscapes, as this not only provides a backdrop for the discussion but in many cases informs the cognitive foundations of contemporary architectures. This next section will describe the homesteads as planned units and then speak more fully about the individual units, the *iQhugwane* (grass dome) and the *rondawel* (thatched cone-on-cylinder).

Homestead Planning

Well documented in both historical and contemporary literature, the Zulu homestead, or *uMuzi*, is located on a hill distant from other homesteads. The site is awarded to the homestead head by the King, meaning that the land is neither bought nor sold, and remains the property of the King.

The essential large-scale planning principles of the homestead in many rural examples are constant. A hierarchy of individual units with different functions is situated around a central cattle byre, the whole enclosed with a fence. Access to the complex is usually from the bottom of the slope. At the apex is the dwelling belonging to the head of the family, the *indluNkulu*, with the paternal mother's dwelling, or *Gogo's* house. Each of the wives has a separate sleeping and kitchen unit. The young unmarried men usually live next to the entrance, and guests stay in a unit opposite. Internally the circular buildings are carefully demarcated, with specific places occupied by specific people with specific relationships, under the broad premise of men on the right and women on the left. A single building may be dedicated to consulting *amaDlozi*, the ancestors, and in such cases the offerings are placed in the *uMsamo* at the rear of the space.

The only constant that can be ascribed to Zulu building forms is that in a traditional society they follow a circular format. Only in more recent vernacular examples does the rectangle emerge as a dominant form (Fig. 1).

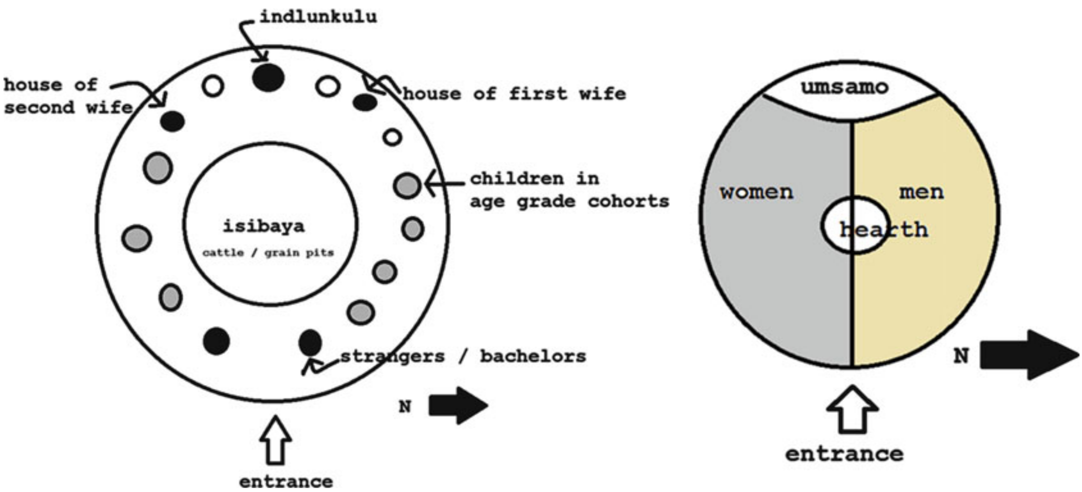
Today, change occurs through pressure from a variety of sources. In addition, dwindling natural resources used for housing, the vulnerability of the grass dome to fire, scarcity of thatching grass, and the rapid urbanization and migration of many hundreds of thousands of people in the last four decades have resulted in contemporary hybrid architectures that represent a variety of approaches to life, demonstrating origins and aspirations.

Individual Units

Two broad types of building forms exist: the domed beehive and the rondawel. These are not necessarily related and do not necessarily mutate from one to the other. Establishing their origins is a matter of debate.

- ***The Beehive Dwelling (iQhugwane)***

  The *iQhugwane* is the archetypal Zulu building, perpetuated partly by contemporary tourism initiatives as iconographic of "The Zulu Kingdom." The grassland environment of the southern littoral ensured the availability of grass for thatch.



Architecture in South Africa: Domestic Architecture, Fig. 1 Generic layout of traditional uMuzi (*left*) and typical spatial layout of iQhugwane (*right*) (Author: 2014) derived from Kuper (1980) and Argyle and Buthelezi (1992)

In simple terms, the *iQhugwane* is constructed of a series of concentric half circles of laths, cut by men, and set into the ground to the required diameter to form a dome. These are tied with grass, and then the whole framework is thatched by the women, starting at the bottom and leaving space for a doorway low enough to force one to bend down. The size of the structure is dependent on the number of central posts or *umGodi* that support it. The thatch is usually held down by plaited grass ropes, the floor plastered or *'usinda'd* on a weekly basis with a cow dung and water mixture. The original floor bed usually contains some measure of termite mound which acts as a binder. Inside is located a central hearth ringed with stones: the smoke from these fires acts as protection against insect activity. A grass topknot known as *inQhongwane* protects the most vulnerable part of the structure from rain. The door, *omnyango*, is built by specialists and consists of a mat of interwoven withies. It neither locks nor is it hinged; a brace consisting of a stick and a plaited rope holds it in place (Fig. 2).

The "properly constructed" beehive dwelling, as documented by Knuffel (1975) amongst the amaNgwane people, consists of up to 11 different types of grass, each with a different function and integrity. However, this is not the sole solution, as the building form is also represented by a number of other approaches, in which some are decorated with a looped rope system, others with lozenge patterns, and some are merely thatched with little regard for the more permanent fixing of the grass with rope. In addition, an extremely rare example today is that in which a number of mats cover the frame and are tied down (Biermann in Denyer, 1973).

Importantly, there is little in the historic record that documents buildings as being decorated. Other aspects of Zulu material culture such as ceramics and beadwork are internationally renowned for their decorative merits, but little in terms of house decoration exists.

- ***The Rondawel***

  This is a building form that characterizes much of the contemporary rural landscape of KwaZulu-Natal, comprising a conical roof that is thatched or under corrugated sheeting, on a cylindrical base comprised of a variety of materials. The rondawel has, in most rural communities, taken over from the beehive dwelling in which the latter was deemed unsuccessful or impractical (Fig. 3).

  The adherence to these basic principles of homestead construction as practiced in recent

Architecture in South Africa: Domestic Architecture, Fig. 2 Typical (traditional) domed iQhugwane, part of reconstruction of the umGungundlovu homestead, emaKhosini, KwaZulu-Natal (Photo: Author 1997)

Architecture in South Africa: Domestic Architecture, Fig. 3 Rondawel structure (Photo: Author ca 1999)

times has had to face many challenges, many due to the legislations and pressures placed through apartheid, but also dwindling resources, whether land or material. In addition, a recent rapidly rising middle class has accelerated the transitions of space and tradition, adding to the manner in which the hybrid architectures are produced. Only with these factors in mind is it appropriate to discuss new hybrids and the factors underpinning their development.

Pressures Creating New Building Forms and Spatial Planning

In the past, political initiatives by the erstwhile Colonial (1843–1910) and Nationalist Governments (1910–1994) have been influential in pressuring people living in traditional and vernacular homesteads to alter the form of the spaces and the buildings that they inhabit in order to conform to a European-imposed paradigm. Such pressure to build rectangular dwellings came from legislation such as that of Hut Tax (1849–1906) which encouraged people living in circular buildings to build orthogonal structures, or else pay tax to the Colonial Government. Other prompts were less demanding: the gradual acceptance of Western furniture into rural homesteads, and, importantly, the stove (Frescura, 1989) is considered to be motivators for change of form (see also Harber (2000) for a discussion on mutated forms of building).

Although anomalies exist, aggregation of a number of homesteads into villages is not part of Zulu spatial planning framework. Forced resettlement prompted this in the case of the baTlokwa people around the Nqutu area, while at Msinga, aggregation into village groups is perhaps as a result of densification due to population explosion, leading to dwindling resources. An oral source suggested that aggregation was also due to the high incidence of faction fighting in which the proximity of other homesteads increased personal security.

Another manifestation of homestead clusters is the creation of villages through implementation of the Tomlinson Commission (UG61/1955), which intended to create settlement areas or "Land Betterment Schemes." These aimed to release agricultural land creating community allotments, rather than itinerant subsistence farming centered around isolated homesteads. While a village culture certainly forms part of the social and spatial organizations of some of Southern Africa's peoples, this was not true of the Zulu, and this initiative had limited success in KwaZulu-Natal.

- ***Urbanization and Its Effect on Innovation***

  As unpalatable as including the informal (shack) house (*imiNjondolo*) within the scope of non-Western domestic architecture is concerned, it should be addressed.

  Rapid urbanization in the decades since the collapse of apartheid, together with the population explosion due in part to immigration from neighboring countries, has meant that the palette for choice of style and material has increased markedly. In KwaZulu-Natal, the 1980s were particularly disruptive, with internecine warfare increasing the flood of refugees moving to the cities. In addition, a major drought and subsequent flooding in 1983–1984 meant that people that had lived in subsistence fashion in rural areas moved to the cities to find work having lost two harvests. This swelled the then small informal settlements based on the peripheries of Durban, located largely close to officially declared townships. In addition, after the deregulation of the Group Areas Act, people previously not allowed residence in the city moved in, again swelling the informal settlements.

  The rise of the urban poor was an unfamiliar challenge, and even more for those who had made the move, with the materials that were traditionally used in vernacular housing being unavailable for cultivation, barter or free procurement. This meant that where thatch, stone, and timber had been used in the past, a monied economy denied the luxury of these items, and more urbane solutions had to be sought. This resulted in a largely orthogonal building from, comprised of found materials, some recycled, with a monopitch roof of corrugated sheeting or other recycled metal (Fig. 4).

  The innovation in style, form, material, and accommodation has boundless variation, in which the manifestation of the interface of society, culture, economy, and belief has resulted in new buildings representative of a plethora of different influences. They are not necessarily site specific, and sometimes they deny cultural affiliation, sometimes embrace it to the fullest, and sometimes only convey the smallest of hints as to the ethnic makeup of the owners.

  These pressures have stimulated a series of smaller-scale conceptual and practical decisions which contribute to the variety of approaches and their implementation.

- ***Assimilation of Different Ideas***

  Alterations in perceptions relating to the manifestation of the spatial envelope may occur, such as the move by communities, for a variety of reasons, to different vertical interpretations, yet retaining the same intrinsic

Architecture in South Africa: Domestic Architecture, Fig. 4 Orthogonal building development – wattle lath and packed stone (Photo: Author 2002)

plan. This is particularly evident in the recently remembered beehive dome-strewn landscape of Msinga.

This district is probably one of the last areas in KwaZulu-Natal that closely follows a strong Zulu tradition, evident in all forms of material culture. While the beehive *iQhugwane* existed until relatively recently, a variety of factors combined with strong traditional and religious convictions allowed for compromise, precipitating the preference for the cone-on-cylinder rondawel. Few move from the circular format. An extreme example is the progressive rondawel, constructed from face brick, updated accommodating orthogonal furnishings, and resolved with an octagonal plan. This "octa-davel," has a porte cochere, thus transcending the language of architecture, but also those of status and hierarchy.

- ***Innovation: New Manifestations of an Existing Form***

In Msinga too, a further innovation, wall decoration, developed with the adoption of the rondawel. The hardened wall surface of the building, as opposed to the grassed dome, enabled this. How and why this happened is not clear, but this does stand out as a phenomenon in the vernacular architecture of KwaZulu-Natal. Initially, it would seem that the Hlubi and Pondo influence, in which painted bands to each side of the doorway, and sometimes the dado area, was adopted. This developed into now rare, painted chevrons (Frescura, 1981) and appears to have formed the beginning of an evolutionary path of embellishment. Moreover, the rapid decay of these structures in the natural environment allows for a speedy development of building decoration (Fig. 5).

A second innovation is the incremental "American flat," a term coined by Harber (2000) that refers to the articulated form of the two-room dwelling that has been added to in a variety of ways, with conflicting and cascading roofscapes. The buildings are usually owner-built, sometimes over a long period of time in which parts are added as finances determine. This incremental building practice is common; thus, the banal factor of irregular income may determine the building form.

A particular idiosyncrasy of rural housing forms, and their officially constructed "Reconstruction and Development Programme" (RDP) counterparts, is the extension of identity in which the house is given a specific stamp that identifies it above its neighbors, through the vertical extension of the parapet in a molded form. The correlation of this feature, I would suggest, is linked to Harber's "American Flat." These modifications strongly suggest a vested interest in property and commitment to the inhabited space. Time, money, and effort would not be spent in the manufacture of these elaborations, and this is common of both rural and urban and peri-urban houses. In this case, the parapet of a "flat-roof" or monopitch is raised beyond the roofline, stepped, or Dutch-gabled, to create some discerning feature on the landscape.

- ***Adaptation of Material***

  Another means of staying within the boundaries of culture, while still embracing the traditional forms of the vernacular environment, has been the adaptation and adoption of materials in a creative and sometimes very effective manner.

  This phenomenon is not new. Early documented beehive domes were often described as "badly made structures," usually made out of flexible segments of *Dichrostachys* (sickle) bush, which had to be joined. Structurally, their pliability affected the shape of the building, as early photographs show a distinctive curve at the base, partly due to people squatting against the walls for support and partly in response to the weight of the building. The arrival of wattle (*Acacia mearnsii*) from Tasmania meant that a new timber with straighter and stronger lengths could replace the somewhat unwieldy sickle bush, producing a more rigid dome. Once its efficacy had been discovered, its subsequent popularity meant that it was adopted with alacrity by the Zulu, resulting in an altered form in which the shorter, straighter lengths of wattle produced a more upright building, with less of the characteristic bulge at the base. This innovation within the strictures of the beehive form provides for discourse surrounding the assimilative natures of the Zulu people and sets the tone for the development of vernacular architectures, not only varying the types of materials that can comprise such a structure, but also notionally in the adoption of different types of structure, whether the rondawel popular amongst the southern Sotho and Xhosa/Mpondo people, or the rapid adoption of the rectangular "cottage" in later years (Fig. 6).

Architecture in South Africa: Domestic Architecture, Fig. 5 Lady standing in doorway of decorated home in Msinga (Photo: Author 1999)

  Such translation of materials is emphasized in a particular structure from Richards Bay, in which an ancestral building was constructed in a homestead consisting largely of rectangular and orthogonal buildings. Its materials mutated. Rather than the anticipated grass covering common to such structures, the wattle laths of the *iQhughwane* were covered with white building plastic membrane usually used in waterproofing roofs. The base of this structure consisted of courses of concrete brick laid in a dry-stone manner, and the inside of this space was paved with similar bricks. The light

Architecture in South Africa: Domestic Architecture, Fig. 6 iQhugwane constructed of alternative materials, Richards Bay (Photo: Author 1998)

inside was no less than ecclesiastical, an unexpected irony in the considered resolution of spaces.

- ***Cultural Compromise***

  Travelling around KwaZulu-Natal, one often sees rondawels under corrugated sheeting, with a topnotch of thatch, often extending part of the way down the roof slope. This was, some say, to appease the ancestors who recognize thatch, for the use of modern corrugated sheeting, and to guide them to their "home." This signal to the ancestors is thus a cultural compromise between living under a material with less maintenance than thatch and at the same time allowing for a cultural continuum of religious belief.

Conclusion

Rapid immigration into urban areas, intermarriage, rapidly erected shelter, and immigration from surrounding countries all act as factors that force compromise in some of the dwelling solutions. Being able to embrace the African and the Western tradition, whether medicine, architecture, music, art, or drama, creates new and exciting and controversial fusions, and this is also manifest in the vernacular architecture tradition. It demonstrates the unexpected, yet totally justifiable, given that the architecture embodies the very nature of the cultural traditions and expresses, to a large extent, religious conviction.

The traditional and vernacular architectures in KwaZulu-Natal in many ways mirror the culture of assimilation and adaptation that exists in other areas. The open-mindedness of the Zulu people to novelty, as well as the impetus of poverty being a motivator, mean that the new architectures that are being created have a special quality that places them in a specific time and place. In addition, as mentioned, the short lived nature of much of the materials that are used means that these buildings form a particularly fragile part of the architectural and material cultural record, and as such say much for our current society and its value systems. Documenting the works is not easy, and much of the charm of the vernacular built environment lies in its ephemeral nature (see Healy-Clancy and Hickel (2014) for contemporary interpretations of 'home' in Zulu culture).

References:

Argyle, J., & Buthelezi, F. (1992). *Zulu Symbolism of right and left in the use of domestic and public space*. South Africa: Association of South African Anthropologists Conference proceedings, University of Durban Westville.

Biermann, B. (1971). Indlu: The domed dwelling of the Zulu. In P. Oliver (Ed.), *Shelter in Africa* (pp. 96–105). London, UK: Barrie and Jenkins.

Denyer, S. (1973). *African traditional architecture*. London, Great Britain: Heinemann.

Evers, T. (1988). *The recognition of groups in the Iron Age of Southern Africa*. Johannesburg: University of Witwatersrand Unpublished. Ph.D. (Archaeology) Thesis.

Frescura, F. (1981). *Rural shelter in Southern Africa*. Johannesburg, South Africa: Ravan Press.

Frescura, F. (1989). The South African flat-roofed dwelling: A study in geographical adaptation and cultural tradition. *South African Journal of Culture and Art History, 3*(4), 365–387.

Harber, R. (2000, March). The American flat in Africa. *SA Architect*, *3*, 37–40.
Healy-Clancy, M., & Hickel, H. (2014). *Ekhaya-The politics of home in KwaZulu-Natal*. Pietermaritzburg, South Africa: University of KwaZulu Natal Press.
Knuffel, W. (1975). *The construction of the Bantu grass hut*. Graz, Austria: Akademische Druck-uVerlangsanstalt.
Krige, E. (1962 [1936]). *The social system of the Zulus*. Pietermaritzburg, South Africa: Shuter and Shooter.
Kuper, A. (1980). Symbolic dimensions of the Southern Bantu Homestead. *Africa, 50*(1), 8–23.
Oliver, P. (1997). *Encyclopedia of vernacular architecture of the World*. Cambridge, UK: Cambridge University Press.
Union Government. (1955). *Summary of the report of the commission for the socio-economic development of the Bantu areas within the union of South Africa* (pp. 50–51). Pretoria, South Africa: UG61/1955.
Walton, J. (1956). *African village*. Pretoria: Van Schaik.

Architecture in Suakin

Jacke Phillips
SOAS, University of London, London, UK

Traditional architecture, developed over time by communities in response both to ecological conditions and availability of materials, differs considerably from place to place. Conditions along the Red Sea coast combine excessively salty-humid daytime heat and strong sunlight, cold nights, strong but predictable winds, sandstorms, and rare but torrential rainfall. The particular architecture developed in response to these conditions is collectively known as the Red Sea Style, which varies slightly through local initiatives, resources, and conditions. One of the few exemplar locations is the island-port-city of Suakin on its Sudanese coast. The heavily restored old town of Jeddah survives to a greater extent and is still inhabited, but Suakin's abandonment in the early twentieth century and its detailed recording especially in the early 1950s allow its preservation to best represent the style. Sadly, its buildings have now largely collapsed over the past century or so, following the islanders' gradual migration to Port Sudan after 1909. Nonetheless, a few are now being investigated archaeologically and some are undergoing restoration, enabling direct study of construction techniques and a glimpse of the island's underlying architecture. Greenlaw's drawn record, the most accessible and most cited, sadly is not always confirmed in excavation.

Suakin's geographical situation is highly unusual: this low and now artificially oval coral island lies in a lagoon at the end of a long open channel from the Red Sea through a thick coral reef (Fig. 1). A long seasonal stream from the Red Sea hills farther inland annually deposits sandy sediment on the flat, almost desert plain behind the reef. These physical circumstances make it a virtually ideal harbor and port and are the key to its longevity. Structures recorded in detail on the island and the *Geyf*, its mainland extension, are as known in the nineteenth–early twentieth centuries, but archaeological evidence for earlier foundations and even earlier buildings recently has been exposed below. Today, the island is just over 3.1 m above sea level, with eleventh-century occupation found just above the present water table, but written records indicate its continuous existence from at least a century earlier.

The earliest excavated levels near the island's center have revealed postholes indicating wooden post-and-wattle structures. No adaptive features can be projected from the surviving evidence, but they may compare with traditional reed-and-branch huts ('*ushshash* and other names) still in use elsewhere along both coasts today. This building technique continued to be erected after the earliest masonry structures appeared in early sixteenth-century levels that broadly coincide with the arrival of the Ottomans in 1517. João de Castro's map (1541) already depicts the island crowded with two- and three-storeyed masonry buildings, together with a tall chimney-like tower often identified as the minaret of a mosque. It is the masonry structures (ubiquitous from this time onwards) that represent the "Red Sea Style" at Suakin.

Building façades faced toward the island's shore, to catch as much breeze as possible. The entire shoreline consisted of a repeatedly extended quay installation of mostly coralline

Architecture in Suakin, Fig. 1 Aerial view of Suakin island town, showing the radiating arrangement of buildings and streets. Government buildings, structures dedicated to the caravan trade, and mosques are mostly at the right side of the island. It is connected to the *Geyf* by a causeway at the top (© SARS Greenlaw Archive GRE P034.06)

blocks. Roads and passages emanated from its central *suq* in an irregular, haphazard manner with many irregular open squares due to differential property ownership. Some 279 still privately owned properties are registered today, in addition to the government buildings. Each was surrounded and defined by a boundary wall. Freshwater had to be brought from the mainland and stored in cisterns, and (at least from the nineteenth century but probably earlier) common vertical shafts from roof to ground level and underground piping drained household wastewater. Drainage holes with guttering on roofs also provided rainwater. It was not until 1878 that a causeway was built, linking the island to the mainland (Figs. 1–2).

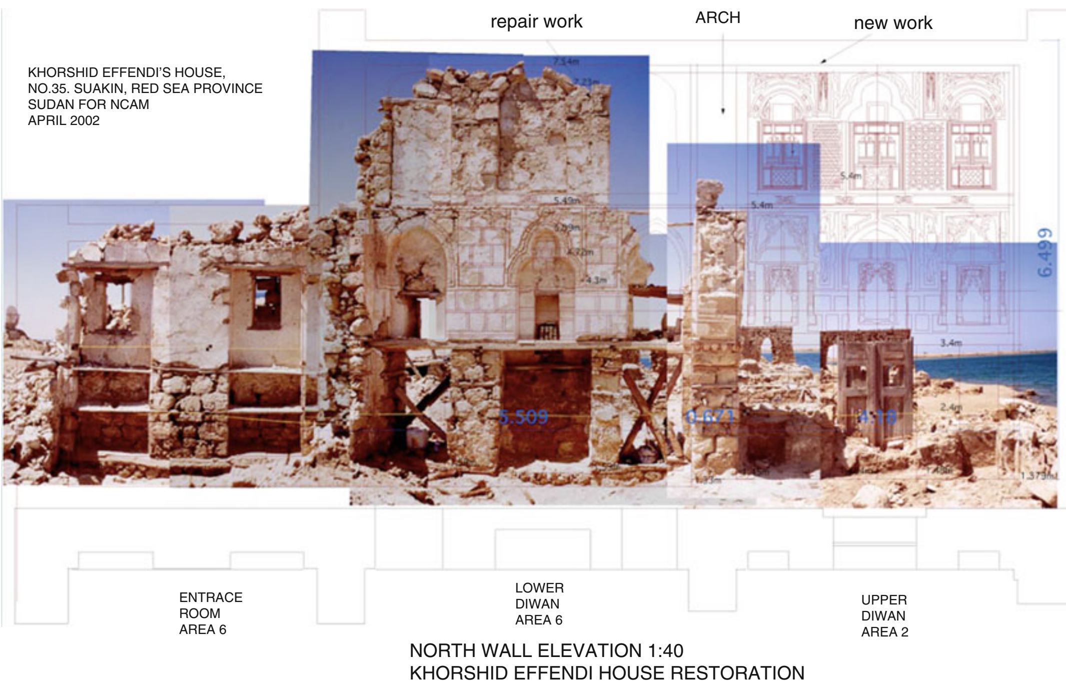
The vast majority of recorded buildings were private houses of varying scale, in inappropriately named Turkish or Ottoman style (see Um, 2010, pp. 42–43) that followed general Islamic principles and requirements especially in terms of internal segregation and privacy. They combined open yards, courtyards, and breezeways within, usually having two- to three-storey interiors accessed by one or more stairwells up to the roof that also was utilized. Most individual rooms had at least one wall against an unroofed space. Commercial storerooms at ground level were a regular feature of the large traders' establishments; those on the immediate shoreline could accept goods directly from ships docked on the quay. Most structures as recorded postdate the arrival of the Egyptian army and bureaucracy in 1821. Many nineteenth-century government buildings and houses had transplanted but less appropriate Egyptian features, but the two mosques, customs installations, and the central *suq* shops are traditional constructions. The study of *Beit Khorshid Effendi* underlines the point that all structures would have been continuously modified, extended, and repaired over their lifetimes as changing needs dictated. The only certain early structure recorded is the *Beit el-Basha*, with archaeologically confirmed sixteenth-century foundations as Matthews and Greenlaw had thought, but their widely cited "three-period" phasing must be considered problematic. Original construction dates cannot yet be quoted with any accuracy on architectural criteria alone, nor can any subsequent modifications. The nineteenth-century *Muhafaza* structure, for example, clearly incorporates an older house of uncertain date and itself exhibits considerable evidence for constant modification and structural repair over its lifetime. Nonetheless, both mosques should be of early date, although an unidentified coralline building revealed in a limited trench below the *Shafa'i* mosque courtyard suggests the present structure may have replaced an earlier mosque.

Architecture in Suakin, Fig. 2 Street scene of several houses, including *Beit Sayd el-Safi* (House 225) on the left, showing the variety of *rawashin* and other exterior decoration. *Shish*-work is best seen at center left. Note the added vertical bars on the ground-level *rawashin* and windows and the deteriorating walls at ground level (© SARS Greenlaw Archive GRE P034.01)

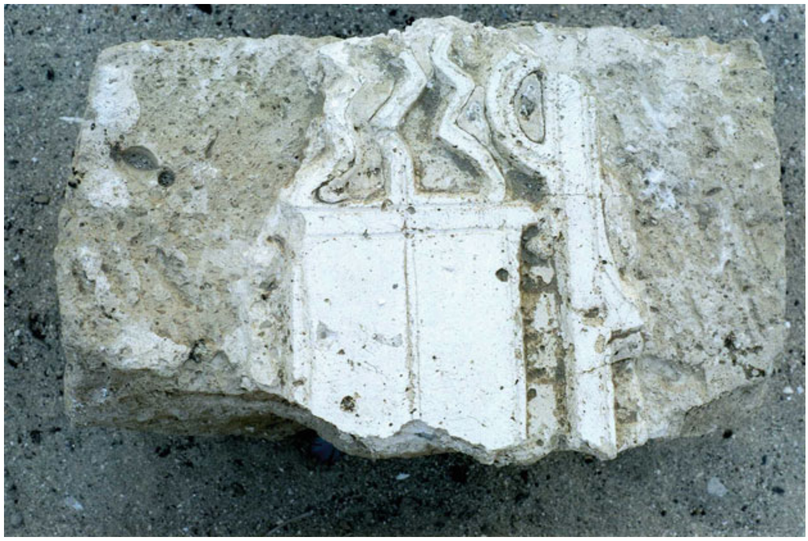
Buildings were constructed of porous coralline limestone (coral rock), quarried from the reef south of the channel. Most were roughly shaped into similar-sized blocks with only the back side left as is. Coral from the inner reef, of finer texture, was smoothly ashlar-cut and used for some structural and focal features such as door hoods and for exterior carved decoration (Fig. 3). Building foundations were necessarily rather shallow but stable, consisting of oversize coral rocks atop coral bedrock. Walls were laid in courses with the inner and outer vertical surfaces flat, then infilled with coral rubble. They were strengthened using long wooden timbers and integral cross bracing at specific intervals and

Architecture in Suakin, Fig. 3 Loose decorative blocks recovered from House 184 (*Beit el-Basha*) during Suakin Project excavations (Photographed by Laurence Smith, © Suakin Project)

Architecture in Suakin, Fig. 4 View of the upper storey of a partly collapsed house on Suakin Island, exposing its construction techniques. Note the large dressed surface blocks of the wall and its rubble infill and thick multilayered upper floor. The light-green rectangular wooden beams in the foreground are rectangular beam fragments of a late *rawshan* (likely not from this house) and the rectangular roof and floor beams used during the island's more recent lifetime; earlier structural beams are round in section (Photo Jacke Phillips)



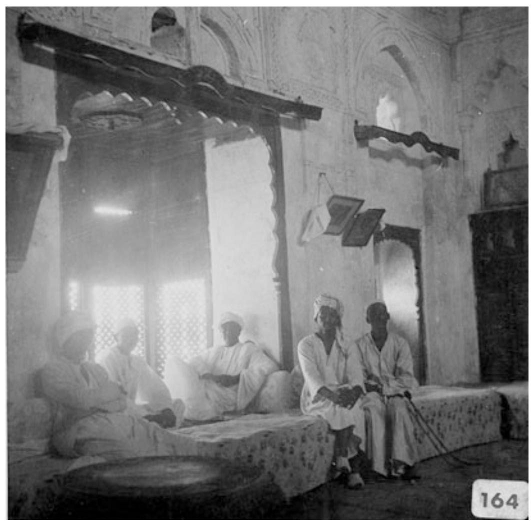
Architecture in Suakin, Fig. 5 Composite photograph of the north wall of House 35 (*Beit Khorshid Effendi*) as cleared in 2002 by the Suakin Project, with added line drawing of the original decorative plasterwork and its basic plan. The lower *diwan* is in the center, with the (missing) upper *diwan* at right and at left the entrance room (from the interior courtyard, a storeroom) with niches and inbuilt shelving. It is the only wall of the house still standing; the crossed poles of doorways/windows were inserted by the excavators to prevent entry by tourists. The central niche later was realized to be an entrance doorway, blocked by the owners during its lifetime. Note the severe deterioration due to nearly a century of neglect (Photographs and compilation Michael Mallinson, © Suakin Project)



Architecture in Suakin, Fig. 6 Individual block recovered by the Suakin Project from the upper *diwan* of House 35 (*Beit Khorshid Effendi*), with added pink plaster to infill the relief decoration (SKN02/C17, photographed by Laurence Smith, © Suakin Project)

features, including staircases and floors. Floors and roofs were usually laid palm canes over timbers, covered with palm fiber and rendered, although stone-flagging is known at ground level (Figs. 4–5). Lime mortar and render, composed mostly of powdered coral, sealed all wall surfaces and most structural timbers, reflecting the sunlight externally and brightening interior spaces, although most external timbering was exposed to allow later maintenance. Interior walls were thickly rendered, with the most important public rooms of many houses highly decorated in a wide variety of mostly geometric designs in deep relief. The elaborate relief decoration of the *Beit Khorshid Effendi diwan* was partly infilled with a contrasting soft pinkish plaster (Fig. 6). Other houses used dark pebbles decoratively inset into wet plaster, and several employed painted designs. Interior wall niches and cupboards (some with integral shelving and added doors) were framed in wood or the finer coralline, mostly rendered over. Some interior exposed woodwork such as doors, windows, niches, and shelving may have been painted. Both interior and exterior *mastaba* benches also were integral (Fig. 7).

The glory and most distinctive feature of these houses was, however, the *rawashin* (sing. *rawshan*), projecting balcony windows intricately pieced together from separate wooden



Architecture in Suakin, Fig. 7 Interior of House 35 (*Beit Khorshid Effendi*), in the upper *diwan* showing the extensive decorative plasterwork and use of structural and decorative woodwork. The men are seated on the *mastaba* (integral bench), partly in the alcove created by the projecting *rawshan* of the house façade behind them. Note the filtered light created by its *shish*-work (© SARS Greenlaw Archive GRE P102.02)

planks almost exclusively using mortise-and-tenon joints with wooden pegs (Figs. 2 and 8). Traditionally painted red and green, with individually shaped flat decorative elements added to external flat vertical surfaces to create shade patterns, they contrasted strongly with the buildings'

Architecture in Suakin, Fig. 8 Color view of *rawashin* as reerected in the *Muhafaza* courtyard in the 1930s, removed from deteriorating private houses on the island. These are late examples of simplified and inferior construction but indicate the contrasting colors typical of the decorative woodwork involved. These colors also are indicated in Fig. 2 (© SARS Greenlaw Archive GRE P147.03)

white walls. *Rawashin* incorporated large areas of overlapping, creatively shaped thin wooden strips that, when assembled, produced elaborate open latticework panels (*shish*) within an extensive structural framework. They served multiple functions, the *shish* allowing cross-ventilation, air conditioning, and sunlight filtration into the interior rooms while also ensuring privacy. Sliding sash-panels and shutters allowed greater control of wind and sun. Those on the ground floor were barred for security. *Rawashin* also provided a deep internal seating platform for social occasions (Fig. 7). Smaller windows also employed these same functional features to varying degrees, depending on size and location. The simplest and also the internal ventilation grilles consist merely of framed *shish*-work. All elements were individually hand carved.

Recent limited analyses of Suakini architectural wood have identified almost exclusively indigenous *acacia* and *ficus* hardwoods for smaller structural timbering and carved elements and local hollowed-out palm wood for guttering. Other than *Shorea* hardwood imported from Southeast Asia for *shish*-work, virtually no other imported wood has been identified. Java teak, widely cited in print as imported from the same region for construction use at Suakin, has not yet been identified among the analyzed wood. This strongly suggests many wooden features were locally produced, not imported ready-made as sometimes suggested.

Regular maintenance was necessary to combat weathering, loss of render, and rising damp, especially following rainstorms. Even the earliest nineteenth-century photographs all illustrate the deterioration of (especially) the base and lowest courses even of well-maintained, inhabited buildings (Figs. 2 and 4). Lack of maintenance after the island's abandonment is the principal cause of still-ongoing building collapse and the present ruined state of the island.

References

Abdulla Telmesani, Fuad Sarouji & Adnan Adas (2009). *Old Jeddah. A Traditional Arab Muslim City in Saudi Arabia*. [Jeddah]: Jeddah Historical Area Preservation Department.

Aljofi, E. (2005). The potentiality of reflected sunlight through Rawshan screens. In M. Santamouris (Ed.), *Proceedings of the 1st international conference on passive and low energy cooling for the built environment, PALENC 2005, 19–21 May 2004, Santorini, Greece* (II, pp. 817–822). Santorini: Heliotopos Conferences. Retrieved from http://www.inive.org/members_area/medias/pdf/Inive/palenc/2005/Aljofi.pdf

Breen, C., Forsythe, W., Smith, L., & Mallinson, M. (2011). Excavations at the medieval Red Sea port of Suakin, Sudan. *Azania, 46*, 205–220.

Calia, M. (1999). Suakin. Memory of a city. *Environmental Design: Journal of the Islamic Environmental Design Research Centre, 1–2*, 192–201. Retrieved from http://archnet.org/system/publications/contents/4417/original/DPC0899.pdf?1384785432

Greenlaw, J.-P. (1976). *The coral buildings of Suakin*. Stocksfield/London/Boston: Oriel Press.

Greenlaw, J.-P. (1995). *The coral buildings of Suakin: Islamic architecture, planning, design and domestic arrangements in a Red Sea Port*. London/New York: Kegan Paul International. (Reprint of 1976 edition).

Hansen, E. (1973). *Preservation of Suakin October – November 1972*. Retrieved from http://unesdoc.unesco.org/images/0000/000066/006626eo.pdf

Hinkel, F. W. (1992). *The archaeological map of the Sudan (Vol. VI), The area of the Red Sea coast and Northern Ethiopian Frontier*. Berlin: Akademie Verlag.

Hulbert, H. R. (1938). Letter to editor. *Sudan Notes and Records, 21*, 343–344.

King, G. (1998). *The traditional architecture of Saudi Arabia*. London/New York: I. B. Taurus.

Mallinson, M. D. S. (2012). Suakin: Paradigm of a port. In D. A. Agius, J. P. Cooper, A. Trakadas, & C. Zazzarro (Eds.), *Navigated spaces, connected places. Proceedings of Red Sea project V held at the University of Exeter 16–19 September 2010* (British foundation for the study of Arabia Monograph, 12/BAR International Series, Vol. 2346, pp. 159–172). Oxford: Archaeopress.

Mallinson, M. D. S., Smith, L. M. V., Breen, C., Forsythe, W., & Phillips, J. (2009). Ottoman Suakin 1541 – 1865: Lost & found. In A. Peacock (Ed.), *The frontiers of the Ottoman World* (Proceedings of the British Academy 156, pp. 469–492). Oxford: Oxford University Press.

Matthews, D. H. (1953). The Red Sea style. *Kush, 1*, 60–86.

Matthews, D. H. (1955). Suakin postscript. *Kush, 3*, 99–111.

Orbasli, A. (2009). The conservation of coral buildings on Saudi Arabia's northern Red Sea coast. *Journal of Architectural Conservation, 15*, 49–84.

Peacock, A. C. S. (2012). Suakin: A Northeast African port in the Ottoman empire. *Northeast African Studies, 12*(1), 29–50.

Phillips, J. S. (2012). Beit Khorshid Effendi: A 'trader's' house at Suakin. In D. A. Agius, J. P. Cooper, A. Trakadas, & C. Zazzarro (Eds.), *Navigated spaces, connected places proceedings of Red Sea project V held at the University of Exeter 16–19 September 2010* (British Foundation for the Study of Arabia Monograph, 12/BAR International Series, Vol. 2346, pp. 187–199). Oxford: Archaeopress.

Rhodes, D. (2011). The nineteenth-century colonial archaeology of Suakin, Sudan. *International Journal of Historical Archaeology, 15*, 162–189.

Roden, D. (1970a). The twentieth century decline of Suakin. *Sudan Notes and Records, 51*, 1–20.

Roden, D. (1970b). *The twentieth century decline of Suakin* (Sudan project series, 1). Khartoum: Khartoum Research Unit.

Smith, L. M. V., Mallinson, M. D. S., Phillips, J. S., Adam, A. H., Said, A. I., Barnard, H., et al. (2012). Archaeology and the archaeological and historical evidence for the trade of Suakin, Sudan. In D. A. Agius, J. P. Cooper, A. Trakadas, & C. Zazzarro (Eds.), *Navigated spaces, connected places proceedings of Red Sea project V held at the University of Exeter 16–19 September 2010* (British foundation for the study of Arabia monograph, 12/BAR international series, Vol. 2346, pp. 173–186). Oxford: Archaeopress.

Um, N. (2010). Reconsidering Red Sea architecture: Building traditions at the Hinge between the Mediterranean Sea and the Indian Ocean. *Traditional Dwellings and Settlement Review Working Papers Series, 226*, 37–60.

Um, N. (2011). Greenlaw's Suakin: The limits of architectural drawing and the continuing lives of buildings in coastal Sudan. *African Arts, 44*(4), 36–51.

Um, N. (2012). Reflections on the Red Sea style: Beyond the surface of coastal architecture. *Northeast African Studies, 12*(1), 243–271.

Architecture in Sumba

Irene Doubrawa
Vienna University of Technology, Vienna, Austria

The architecture of the Indonesian island of Sumba is to this day strongly based on vernacular traditions, which include buildings of rectangular layout, constructed from wood and bamboo with large, grass-thatched roofs. Today less than one fifth of Sumba's population live in and around one of the two towns Kota Waingapu and Kota Waikabubak on the island, while the majority of the population lives in rural settlements ("City Population," 2014). The location of the villages was traditionally dominated by the need to defend the settlements. Thus, they were preferably located on hilltops and were surrounded by thick vegetation, thorny hedges, fences, and stone walls (Forth, 1981, pp. 46–50; Kuipers, 1998, pp. 24–25, 30–31). Today many of these settlements remain in their original location, but since the need for defense has declined, numerous families have moved closer to their fields, to water sources, and to roads, and larger settlements or towns have formed around clusters of traditional villages.

Within the traditional village, the houses are the most prominent buildings. They are arranged

Architecture in Sumba, Fig. 1 Village in West Sumba. The houses are arranged around a narrow square. In the center of the village, stone graves and a small *marapu* house are set on low stone platforms (©author)

in two rows facing each other across a longish square that may be quite narrow due to the limited space on top of the hills. The orientation of the village follows the natural features of the landscape. Since on Sumba many rivers and mountain backs run along a north–south axis, the villages are also often extended along this axis. As a consequence, the houses either face toward the east or the west, resulting in a "morning side" and an "afternoon side" of the village (Adams, 1974, pp. 326–327). In the Sumbanese perception of space, houses and villages are oriented according to the flow of rivers (upstream–downstream) and the course of the sun (sunrise–sunset) (Forth, 1981, pp. 50–57). As in many Southeast Asian cultures, this spatial orientation is imbued with a strong symbolical meaning and reflects the cosmological concept of the Sumbanese people (Forth, 1981, pp. 66–72).

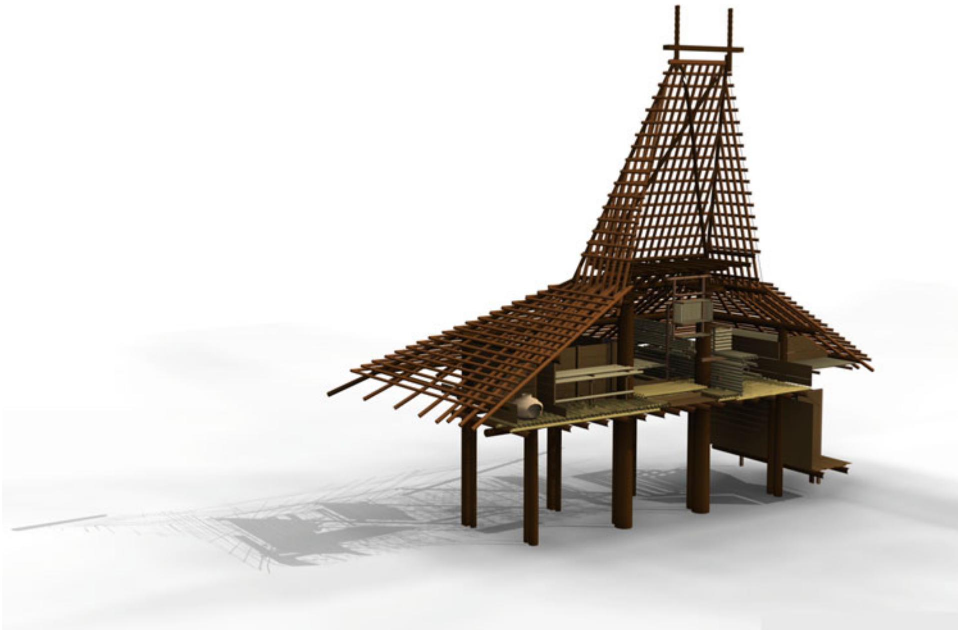
For moving through the village, walkways are established along the front sides of the houses. These may be used for everyday activities, such as drying crops or as playing areas for children, together with the space directly in front of the house. During ceremonies, the whole village square is used for dancing, sacrifices, and meetings. The central village space, which is often marked through a low wall or platform, is considered sacred, and parts of it may only be entered by certain people and on certain occasions. In this central village space, different sacred structures are located, which may include village altars; stone statues; the *marapu* house, which serves as a village temple; and traditionally also a skull tree, where in former times skulls obtained through headhunting were displayed in order to ritually renew the health and fertility of the community (Hoskins, 1996a, p. 224). Furthermore, the graves of important ancestors can be found in the center of the village, located as close as possible to the houses of their heirs to ensure their continuing guidance in all important matters (Fig. 1). The rectangular table- or sarcophagus-shaped graves are made from stone – or more recently from concrete – and some feature elaborately carved headstones. The monolithic stone slabs, weighing up to several tons, are to this day dragged by hand from the stone pit to the gravesite. The stone graves are symbols of status, since their construction and the dragging of the stones require large labor forces and are accompanied by expensive ceremonies (Gunawan, 2000, pp. 36–37; Kurniawan & Pramanasari, 1994, pp. 349–352; Tjahjono, 1998, p. 49; S. Lernet, personal communication, December 2007) (Fig. 2).

Architecture in Sumba, Fig. 2 Stone grave with a delicately carved headstone, depicting symbols and ornaments, animals, and a human figurine (©author)

Along the sides of the square, two types of houses, *uma*, are aligned, which feature a rectangular or almost square layout. Both types of houses serve as dwellings and are similar in layout, but one type is additionally believed to serve as home for the ancestors' spirits and is therefore subject to a deep spiritual meaning and frequent ceremonies. The two types of houses are distinguished by their roof shapes. The *uma kamudungu* ("bald, bare house") features a simple hipped roof, while the *uma mbatangu* ("bridge house") (Forth, 1981, p. 23) features an extremely high and steep hipped roof, which is surrounded on all four sides by a roof area of lower pitch. This towering central roof area of the *uma mbatangu* is where the spirits of the ancestors are believed to reside and where the rice crop and heirlooms are stored. It is thus the most sacred part of the house with access limited to only one or two members of the family.

In its vertical composition, the Sumbanese house follows the typical Southeast Asian concept of the house as a tripartite structure (e.g., Lehner, 2008, pp. 9–12; Waterson, 1990, p. 100). Thus, the space between the posts, which form the substructure underneath the raised floor, is considered the zone for animals and is often used as a stable. In many Southeast Asian cultures, this area underneath the house is avoided altogether, since it is considered the area of unkind earth spirits. Above the substructure, the middle zone is the space where the people live on a raised floor. The raised floor not only provides a dry and safe living area away from all sorts of animals but also an area lifted off the spiritually ambivalent ground. Finally, the roof space is associated with the ancestors' spirits. On Sumba, as in many other Southeast Asian cultures, this upper zone is a sacred space within the house. During ceremonies, the spirits of the ancestors are believed to descend to the middle zone, the space of the people, to support and guide them in decision-making and other matters.

Inside the *uma mbatangu*, four large, wooden posts that are often adorned with carved, geometrical patterns support the towering roof. The posts are earthbound and reach all the way up to the attic that supports the central part of the roof. On their upper ends, they carry large, wooden disks that are also often covered with carvings. Similar wooden disks can be found in granaries of many cultures worldwide to prevent rats and other vermin from reaching the stored crops. Inside the Sumbanese house, these disks have lost their function as rat guards, since vermin may reach the roof via any of the other posts supporting the outer part of the roof, but they may point to the possible origins of this house type as a granary. The use of granaries as temporary or permanent dwellings for boys, men, or visitors and their subsequent development into proper dwellings by enlargement and addition of platforms can be observed in many cultures of the neighboring islands, such as the Donggo on Sumbawa, the Dagada in East Timor, the Ema in West Timor, and the Toba Batak on Sumatra or on Alor (e.g., Domenig, 2003, pp. 62–64, 2008, pp. 500–502; Waterson, 1990, p. 53). The Sumbanese house seems to be an even further developed type, where the dwelling fully surrounds the former



Architecture in Sumba, Fig. 3 3D section of an *uma mbatangu*, showing different types of posts supporting floor, roof and attic, the towering roof structure, and the design of the interior space (©R. Humenberger & author)

granary, which is now a fully integrated part of the house but still features rat guards, its own roof construction, and the spiritual meaning that granaries are generally imbued with.

During the construction process of the house, the four central posts are the first part of the house to be constructed. The right front post is raised first, with the other three posts raised proceeding in an anticlockwise direction, i.e., "moving to the right" (Forth, 1981, pp. 27–28). On Sumba, as on some other Eastern Indonesian islands, raising posts in a clockwise direction and thus "moving to the left" is associated with death (Forth, 1981, p. 172; Visher, 2003, p. 344), in contrast to most Asian cultures, where the clockwise movement, for example, in Hindu and Buddhist rituals, is considered the "direction of life" (Lehner & Doubrawa, forthcoming, p. 28). Once the central posts are planted, the attic and the towering part of the roof are constructed. Thus the central part of the house is finished, before two further concentric series of posts supporting the outer, less-sloping part of the roof are placed around the four central posts. Only when the construction of the roof is finished, separate posts supporting the raised living area are installed, and the living area is finished. Walls are installed along the second series of posts, forming a large space inside the house with the four central posts being the only vertical structural elements inside the house. The living area is structured with different floor levels and platforms, each serving certain functions. Light walls or curtains may be added to separate private rooms for sleeping, which seems to be a rather recent development. Depending on time management, the roof may be thatched before or after the living area has been constructed (H. Ndamanggilik, personal communication, April 2007) (Fig. 3).

The building material used for the main structure of the house is wood, traditionally of round sections. Smaller structural elements, such as the rafters, are made from bamboo cane. Tightly tied bamboo canes are also used to form the floor as well as internal platforms, partitions, and shelves. Floors and walls are today often made of timber

Architecture in Sumba, Fig. 4 Detail showing different types of lashed joints to connect the beams and roof structure of a house (© author)

boards that allow the use of western-style furniture. All elements are traditionally tied together with rattan or lianas, structurally forming a three-dimensional grid that possesses flexibility and at the same time a high stability (Fig. 4). This makes the Sumbanese house extremely well suited for the frequently occurring earthquakes. The earthquake resistance is additionally enhanced through the storage of rice in the attic inside the towering roof. Several tons of rice may be kept in the attic at times, which accounts for a heavy and stable core structure that is surrounded by the compact, lightweight, and flexible rest of the house (I. Dapawole, personal communication, April 2007). In terms of earthquake resistance, this is an ideal structural concept.

The large roof of the house is traditionally thatched with bundles of *alang alang* grass, which are tied to the battens and fixed along the ridge with a timber board and two prominent wooden "horns." Today, instead of grass, corrugated iron may be used as roofing material. In contrast to metal sheets, the traditional thick layer of grass provides good insulation against the heat and muffles the sound of the heavy rain. The roof features low eaves that may reach almost to the raised floor, thus blocking all direct sunlight from the interior of the house and the verandas and providing shaded, cool, and dry areas for living and working, independently of the prevailing weather. The interior of the house remains rather dark. Only little natural light filters through the floor and walls, and the only large openings in the walls are two doorways.

The lack of light inside the house is a typical feature of many house types in Indonesia. The Sumbanese house features one or two verandas that provide well lit but shaded space in front of the house and that are used for nearly all daily activities. They serve as transitional areas between the public village space and the private interior of the house and are used for receiving guests, meetings and discussions, working, and generally spending time during the day. While more or less every person is allowed to enter the veranda after having requested to do so, access to the interior of the house is much more limited (Fig. 5).

The interior of the house is divided into two parts with different functions. In West Sumba this division is also of physical nature, and a low wall of bamboo runs from the front to the back of the house. While the left side of the house (as seen facing the front of the house) is considered the private part of the house and is closely associated with women, the right side of the house is of semiprivate character and is closely associated with men (H. Ndamanggilik, personal communication, April 2007). This gendered differentiation does not refer to the actual users of each side but rather to the function and its respective connotation within Sumbanese society. Thus the private

Architecture in Sumba, Fig. 5 Front veranda decorated with skulls of buffaloes and pigs that were sacrificed during ceremonies. This decoration represents the wealth and prestige of the house and its owners, who provided the animals (©author)

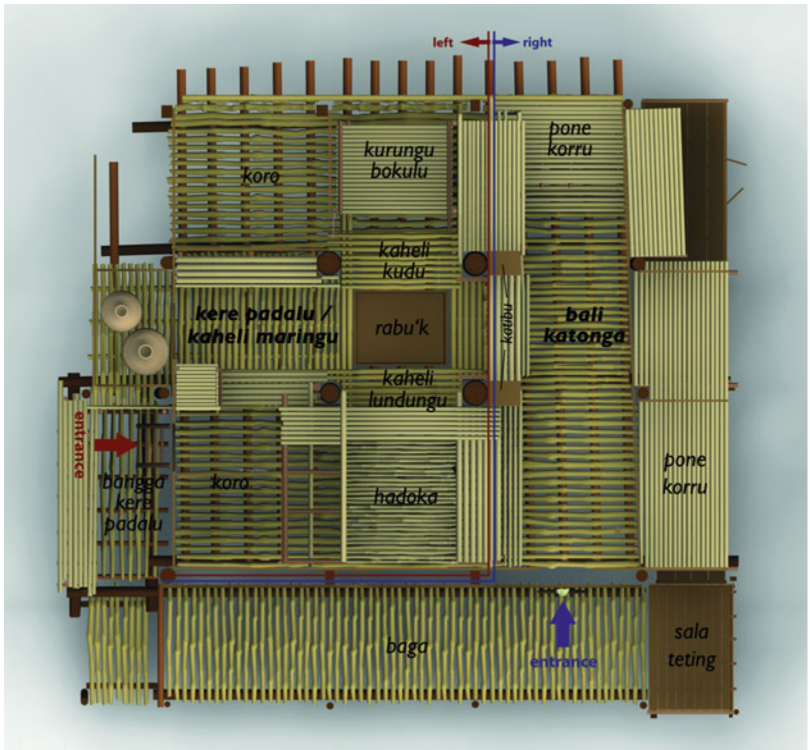
family rooms and platforms are located in the left side of the house, which is used for sleeping, working, cooking, and the storage of personal possessions, tools, and the water jars, and may only be entered by family members. In Sumbanese society these functions are closely associated with women, therefore leading to this side of the house being considered the female side of the house. The right side of the house is used for ceremonies and as sleeping area for guests and can thus be seen as a semiprivate space. Since in Sumbanese society men are expected to take care of the communication with the outside world, this side of the house is considered to be male.

Each side of the house is entered through a separate door, which can be reached via a veranda. While the door to the male side of the house is always in the front façade and can be reached via the front veranda, the door to the female side of the house, and therefore the respective veranda, may either be in the left half of the front façade or in the left or the rear side of the house. In houses in West Sumba, where the left and the right side of the house are divided through a low wall, one has to leave the house and reenter it through the other door, in order to reach the other side of the house (Fig. 6).

The center of the house is occupied by a large fireplace with three hearth stones. Traditionally the fireplace is the only source of light inside the house. It is not only used for cooking, but is also the center of many ceremonies concerning the house and the clan. The four large posts surrounding the fireplace define the seating order during ceremonies and symbolize the unity of different members of society (Gunawan, 2000, p. 42; Forth, 1981, p. 27; H. Ndamanggilik, personal communication, April 2007). Offerings for the ancestors are placed on the disk-shaped rat guards on the upper ends of the four posts. The four posts, the attic, and the fireplace form the physical, functional, and spiritual center of the house (Fig. 7).

The architectural traditions have been widely retained, and to this day, many examples of the above-described houses and villages continue to exist. New materials, such as corrugated iron sheets and concrete, have been introduced to the island, but the number of timber and bamboo buildings is still very high and people continue to live in the traditional houses. Consequently the house still is of central meaning for the Sumbanese society. The term *uma* not only describes the physical building, but also the family or clan feeling connected to and living in a certain house. The people in the houses are related to each other resulting in "mother houses" and "child houses." Even if a house has been abandoned and has collapsed, the people will still try to rebuild it as soon as possible (Gunawan, 2000, pp. 56–57). Thus, the idea of

A



Architecture in Sumba, Fig. 6 Ground plan of a house in West Sumba including the terms for each area of the house that each serves a designated function. The four central posts surrounding the hearth (*rabu'k*) can clearly be seen. Note the separate entrances to the left and the right side of the house (© R. Humenberger & author)

Architecture in Sumba, Fig. 7 Interior of a house in West Sumba, showing the four central posts with wooden disks on their upper ends. They surround the hearth with three hearthstones and a rack for storing wood, food, and cooking utensils. Note the different floor levels and platforms, all constructed with tied bamboo cane (© author)

the house continues to exist through the memory of the connected people and may even lead to the rebuilding of the physical structure.

The importance of the traditional house for the people in Sumba has led to a high preservation rate of buildings following traditional concepts and in many cases even to the construction of new houses, even though the required timber has become hard to obtain. Nevertheless, the perpetual use and rebuilding of these houses ensure the continuity of the spiritual and cultural identity of the Sumbanese people.

References

Adams, M. (1974). Symbols of the organized community in East Sumba, Indonesia. *Bijdragen tot de Taal-, Land- en Volkenkunde, 130*(2/3), 324–347.

City Population. (2014). *Indonesia – Districts – Nusa Tenggara* (GIS Data file). Retrieved from http://www.citypopulation.de/php/indonesia-nusatenggara-admin.php

Domenig, G. (2003). Consequences of functional change: Granaries, granary-dwellings, and houses of the Toba Batak. In R. Schefold, G. Domenig, & P. Nas (Eds.), *Indonesian houses: Tradition and transformation in vernacular architecture* (pp. 61–98). Leiden, NL: KITLV Press.

Domenig, G. (2008). Round houses of Indonesia: A comparative study. In R. Schefold, P. J. M. Nas, G. Domenig, & R. Wessing (Eds.), *Indonesian houses (Vol.2): Survey of vernacular architecture in western Indonesia* (pp. 487–522). Leiden, NL: KITLV Press.

Faculty of Engineering, University of Indonesia. (1994). In *Proceedings from International Seminar on Vernacular Settlement: The role of local knowledge in built environment*. Depok, ID: Faculty of Engineering, University of Indonesia

Forth, G. L. (1981). *Rindi: An ethnographic study of a traditional domain in eastern Sumba*. The Hague, NL: Martinus Nijhoff.

Gunawan, I. (2000). *Hierarchy and balance: A study of Wanokaka social organization*. Canberra, AU-ACT: Department of Anthropology Research School of Pacific and Asian Studies, The Australian National University.

Hoskins, J. (1996a). The heritage of headhunting: History, ideology, and violence on Sumba, 1890–1990. In J. Hoskins (Ed.), *Headhunting and the social imagination in Southeast Asia* (pp. 216–248). Stanford, CA: Stanford University Press.

Hoskins, J. (Ed.). (1996b). *Headhunting and the social imagination in Southeast Asia*. Stanford, CA: Stanford University Press.

Kuipers, J. C. (1998). *Language, identity, and marginality in Indonesia: The changing nature of ritual speech on the island of Sumba*. Cambridge, GB: Cambridge University Press.

Kurniawan, K. R., & Pramanasari, P. A. (1994). The spiritual path of the gravestone moving ritual in the west Sumbanese settlement tradition: The case of Anakalang. In Faculty of Engineering, University of Indonesia, *Proceedings from International Seminar on Vernacular Settlement: The role of local knowledge in built environment* (pp. 343–354). Depok, ID: Faculty of Engineering, University of Indonesia.

Lehner, E. (2008). Architekturtradition und ethnische Identität: Bautypen der Karo-Batak und Toba-Batak auf Sumatra. *archimaera: architektur.kultur.kontext.online, 1*, 7–22.

Lehner, E., & Doubrawa, I. (2015, forthcoming). *Dwelling space and gender: Aspects of social traditions in nomadic and sedentary cultures*. Wien, AT: IVA-ICRA Institute for Comparative Research in Architecture.

Schefold, R., Domenig, G., & Nas, P. (Eds.). (2003). *Indonesian houses: Tradition and transformation in vernacular architecture*. Leiden, NL: KITLV Press.

Schefold, R., Nas, P. J. M., Domenig, G., & Wessing, R. (Eds.). (2008). *Indonesian houses (Vol.2): Survey of vernacular architecture in western Indonesia*. Leiden, NL: KITLV Press.

Tjahjono, G. (1998). *Indonesian heritage: Architecture*. Singapore, SG: Archipelago Press.

Visher, M. (2003). The two-faced Palu'é house: Multiple orientation and structural transformation in an eastern Indonesian dwelling. In R. Schefold, G. Domenig, & P. Nas (Eds.), *Indonesian houses: Tradition and transformation in vernacular architecture* (pp. 333–368). Leiden, NL: KITLV Press.

Waterson, R. (1990). *The living house: An anthropology of architecture in South-East Asia*. London, GB: Thames & Hudson.

Architecture in the Andes: Domestic Architecture

Jason Leigh Toohey
Department of Anthropology, University of Wyoming, Laramie, WY, USA

The domestic built environment, encompassing domestic houses and other open spaces including patios and plazas, has been of interest to Andean archaeologists for over 100 years. For nearly as long, though, the archaeology of the everyday domestic realm and its architecture has taken a backseat to the study of temples and tombs. That said, since the 1970s, some have shifted focus to the archaeology of everyday life, which in most cases takes place in and around the quotidian built environment, which is often demarcated and internally differentiated by the structure of domestic architecture. Domestic architecture in the Andes and elsewhere can often be broken down between common and elite, and these will be discussed separately here. I wish to present the range of domestic architectural patterns in the Andes chronologically and regionally, with primary focus given to the patterns on the Pacific coast and the central Andean highlands. I then discuss the theoretical arguments that have focused on domestic architecture.

Some of the earliest discussions of households and domestic architecture come from the north and central coasts (Donnan, 1964; Willey, 1953). In the past 30 years, though, an increased interest in the archaeology of the everyday has led some in the Andes to focus on the analysis on the household with studies of household- and community-level architectural patterns (Moore, 2012; Nash, 2009).

Early domestic architecture in the Andes was in general quite ephemeral and difficult to see or recover in the archaeological record. Over the past 4,000 years, though, a wide range of variability in domestic architectural patterns and styles has developed in the Andes on both the coast and in the highlands.

Coastal Patterns

On the coast of Peru, perhaps the most ubiquitous and long-lasting domestic architectural tradition involves the construction of *quincha* (wattle and daub) walled structures. This form of construction is economical and common in many regions of the world; walls are built from branches or reeds woven through thin vertical branches or sticks, which are inserted into linear rows in the ground. Structure corners are often formed with larger diameter vertical posts. In many cases, but not all, clay or mud is then applied to these walls, creating a relatively durable wall. Quincha has been used for several thousand years for the construction of commoner domestic houses on the coast and is still used today. Slightly more complex adaptations will have one or more foundation courses of cobbles or adobe bricks with perishable walls rising from this base.

Some of the earliest evidence for domestic architecture on the coast comes from the Chilca valley. At the preceramic site of Chilca, Donnan (1964) has described a series of conically shaped, semisubterranean domestic pithouse structures with circular or semicircular plans and largely perishable walls, some of which had fallen in and been covered with sand, creating uncommonly well-preserved early domestic contexts. Walls were constructed here of bound cane and wood and occasionally braced with whalebone. At the site of Paloma, also in the Chilca, Quilter (1989) excavated a series of similar dwellings located near to the economically valuable lomas ecological zone.

In many of the western valleys, domestic architecture was placed on terraces, and we have good examples from the Nasca region for domestic constructions with stone and cobble foundations. In their studies of domestic and community organization, Conlee (2000), Van Gijseghem and Vaughn (2008), and Vaughn (2005, 2009) have documented semicircular to semirectangular structures which were organized into groups or households of multiple structures connected by bounding walls and often surrounding a central open space or patio. This general pattern was probably very common in coastal valleys in the north and south from early in time through to Spanish contact.

Middle-class domestic architecture within the Moche polity (or polities) (AD 100–700) has been investigated at a number of sites on the north coast, primarily at large Moche political centers. At sites like the Pyramids at Moche in the Moche valley and Pampa Grande in the Lambayeque valley, middle-class Moche constructed and lived in complex urban zones of adobe domestic architectural spaces interspersed with more public, open plazas and connected by networks of streets and alleyways (Van Gijseghem, 2001). Roofed rooms and open patios were delineated by adobe walls that were often plastered. Domestic styles also included the placement of low benches along some interior walls, some becoming the locations for domestic burials at various points in a structure's life span. Corridors and ramps connected domestic spaces, rooms, and patios. At the large Moche center of Galindo in the Moche valley, Bawden (1982) has intensively studied patterns of commoner and middle-class domestic architecture elucidating fine differences in patterns, construction styles, and materials in analyses of social and community organization and class formation.

Architecture in the Andes: Domestic Architecture, Fig. 1 Zone of U-shaped audiencia rooms within a Chimu Ciudadela at the site of Chan Chan. This is from the Tschudi Complex (Photo by the author)

On the coast, the ubiquitous and relatively simple structures of the common people can be contrasted with the massive and elaborate domestic architectural patterns of elite and ruling classes. During the Late Intermediate Period (AD 1000–1476), the Chimú Empire developed and expanded over much of the north and central coasts of modern-day Peru. It was centered at the capital of Chan Chan in the Moche valley, an urban center built up around a series of ten huge royal *ciudadelas* (Moore, 2005; Pillsbury & Leonard, 2004). These acted as the domestic palaces, administrative centers, and burial places of the Chimú ruling class. Elite domestic architecture here was characterized by the creation of monumental spaces, including large open reception plazas, repeated administrative features called *audiencias* possibly associated with state storage facilities, elaborate niched halls, domestic spaces, and large royal mortuary platform mounds (Fig. 1). Interior movement of people was carefully controlled and monitored through the use of narrow doorways, long narrow corridors, and other architectural features meant to control access. Importantly, all of these features were carefully separated from the outside, everyday world of the masses by battered compound walls which measured nine meters in height (Moore, 1996, 2005; Moseley & Mackey, 1974). The extreme class-based social separation present in Chimú society was thus materialized and made permanent through its physical representation in the built environment of royal domestic architecture.

In the Rimac and Lurin valleys of Peru's central coast during the Late Intermediate Period (AD 1000–1476), the political environment was one of a series of interrelated and possibly confederated complex chiefdoms called the Ychma society. The characteristic architectural feature of the Ychma is the "pyramid with ramp," often considered to have functioned as elite domestic residences (Eeckhout, 1999–2000). These were characterized by large rectangular adobe platform mounds fronted by open plazas or patios and reached by long prominently located ramps. Domestic rooms, cooking areas, and storage spaces were present on the leveled summits of each of these platforms, and each of these complexes was separated from exterior spaces by a defining wall. The private living spaces of the elite were situated on high while semipublic gatherings may have taken place within the plazas below. While at some Ychma sites only a single ramped pyramid residence was present, many existed at the oracle site of Pachacamac, forming an elite domestic zone. In both the Ychma and the Chimú cases, though perhaps the Chimú case is the more extreme, a major function of the elite domestic built environment was to physically separate ruling elites from common people, materializing existing social differences.

Highland Patterns

Although the earliest domestic spaces in the Andean highlands were probably the interiors of caves with space divided into functional zones and features such as hearths and storage pits, later open air settlements of the archaic period saw the construction of domestic houses which were often, but not always, round to semicircular in plan and were set on the surface or semisubterranean in profile. These were created from a perishable superstructure, occasionally with a partial stone foundation. These kinds of relatively ephemeral domestic structures have been seen at sites like Asana (Aldenderfer, 1998) and Jiskairumoko (Craig, 2005; Craig, Aldenderfer, Baker, & Rigsby, 2010) in the south central Peruvian Andes. At Asana, domestic architecture shifted through time from small (~2.5 m diameter) round houses bounded archaeologically by post-molds to slightly larger, semicircular structures also brush covered. Still later, Archaic domestic structures here were oval to rectangular and were probably also walled and roofed with perishable materials (Aldenderfer, 1993b).

Archaeologists have traditionally recognized a generalized dichotomy in the shape of domestic structures in the Andean highlands as opposed to those along the coast, with highland houses generally being round in shape and those on the coast often being rectangular in plan. Although this is generally the case in many regions, there are notable exceptions. Good examples of highland round domestic structures come from the work of DeMarrais (2001) and the broader archaeological project (D'Altroy & Hastorf, 2001) that traced the later prehistory of the upper Mantaro valley through community and household levels of analysis. Domestic architecture here was characterized by circular structures and associated outdoor patios and activity areas, forming patio groups. These complexes ranged from simple, with one or two circular structures, to more complex integrating multiple circular buildings and smaller possible storage structures forming patio groups and possibly representing immediate family units. Large communities were made up of many of these patio groups integrated by a network of corridors. Bermann (1994) described similar spatially distinct circular domestic houses for villages at the southern end of Lake Titicaca in the south central highlands and documented changes to domestic and political economy at the household and community levels. Domestic architecture in the Chachapoyas region of the northeastern slope of the Andes is characterized by large circular stone structures often densely packed into hilltop or ridgeline communities (Fig. 2). Although some of these may have functioned as communal spaces, most were domestic, containing benches, hearths, storage features, and typically domestic suites of artifact classes (Guengerich, 2014).

Immediately west of Chachapoyas, the Cajamarca region of the north central Andes sees another pattern. Here, circular structures are rare to absent and domestic architecture is characterized by the construction of often-agglutinated rectangular stone rooms. Domestic complexes are often located on narrow domestic terraces, with roofed rooms closely associated with open patios and plazas and terraces connected by stone stairways (Julien, 1988). These patterns have been described at sites like Tantarica (Watanabe, 2002) and Yanaorco (Toohey, 2009) (Fig. 3). This pattern of rectangular design in the domestic built environment is also present in the Recuay culture of the Callejon de Huaylas in the central highlands (Lau, 2010).

Elite domestic residences in the highlands can perhaps best be exemplified by the country palaces of the ruling Inka elite such as at Machu Picchu (Salazar & Burger, 2004) and by elite residential structures associated with regional administrative centers like Huanuco Pampa

Architecture in the Andes: Domestic Architecture, Fig. 2 Densely spaced round domestic structures of the Chachapoyas

(Morris, 2004; Morris & Thompson, 1985). The domestic built environment of the Inka ruling elite was designed to integrate an architectural stamp of Inca power within the local physical and social landscapes, utilizing all of the classic architectural features of the Cusco Inca architectural style including the repeated *kallanka* pattern, double jammed doorways, windows, and niches and both cut stone polygonal and ashlar masonry styles.

Theoretical Directions in the Study of Andean Domestic Architecture

From a theoretical standpoint, the investigation of domestic architectural patterns has focused on a number of broad avenues of inquiry. An interest in ethnicity, identity, and interregional interaction has utilized the study of domestic architecture. Patterns in the domestic built environment have also been brought to bear on investigations of community and regional social organization and the study of social differentiation and stratification. Finally, architectural patterns are also utilized in the analysis of domestic economy at both the household and community scales.

Community Organization, Economy, and Social Organization

Household organization and patterns of economy are reflected in the organization of domestic space. Community organization and social organization on the other hand have been documented through the analysis of patterns of domestic architecture and its variability across archaeological sites. Domestic architectural units are often described as repeated patterns of architectural areas such as living/sleeping rooms, cooking rooms or spaces, storage features, and open patios which may be the locations of craft production activities or social gatherings (Bawden, 1982; Van Gijseghem, 2001; Vaughn, 2005). These minimal suites of domestic spaces are repeated at sites in the Andes both on the coast and in the highlands,

Architecture in the Andes: Domestic Architecture, Fig. 3 Densely spaced domestic rooms and long corridors (to the *right*) on a broad domestic terrace at the Cajamarca site of Yanaorco (Photo by the author)

perhaps representing immediate family units. Variability among these units has been utilized to understand community and social organization better. Inequality in variables such as patio size, quality of wall construction, and elaboration of interior spaces can be indicative of the presence of strong economic or class distinction at sites like Galindo in the Moche valley. There, classes were physically separated with large adobe walls running between zones of low-status dwellings and those of higher-status residents. Architecture here is used to physically ensure social separation within the community (Bawden, 1982). The materialization of social separation is perhaps best seen in elite domestic architecture at the site of Chan Chan on the north coast (Conklin, 1990; Kolata, 1990; Moore, 1996; Moseley & Mackey, 1974).

Ethnicity, Identity, and Verticality

As a culturally conservative form of material culture, domestic architectural patterns are believed to mark social identity and be slow to change (Parker Pearson & Richards, 1994). Because of this conservative nature, it has been used to study issues of cultural identity in the Andes (Aldenderfer, 1993a; Aldenderfer & Stanish, 1993). Aspects of domestic architecture including form and plan, as well as the patterning of activities within space, are seen as outward signs of ethnic identity. Aldenderfer and Stanish's (1993) work has been done within a broader interest in Andean archaeology in themes of economic complementarity and verticality. Shifts in the organization of local domestic spaces can also signal the development of novel identities as well as sociopolitical relations as has been proposed for the late Moche site of Galindo (Bawden, 2005) in the north and on the south coast in the Nasca region (Van Gijseghem & Vaughn, 2008).

This necessarily brief review of domestic architecture in the Andes is limited in breadth and could not hope to discuss the entire range of the subject geographically, culturally, or temporally. Here, I hope to have presented some of the range and richness of patterning in the domestic built environment of the Andes and the anthropological questions that continue to be asked of it (Figs. 1, 2, and 3).

References

Aldenderfer, M. S. (Ed.). (1993a). *Domestic architecture, ethnicity, and complementarity in the south-central Andes*. Iowa City, IA: University of Iowa Press.

Aldenderfer, M. S. (1993b). Domestic space mobility, and ecological complementarity: A view from Asana. In M. S. Aldenderfer (Ed.), *Domestic architecture, ethnicity, and complementarity in the south-central Andes* (pp. 13–24). Iowa City, IA: University of Iowa Press.

Aldenderfer, M. S. (1998). *Montane Foragers: Asana and the south-central Andean archaic*. Iowa City, IA: University of Iowa Press.

Aldenderfer, M. S., & Stanish, C. (1993). Domestic architecture, household archaeology, and the past in the south-central Andes. In M. S. Aldenderfer (Ed.), *Domestic architecture, ethnicity, and complementarity in the south-central Andes* (pp. 1–12). Iowa City, IA: University of Iowa Press.

Bawden, G. (1982). Community organization reflected by the household: A study of pre-Columbian social dynamics. *Journal of Field Archaeology, 9*(2), 165–181.

Bawden, G. (2005). Ethnogenesis at Galindo, Peru. In R. M. Reycraft (Ed.), *Us and them: Archaeology and ethnicity in the Andes* (pp. 12–33). Los Angeles: Cotsen Institute of Archaeology, UCLA.

Bermann, M. (1994). *Lukurmata: Household archaeology in prehispanic Bolivia*. Princeton, NJ: Princeton University Press.

Conklin, W. (1990). Architecture of the Chimu: Memory, function, and image. In M. Moseley & A. Cordy-Collins (Eds.), *The northern dynasties: Kingship and statecraft in Chimor* (pp. 43–74). Washington, DC: Dumbarton Oaks Research Library and Collections.

Conlee, C. A. (2000). *Late prehispanic occupation of Pajonal Alto, Nasca, Peru: Implications for imperial collapse and societal reformation*. Unpublished doctoral dissertation, University of California- Santa Barbara, CA

Craig, N. M. (2005). *The formation of early settled villages and the emergence of leadership: A test of three theoretical models in the Rio Ilave, Lake Titicaca Basin, Southern Peru*. Unpublished doctoral dissertation, University of California-Santa Barbara, CA

Craig, N., Aldenderfer, M., Baker, P., & Rigsby, C. (2010). Terminal archaic settlement pattern and land cover change in the Rio Ilave, Southwestern Lake Titicaca Basin, Peru. In R. M. Dean (Ed.), *The archaeology of anthropogenic environments* (pp. 35–53). Southern Illinois University, IL: Occasional Papers #37. Center for Archaeological Investigations, Southern Illinois University.

D'Altroy, T. N., & Hastorf, C. A. (Eds.). (2001). *Empire and domestic economy*. New York: Kluwer.

DeMarrais, E. (2001). The architecture and organization of Xauxa Settlements. In T. N. D'Altroy & C. A. Hastorf (Eds.), *Empire and domestic economy* (pp. 115–154). New York: Kluwer.

Donnan, C. B. (1964). An early house from Chilca, Peru American Antiquity, 30(2), 137–144

Eeckhout, P. (1999–2000). The palaces of the Lords of Ychsma: An archaeological reappraisal of the function of pyramids with ramps at Pachacamac, Central Coast of Peru. In *Revista de Arqueología Americana* (pp. 17–19, 217–254). México, DF: Instituto Panamericano de Geografía e Historia.

Guengerich, A. (2014). The architect's signature: The social production of a residential landscape at Monte Viudo, Chachapoyas, Peru. *Journal of Anthropological Archaeology, 34*, 1–16.

Julien, D. G. (1988). *Ancient Cuismancu: Settlement and cultural dynamics in the Cajamarca region of the north Highlands of Peru, 200 B.C.–A.D. 1532*. Unpublished doctoral dissertation, University of Texas, Austen, TX.

Kolata, A. (1990). The urban concept of Chan Chan. In M. Moseley & A. Cordy-Collins (Eds.), *The northern dynasties: Kingship and statecraft in Chimor* (pp. 107–144). Washington, DC: Dumbarton Oaks Research Library and Collections.

Lau, G. (2010). *Ancient community and economy at Chinchawas (Ancash, Peru)*. Cambridge, MA: Yale Peabody Museum.

Moore, J. D. (1996). *Architecture & power in the ancient Andes: The archaeology of public buildings*. Cambridge, MA: Cambridge University Press.

Moore, J. D. (2005). *Cultural landscapes in the ancient Andes: Archaeologies of place*. Gainseville, FL: University Press of Florida.

Moore, J. D. (2012). *The prehistory of home*. Berkeley, CA: University of California Press.

Morris, C. (2004). Enclosures of power: The multiple spaces of Inca administrative palaces. In S. T. Evans & J. Pillsbury (Eds.), *Palaces of the ancient new world* (pp. 299–323). Washington, DC: Dumbarton Oaks Research Library and Collection.

Morris, C., & Thompson, D. E. (1985). *Huánuco Pampa: An Inca city and its hinterland*. London: Thames and Hudson.

Moseley, M., & Mackey, C. J. (1974). *Twenty-four architectural plans of Chan Chan, Peru*. Cambridge, MA: Peabody Museum Press.

Murra, J. (1975). *Formaciones económicas y políticas del mundo andino*. Lima, Peru: Instituto de Estudios Peruanos.

Nash, D. (2009). Household archaeology in the Andes. *Journal of Archaeological Research, 17*, 205–261.
Parker Pearson, M., & Richards, C. (1994). Architecture and order: Spatial representation and archaeology. In M. Parker Pearson & C. Richards (Eds.), *Architecture and order: Approaches to social space* (pp. 38–72). London: Routledge.
Pillsbury, J., & Leonard, B. L. (2004). Identifying Chimú palaces: Elite residential architecture in the late intermediate period. In S. T. Evans & J. Pillsbury (Eds.), *Palaces of the ancient new world* (pp. 247–292). Washington, DC: Dumbarton Oaks Research Library and Collection.
Quilter, J. (1989). *Life and death at Paloma, society and mortuary practices in a preceramic Peruvian village*. Iowa City, IA: University of Iowa Press.
Salazar, L. C., & Burger, R. L. (2004). Lifestyles of the rich and famous: Luxury and daily life in the households of Machu Picchu's elite. In S. T. Evans & J. Pillsbury (Eds.), *Palaces of the ancient new world* (pp. 325–357). Washington, DC: Dumbarton Oaks Research Library and Collection.
Toohey, J. L. (2009). Community organization, militarism, and ethnogenesis in the late prehispanic northern highlands of Peru. Unpublished doctoral dissertation, University of California-Santa Barbara, CA.
Van Gijseghem, H. (2001). Household and family at Moche, Peru: An analysis of building and residence patterns in a prehispanic urban center. *Latin American Antiquity, 12*(3), 257–273.
Van Gijseghem, H., & Vaughn, K. J. (2008). Regional interaction and the build environment in middle-range societies: Paracas and early Nasca houses and communities. *Journal of Anthropological Archaeology, 27*, 111–130.
Vaughn, K. J. (2005). Household approaches to ethnicity on the south coast of Peru: The domestic architecture of early Nasca society. In R. M. Reycraft (Ed.), *Us and them: Archaeology and ethnicity in the Andes* (pp. 86–103). Los Angeles, CA: Cotsen Institute of Archaeology, UCLA.
Vaughn, K. J. (2009). *The ancient Andean village: Marcaya in prehispanic Nasca*. Tucson, AZ: University of Arizona Press.
Watanabe, S. (2002). El reino de Cuismancu: orìgenes y transformación en el Tawantinsuyu. In P. Kaulicke, G. Urton, & I. Farrington (Eds.), *Identiad y transformacio̒n en el Tawantinsuyu y en los Andes colonials: Perspectivas arqueolo̒gicas y etnohisto̒ricas – Boletín de Arqueología PUCP No. 6* (pp. 107–136). Lima, Peru: Pontifical Universidad Católica del Perú.
Wiessner, P. (1983). Style and social information in Kalahari San Projectile Points. *American Antiquity, 48*, 253–276.
Willey, G. (1953). *Prehistoric settlement patterns in the Virú Valley, Peru. Bureau of American ethnology, bulletin 155*. Washington, DC: GPO.

Architecture of Fiji

Ferenc Zámolyi
Department of History of Architecture and Building Archaeology, Vienna University of Technology, Vienna, Austria

The Fiji Islands are part of Melanesia, one of the large regions within Oceania. They are situated geographically in the easternmost part of this area. Islands belonging to Polynesia can be found very near to the East, thus making the Fiji Islands a contact zone toward several Polynesian groups. It is assumed that the Islands were first settled by the direct ancestors of the Polynesian people (Kirch, 1997). While formerly it was suggested that there was later strong contact and thus adsorbed influences from some Melanesian Islands, newest archaeological evidence does not seem to support this (Clark & Anderson, 2011). It is interesting that vernacular architecture found on parts of the islands nevertheless shows very strong parallels to Melanesian building types (for a more detailed discussion on this, see Freeman, 1986, p. 16). While Polynesian influence in the form of Samoan and Tongan cultural ideas and architecture is more recent and well documented, the possible direct Melanesian connections remain vague, strongly debated, and more difficult to trace, if present at all. The rugged landscape and the division of Fiji into many smaller Island groups allows for a comparably high diversity in built forms, in which also the proximity of certain island groups to others plays an important role: While, for example, the highland areas of the main island, Viti Levu, were for most of their history very isolated and their architecture thus subject to mostly local development and evolution, small islands like the Lau group always had been connected via intensive sea trade to other domains, as in the case of the aforementioned Tonga group. Thus, vernacular architecture on Lau is heavily influenced by Tongan building practices and can in fact be regarded closer to that tradition, than the building culture of Viti Levu (Fig. 1).

Architecture of Fiji, Fig. 1 House in Navala Village, Western Viti Levu Highlands

History of Settlement and Origins of Traditional Buildings

The first settlements on Fiji were established approximately 3,200 years ago (e.g., Lapita site of Nanutuku, Kirch, 1997), by a people whom archaeologists attribute to left behind remains named the "Lapita culture." While some aspects of the emergence and expansion of the Lapita culture are still subject to a certain amount of debate, it can be safely argued that these people spoke a form of Austronesian language and can be regarded as the ancestors of todays' Polynesian people. They came from the West and insular Southeast Asia is regarded as the geographic area where the characteristic traits of this culture formed. As it is difficult to associate a complex of archaeological remains with ethnic and linguistic data, there are diverging scientific opinions on the formation period of the cultural complex in the insular Southeast Asia region. What seems to be sure is that the ancestors of the Polynesian people settled Fiji bringing material culture with them, which consisted apart from a very characteristic set of pottery of a tradition of building stilt buildings over the water or on the shore near the coastline. According to Kirch (1997) gradually these settlements shifted inland as the islands were colonized. Today no stilt buildings can be found in the Fiji Islands. This can be explained by a development, in the course of which buildings were rather built on earthen platforms, rather than on stilts. The earthen platforms provide a high floor, similar to the stilt house, and keep the inhabitants safe from ground moisture. Additionally the earthen platforms did evolve strong symbolic meaning, as at some point in history people started to be buried within these mounds under the house, and thus the platform became an object associated with the spirits of the ancestors.

A very plausible reason for change from stilts to earthen platforms is that unlike in insular Southeast Asia in Oceania, no malaria and no dangerous or highly venomous kinds of snakes or spiders can be found, which would make living in a stilt house very practical. To live in

Architecture of Fiji, Fig. 2 Virtual reconstruction of a fortified lowland village after Parry (1997, p. 100)

a high and well-ventilated place has been proven a good protection against mosquitoes, especially the malaria-transmitting Anopheles variety, as they tend to fly at a certain low height and avoid places with good air circulation.

Neither are there any large predators present. In insular Southeast Asia tigers as large predators represented a real source of danger even for humans. As accounts from Java, which was sparsely settled even a 100 years ago, suggest, people were afraid (and with good reasons) of these animals.

Apparently the protection (high) stilts could offer was not needed anymore. However, the architectural type of stilt houses lived on in the Vale ni Moce (Figs. 26, 27), the so-called sleeping houses. These were small cabins (usually built for persons of special importance) on stilts offering protection against raids in the pre-colonial era. They are not built anymore, and whether they had been an archetypical remnant of earliest history or reinvented at some time later is not clear.

However, one discussion point remains: One form of vernacular building, which was common in Western Viti Levu (the main island of Fiji), the Were Rausina, is difficult to explain architecturally as a direct legacy of stilt Lapita buildings: While Lapita houses were rectangular, the ground plan of Were Rausina is round. This is such a fundamental change that it either requires the local invention of a new house type or strong outside cultural influence. Of course we can credit local invention with the creation of the building type, but it is remarkable that on several near Melanesian island groups (e.g., New Caledonia), very similar round buildings can be found. Although archaeological evidence does not support ideas of direct connections, the geographic and typological proximity of the building types suggests that there is at least some link between these phenomena. It remains to be seen, whether further archaeological research can definitely decide this question.

Villages in the Fiji Islands

As the islands became densely settled over time and Fijian people were definitely warlike, a community had to be prepared for frequent raids and hostilities. The buildings were erected within

Architecture of Fiji, Fig. 3 The village is protected by a ditch filled with water from the nearby stream and ramparts with bamboo spikes. A wooden stockade has been erected on top of the ramparts. There are fortified gates and inside the village square can be discerned, where the chief's house or the mens' house is located surrounded by stone stelae. Opposite to it, in the *lower right corner* in this image, the spirit house (*Bure ni Kalou*) can be seen. It is standing on a large platform (*Yavu*) and has a disproportionately high roof

villages enclosed by palisades and protected by ramparts and ditches. Sometimes gardening structures made for Taro plants, which prefer moist conditions, were located in a way to turn the surroundings of settlements into swamps to protect the inhabitants. Other places had ditches protecting their walls (Parry, 1977, 1981, 1997) (Figs. 2 and 3).

Fijian houses are built around the *rara*, the village square. It actually used to be small, confined and influenced by the space and terrain available in ancient times when the villages were fortified to protect them from outside attacks. Nowadays, it is much bigger and more rectangular in shape and houses are set in rows along it in an orderly manner. In fact, it is a very typical element of the numerous new villages which were founded after the colonial wars when it was safe to spread out.

On one end of the square the village chief's house is built, on the opposite end the church. The living houses are lined up in two rows along the rara between these two foci of power (Zámolyi, 2004, pp. 52–58) (Fig. 4).

Architecture of Fiji, Fig. 4 Rara or village green of a contemporary Fijian village in the Western Viti Levu highlands (Navala village, Ba)

Different House Types According to Geographical Distribution

Most Fijian houses have a rectangular or at least elongated ground plan. They have either gabled or hipped roofs and are built on earthen platforms or mounds. Notable exceptions to the plain rectangular shape are the Lau and Rotuman houses which have rounded, apsidal endings and the Were Rausina, a now extinct building type of the Western Viti Levu highlands, which was round, or some of its variants square.

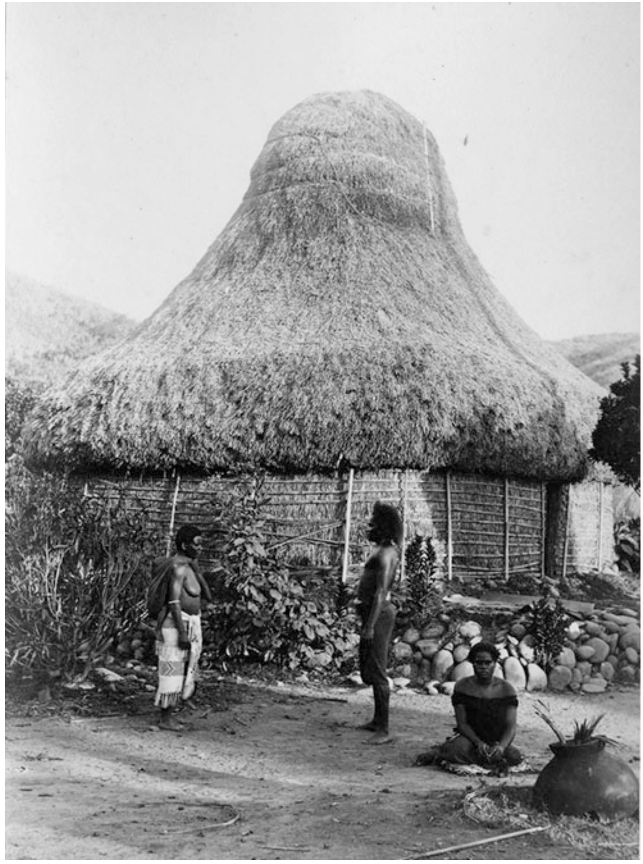
Eastern Highlands of Viti Levu

Buildings of this region have rectangular ground plans. Unlike buildings in the Western highlands, houses of the Eastern highlands do not have a middle post (Freeman, 1986). Often two end posts were used or king posts on tie beams. The design was very similar to coastal buildings, and usually also referred to by the same name (*vasemasema*). However, there seem to have been regional differences in proportions, which caused a slightly different appearance.

Western Highlands of Viti Levu: Were Rausina

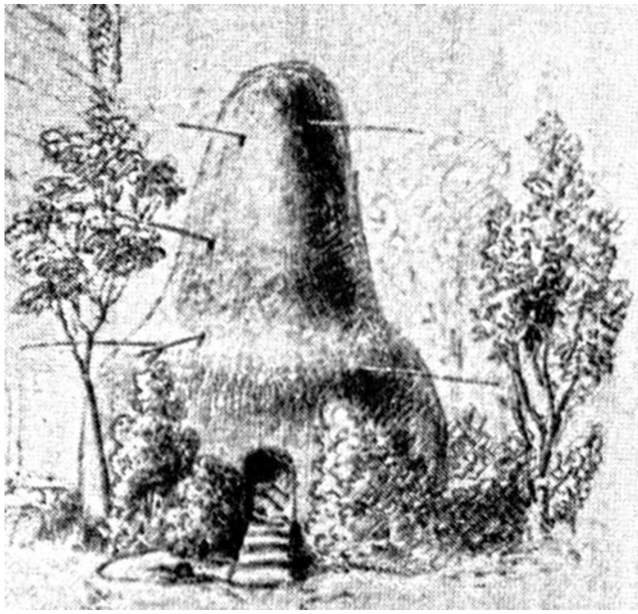
The Were Rausina was a building type which could be found in the Western highlands of Fiji's main island, Viti Levu. It became extinct in the course of recent history, as many temples or buildings associated with spiritual beliefs of the time before the advent of Christianity had been built in the Were Rausina style. They were mostly razed after conversion. As only a few sketches of European travelers (e.g., Kleinschmidt), descriptions, and photographs remain, we cannot be completely sure how this house type looked in every detail. Also there seem to have been at least two variants of the type. The name itself refers to its roof covering (*Rausina* = thatched with grass) and

Architecture of Fiji, Fig. 5 A house of Were Rausina type with unthatched walls (Source: Archive of British Museum)



supposedly stresses the fact that all of the building was covered in grass. This is in contrast to other building types, which were also covered in grass or reed, but only to their eaves, while the wall zone remained uncovered. *Were* is a highland-dialect word for house (*Vale*).

The Were Rausina was definitely round, with walls made of wooden piles dug into the earth. Upon these piles a wall plate in the form of a ring made of twisted lianas rested. Higher up in the roof structure another such ring plate could be found. The building had a middle post with a short roof ridge on top. The thatch covered not only the roof but also the walls and gave the building a shape, which supposedly was the reason that the missionary Williams described some of the Fijian houses as "haystacks" (Williams, 1858, p.79) (Figs. 6, 7). There was also a variant of the house which had a square ground plan and where the thatch apparently was not covering the walls (Fig. 5). The building had one entrance and no windows, and there was a hearth situated inside, as we know from the descriptions of the traveler Kleinschmidt (1879; Tischner, 1961, 1966). There are several Melanesian house types, which show close architectural parallels to the Were Rausina. Buildings in New Caledonia, for example, are very similar both in appearance and in inner structure to the Were Rausina, but as already discussed in this article, actual connections remain highly debated. The distribution area of the Rausina was similar to that of the Nanga cult places, and in that case a



Architecture of Fiji, Fig. 6 A Were Rausina with thatched walls, sketched by the traveler Theodore Kleinschmidt in 1879 in the Viti Levu highlands

Architecture of Fiji, Fig. 7 The reconstruction of the inside of a Were Rausina after the description of Kleinschmidt (1879)

connection would be more plausible. At the end of the Nanga enclosures, usually a circular house was built, which was likely to be related to the Rausina type.

Western Highlands of Viti Levu: Rectangular Buildings

While the ground plan was rectangular, most houses of the Western highlands feature a middle post and a hipped roof with radially arranged rafters. In many cases the rafters are held together by a ring plate of twisted lianas near the ridge pole. Several of these features (middle/main post, ring plate of twisted lianas) are very likely to have been originated from the Were Rausina type. It is without doubt that while the Rausina itself is not built anymore, many of its features transformed the rectangular buildings and made them recognizably different from those of the Eastern Highlands (see also Freeman, 1986). In some villages Kleinschmidt (1879) describes the existence of both rectangular and round buildings. The rectangular house seems to have

Architecture of Fiji, Fig. 8 Rectangular house showing many characteristics of the extinct Were Rausina building type. Navala village, Ba

spread in the Viti Levu highlands in the nineteenth and twentieth centuries (Roth, 1953, p. 9) (Figs. 8, 9, 10, and 11).

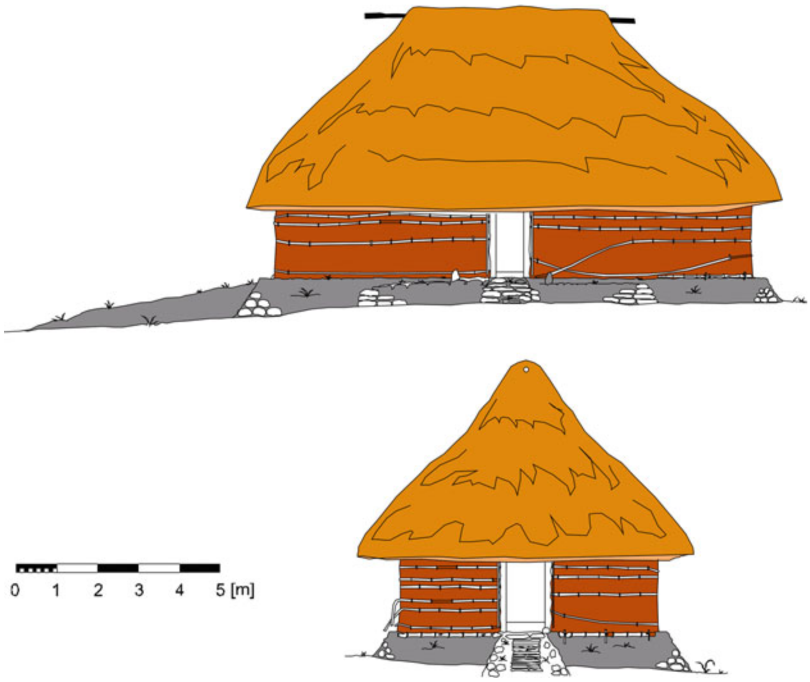
Coastal Buildings (*Vasemasema*)

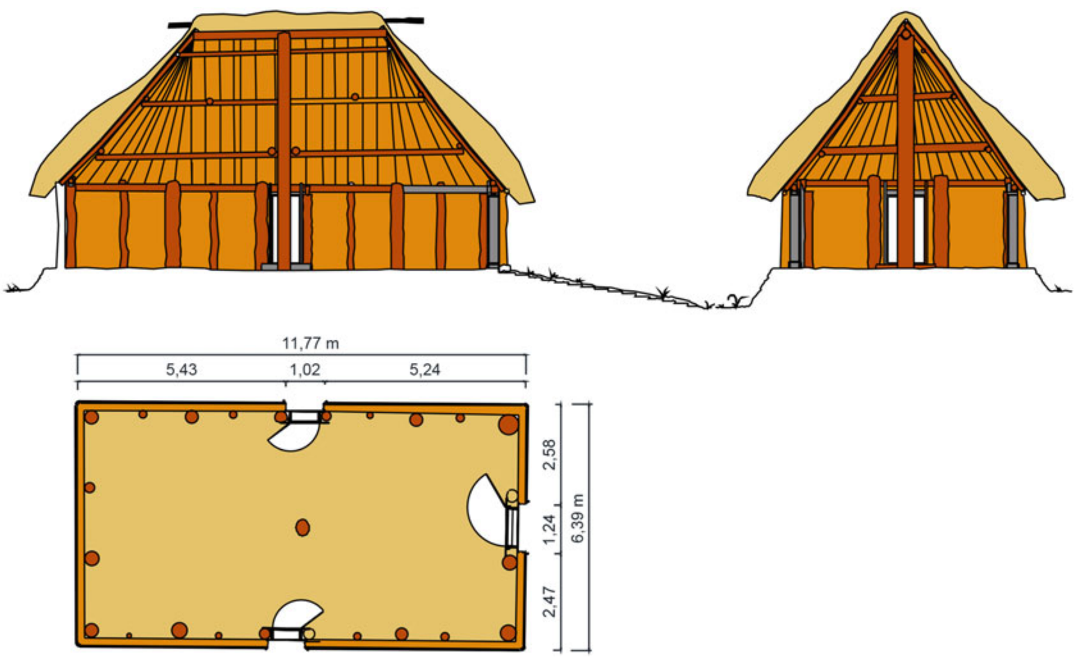
The coastal buildings, which are called *Vasemasema* have gabled or slightly hipped roofs, are rectangular in ground plan and have an entrance on the longer side. With time additional doors were built, and some were even built with windows, although this seemed to be a historically very recent practice linked to European influence. The houses usually featured two main piles at the gable ends or king posts on tie beams within the building. The main piles could be set in the plane of the shorter end walls, then the roof was gabled, or somewhat toward the inner part of the house, then the building would have a slightly hipped roof. The walls were made of different materials and methods than in the highlands; often they were thatched with leaves or branches of certain trees (Figs. 12, 13, 14, and 15).

Coastal Regions: *Vale Leka*

The so-called short house or *vale leka* is an architectural solution which can be found in a very similar form on very exposed islands all over Oceania. It has very low or no walls at all. Instead, the roof is built directly on the ground, giving it its peculiar triangular shape. This enables the house to work with the surrounding terrain and embed itself in a streamlined manner. It is thus able to successfully withstand strong winds and tropical storms, which can occur in coastal regions or low islands. A similar house form exists in Polynesian Hawai'i and Melanesian Vanuatu. In Fiji it can be found in several

Architecture of Fiji, Fig. 9 Plans of a house with middle post in Navala village, Ba





Architecture of Fiji, Fig. 10 Plans of a house with middle post in Navala village, Ba

Architecture of Fiji, Fig. 11 Vernacular house with middle post in Navala village, Ba

coastal areas. It was also said to be built on Vanua Levu. There existed two types, one with low walls of around 60 cm height, often secured with stones, and one type without any walls at all (Fig. 16).

Houses of the Lau group (*Kubololo*)

The Kubololo is a Tongan house style with apsidal, rounded ends. This building type spread in the nineteenth century with Tongan influence. Tongan and Samoan boat builders came to the Lau group, as in their home islands there was a shortage of timber, and some of the Lau islands were in fact annexed by force by Tongans during the nineteenth century. They brought with them their house building technology and style (Kooijman, 1978) (Figs. 17 and 18).

Houses of Rotuma Island

Rotuma was subject to influences from Tonga and Samoa, and the buildings were similar to those of the Lau islands (Fig. 19).

Different Building Types According to Function

Bure/Vale (Living House)

While the term *Bure* in former times referred either to men's houses, temples, or chief's houses, in modern times the term more and more is used for all types of traditionally constructed dwelling houses. The term "Vale" is used in the coastal dialects for house, while in the Viti Levu highlands the word "Were" is more common. Tippet (1968) states that these two expressions are variants of the same word and do not have any difference in meaning.

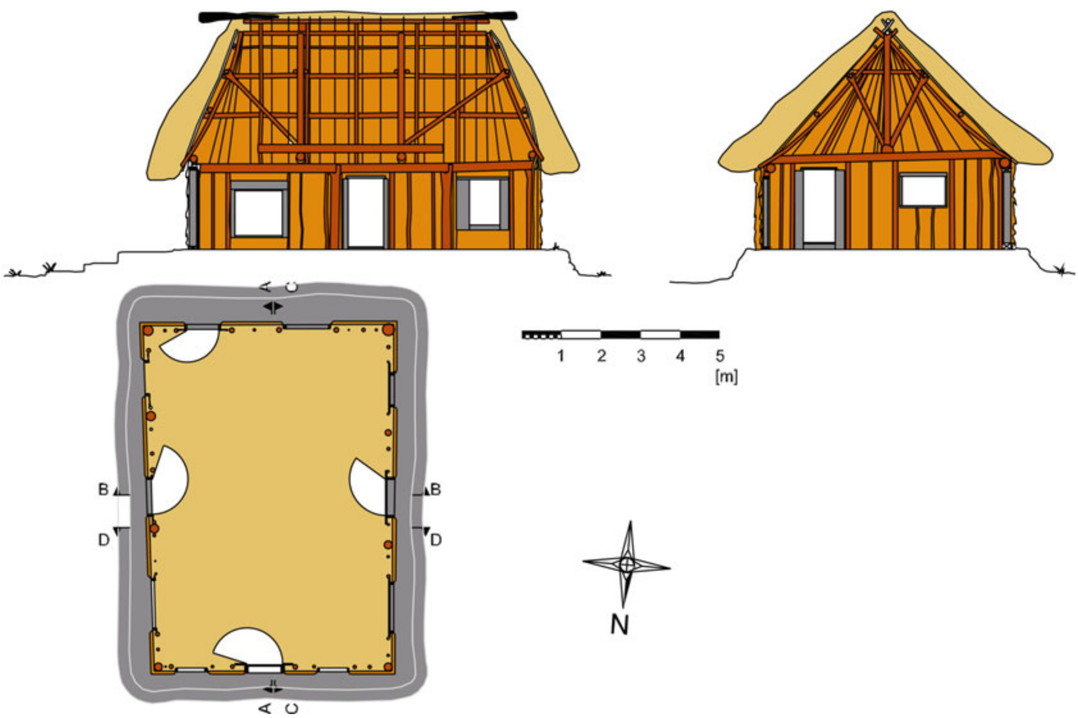
Usually living houses had one entrance on their longer side, but with time more doors became common. Today some buildings have three doors. Windows were not a common feature and were introduced only in the European colonial era. No furniture was used in Fijian houses; the earthen floor was covered with dried grass or if people were affluent enough, with mats made out of the leaves of the Vodra tree (screwpine).

Formerly there was no separate kitchen; food was prepared in the living house. The missionaries and the colonial administration advocated separation of the kitchen in a building different of the main house, as it was deemed healthier. Finally separated kitchens became the norm.

Bure ni Sa (Men's House)/*bure ni cauravou* (House for Bachelors)

In pre-Christian Fiji family life was different from the present norm. Formerly the core family (wife husband and children) was not so emphasized, and the clan was more important. Also husbands spent more time apart from their wives and children, or they had even several wives at once. The men spent much time in the Bure ni Sa, a club house or men's house, while the women usually also had a women's house

Architecture of Fiji, Fig. 12 Building in Lomanikoro, Kadavu



Architecture of Fiji, Fig. 13 Plans of the house in Lomanikoro, Kadavu

Architecture of Fiji, Fig. 14 House in Lavena, Taveuni island

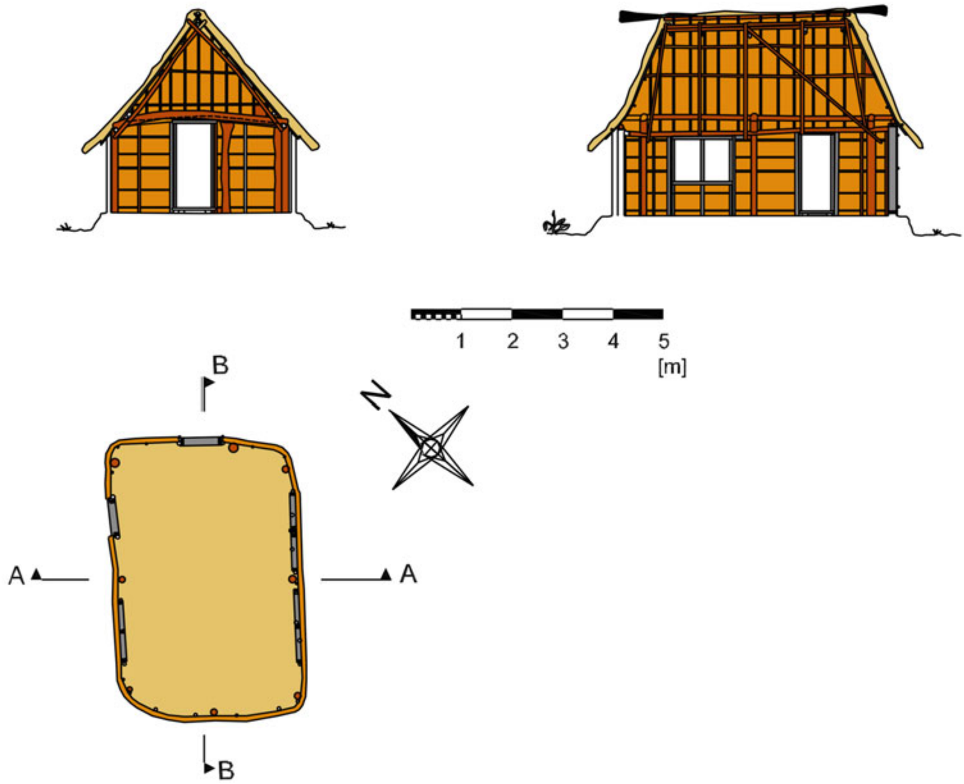
where they would stay, often even overnight. With the advent of Christianity, the missionaries abolished these types of buildings. Kleinschmidt (1879) mentions in his account of travels in the Western Viti Levu highlands that Bure ni Sa could be both round (the Rausina type) or an elongated rectangular building, according to local tradition, with separate areas fenced off within as private areas for each person (Fig. 20).

Bure ni Kalou

The Bure ni Kalou or spirit temple used to be built on high earth platforms which were covered with stones and were also fitted with disproportional high roofs. The high platform was a sign of the high status of the building. While its absolute dimensions (apart from the steep roofs) were apparently not necessarily larger or sometimes even smaller than those of ordinary houses, the quality of materials, the construction work, and also the exquisite decoration of the building set it apart from any other. The joints between the different posts and beams were lashed in elaborate patterns and adorned by coconut cords of different colors. The tree-fern stems of the ridge were decorated with cowries, each shell marking the death of a human in sacrifice to the gods. The construction of a temple required a large number of humans to be sacrificed and gave rise to conflicts and raids with neighboring villages and tribes (Seeman, 1862; Williams, 1858). Kleinschmidt (1879) recorded that in the Western Viti Levu Highlands, Bure ni Kalou was often built in the building type of the Were Rausina. In other places the design was that of the dominant local building type (Fig. 21).

The inside of the building was apparently very similar to dwelling houses, and as within them, also here no special furniture was used. The gods were sometimes represented by two-headed whale ivory figurines. During the day they were placed in small mock houses made out of sennit, while during the night they were put into a basket to "sleep." Additionally it is recorded that a *masi* (bark) cloth was hung either from the ridge inside the temple, or from a corner post, and symbolized

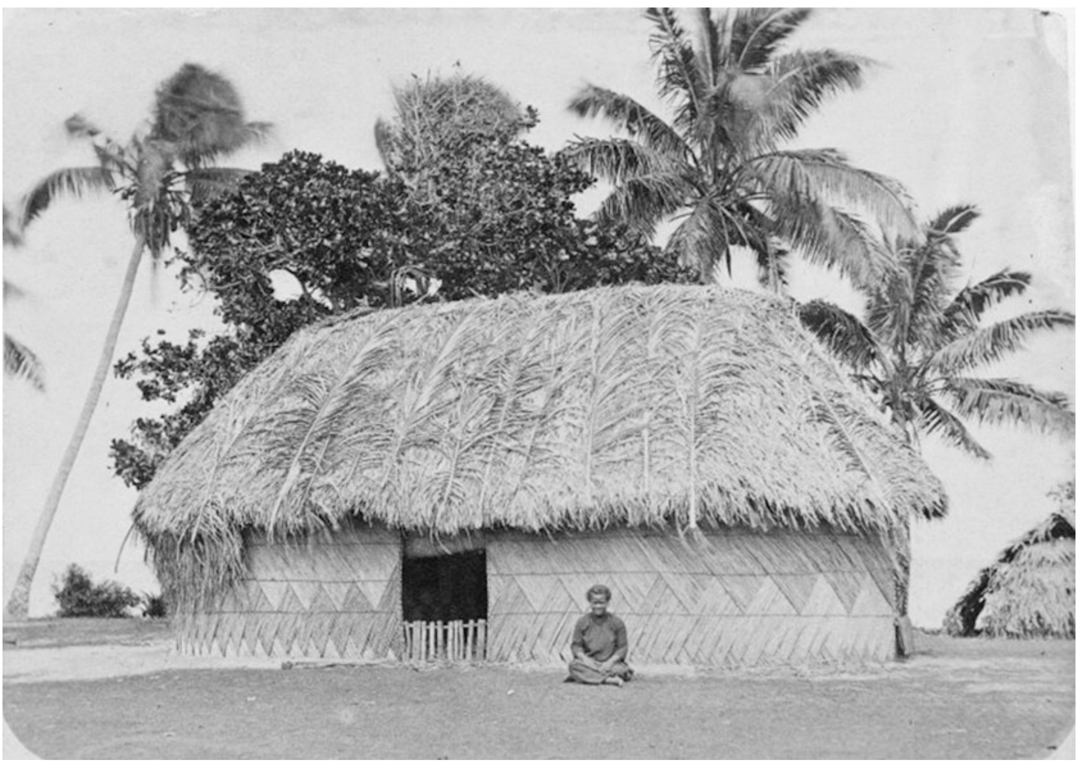
A



Architecture of Fiji, Fig. 15 Plans of house in Lavena, Taveuni island

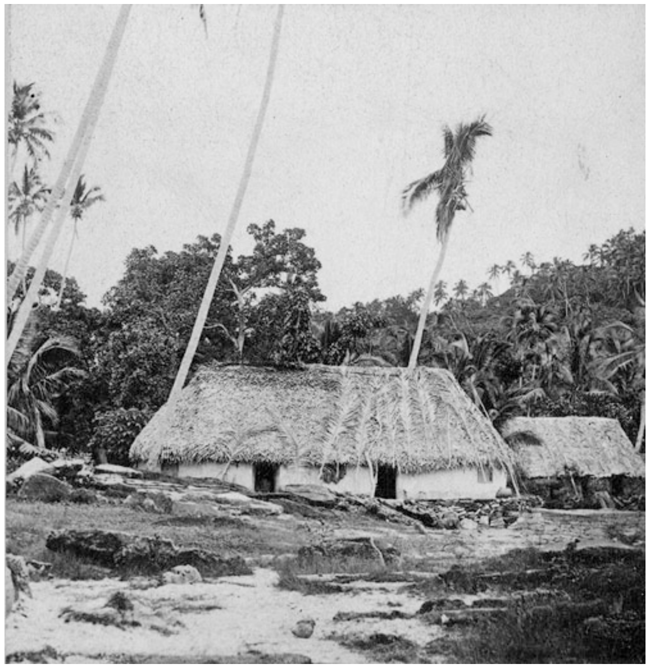
Architecture of Fiji, Fig. 16 Vale leka (short house) on Ra island (Source: Archive of British Museum)

Architecture of Fiji, Fig. 17 House in the Lau group showing Tongan influence



Architecture of Fiji, Fig. 18 House in Tonga, Polynesia (Source: Archive of British Museum)

Architecture of Fiji, Fig. 19 House on Rotuma island (Source: Archive of British Museum)



Architecture of Fiji, Fig. 20 Bure ni Sa on Bau island (Source: Thomson, 1908). This example is a very large and generous one. Bure ni Sa in the highlands for example seem to have been much smaller and had a rather confined inner space. Kleinschmidt (1879) describes Bure ni Sa which had partitions for each person using it, resulting in small private spaces

Architecture of Fiji, Fig. 21 Bure ni Kalou (Source: Williams, 1858). The spirit houses or temples could be recognized by their high platform and their high roof structure

Architecture of Fiji, Fig. 22 Reconstruction of a Naga after Fison (1884)

the path on which a god could descend. Supposedly also trophies of war or weapons thought to have an especially famous reputation were displayed within the temple. There was a hearth within the building. The priest (*bete*) could reside in the temple, but more often he possessed his own building within the village (Seeman, 1862). The temple seems to have held a specific place within the village, supposedly opposite the chief's house, the same location which is today occupied by the Christian church. Although churches (at least in the beginnings) were built with the same methods of traditional buildings, they did not take over the design of temples, but were understandably oriented on western architectural models.

Ritual Enclosure: The *Naga*

Nagas were cult places used for ceremonial gatherings, which only existed in the southwest

Architecture of Fiji, Fig. 23 Reconstruction of Naga after Joske (1886)

Architecture of Fiji, Fig. 24 Bure (house) of a chief being built (Source: Thomson, 1908)

Architecture of Fiji, Fig. 25 Sketch by the author showing a earth in a kitchen in Navala village, Ba, Viti Levu. The kitchen buildings are usually built in the same way as dwelling houses; they are only smaller and less elaborate


Chiefs House and Sleeping Bure.

Architecture of Fiji, Fig. 26 Vale ni Moce behind a chief's house (Source: private collection of Rod Ewins)

highlands of Viti Levu. They are probably similar to Polynesian cult places, such as the marae of New Zealand and the heiaus of Hawai'i.

Nagas generally consist of three rectangular zones which are enclosed by a low stone wall or a perimeter of stone stelae and lined with aromatic trees. At the end of the third zone, there is Vale Tembu (taboo), a forbidden or untouchable house, which symbolizes the watchful place of one's ancestors. Each zone is reserved for a specific rank and clan. Stump pyramid-shaped piles or stone walls with a gap allowing only a narrow passage in between mark the boundaries of each zone. The Vale Tembu, as the innermost

Architecture of Fiji, Fig. 27 Vale ni Moce (Source: Williams, 1858)

Architecture of Fiji, Fig. 28 House building tool before European contact: Stone adze (Source: Archive of British Museum)

Architecture of Fiji, Fig. 29 House building tool before European contact: tortoise-shell adze (Source: Archive of British Museum)

Architecture of Fiji, Fig. 30 After iron was obtained from Europeans, the adzes were modernised (Source: Archive of British Museum). Nowadays nobody in Fiji uses adzes. Common tools are European style axes, hatchets or large bush knives

sanctum, was entered at the culmination of the initiation ceremony, when new members of the cult were admitted to its secrets (Fison, 1884; Joske, 1886).

Nagas were used for initiation rites, harvest feasts, etc., by many villages at the same time. They were built hidden away in remote areas. The walls of the zones within a Naga are actually pervious enough to allow people to leave the place quickly in case of attacks which were a

Architecture of Fiji, Fig. 31 Piles dug into the ground before the house platform (Yavu) is erected

Architecture of Fiji, Fig. 32 Notching of the piles

constant threat in ancient times. After conversion to Christianity these sites were neglected and their locations forgotten. No such cult place is restored, archaeologically excavated, or otherwise presented to a wider public. Only descriptions from the nineteenth century and observations of European travelers of that time remain (Figs. 22 and 23).

Architecture of Fiji, Fig. 33 Men in Navala village, Ba lever a large pile of a house under construction into its final place

Architecture of Fiji, Fig. 34 The yavu (house platform) is built up after placing the piles

Bure Levu

Bure Levu is a term for the chief's house. This building, which sometimes also was termed *Vale Levu* (big house), was a more elaborate, lavishly decorated, and usually larger version of the commoners' houses. It also stood on a higher platform, advertising the higher social rank of the Chief (Fig. 24).

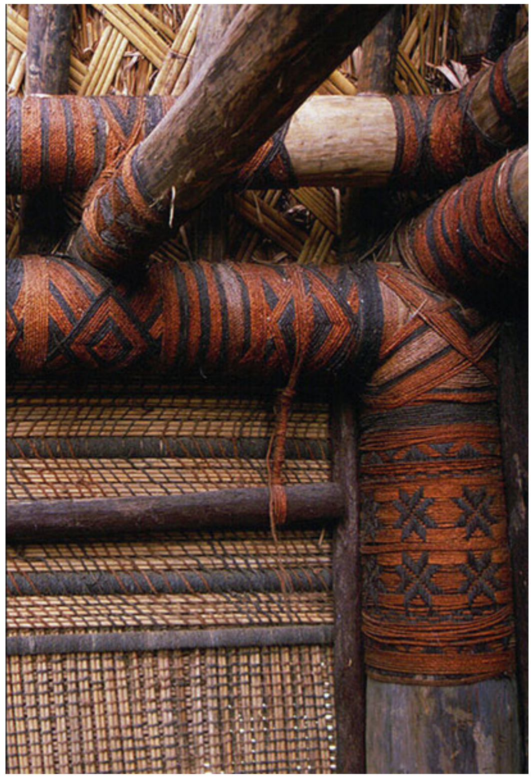
Vale ni Kuro

The kitchen is called *Vale ni Kuro* in Fijian. It seems that the building of kitchens as separate

Architecture of Fiji, Fig. 35 After placing the wall plates, a temporary bamboo scaffolding is set up in the middle of the house. This holds the roof ridge, until the rafters are fixed to it

Architecture of Fiji, Fig. 36 Woven bamboo walls are attached to the sides of the building

Architecture of Fiji, Fig. 37 The length of the rafters is not calculated exactly beforehand, but they are trimmed after they have been placed in the structure



Architecture of Fiji, Fig. 38 Elaborate lashing of a corner joint made of coloured coconut cord in the open-air museum of Pacific Harbour (Source: Erich Lehner). Such lashings are usually not made anymore nowadays

buildings started mainly in the colonial era (from 1874 on), as European authorities deemed the smoke caused by cooking within the dwelling house insanitary. Although a smoky house interior is in no way healthy, a hearth within the dwelling house could have following useful effects: The house itself was "smoked" and thus vermin did not nest within the thatch and the wooden parts of the building lasted longer. Also, at least in the highland regions, people needed the warmth of a fire, as the nights sometimes could be cold. Mosquitoes and other flying insects were also kept from entering the house by the smoke.

Several accounts from the nineteenth century describe cooking utensils and hearths for cooking within the dwelling houses (Kleinschmidt, 1879; Williams, 1858), and it seems that at least in the interior of Fiji's larger islands, it was not usual to build separate kitchens at that time. Whether the custom was different in the coastal areas is not entirely clear, but before the annexation by the British tribal warfare was frequent, and most villages were fortified. Therefore the construction of separate buildings as kitchens seems unlikely (Fig. 25).

Vale ni Moce

Vale ni Moce were raised little house-like annexes for people to sleep in. They were built in a height of 2–3m to guard people from surprise enemy attacks and also from the inconvenience of mosquito bites. Most of the time these houses were built in such a fragile way that any time someone tried to climb the ladder and access the house, the whole house would start shaking and that way woke up the person sleeping inside. He or she was warned in time. After the colonial wars

Architecture of Fiji, Fig. 39 Man in Navala village fixing a wall plate to a pile with wire. In former times such a joint would have been lashed with lianas or coconut cord

Architecture of Fiji, Fig. 40 Beautifully lashed joints of a roof structure on Bau island

more peaceful times arrived and the sleeping house was made redundant. Nowadays, it is not being built anymore (Figs. 26 and 27).

Building Technology, Materials

Fijian houses were built traditionally without the use of any nails or carpenter's joints. All parts were round pieces of wood; only the end of some parts (e.g., the ends of piles) had to be worked in a way that they had grooves or V-shaped cuts to receive other structural elements. First the piles of a house were buried in the ground, and usually afterwards an earthen platform (*Yavu*) was built. In some cases first the platform was built and then the piles dug in. Often old platforms were used to re-erect buildings on them (Figs. 28, 29, 30, 31, 32, 33, and 34).

On the piles wall plates were placed. The ridge of the house was held in place according to type either by one main post (*Bou*), two posts at the end of the building, or two king-posts placed on a longitudinal beam, which in turn was placed on tie-beams. Sometimes also combinations of these parts could occur (e.g., two main posts and two king posts). All parts were lashed together with lianas or coconut sinnet. Strong lianas were used to fix large timbers in place, while coconut sinnet (*Magimagi*) was ideal for producing elaborately patterned connections and lashings. According to Tipett (1968, pp. 141–172) enormous amounts of binding material could be used at larger projects. An example of a large community house built for a school in Kadavu Island in the traditional

Architecture of Fiji, Fig. 41 A liana is beaten with a stone to loosen the bark

Architecture of Fiji, Fig. 42 After having been beaten, the liana is easily torn to strips which are used for lashing in the house structure

manner is mentioned using 7,200 f. (2.16 km!) of coconut sinnet (Magimagi) and 17,500 f. (5.25 km!) of various lianas (Tipett, 1968, p. 152). It has to be remarked though that such buildings were not the norm but the exception. Such a project can only be compared to a chief's house or a temple of former times and required large efforts and considerable time in preparation from the community (Figs. 35, 36, 37, 38, 39, 40, 41, and 42).

However, once the material was prepared, the building of a house itself took only a few days. Of course common village houses did not need such large amounts of binding material, as their dimensions were smaller and their joints far less or not ornamented. It has to be stressed that this particular building described by Tipett had apparently very elaborate bindings as decorations on the wall and the joints, which was the main possibility of adorning a building. At the end of the nineteenth century in certain places there seemed to be a trend of Tongan patterns to be used in binding, very likely connected to the import of the Tongan house type in the Eastern island groups of Fiji.

House walls were made of split bamboo or mats or covered by grass thatch. Especially in the Inland areas of Viti Levu, the grass-thatched

Architecture of Fiji, Fig. 43 House before thatching

Architecture of Fiji, Fig. 44 Detail showing the rafters of a roof lashed to purlins within the roof structure (Navala village, Ba, Western Viti Levu highlands) (Source: Josef Schuller)

walls of houses were secured by bamboo strips, which produced a very characteristic horizontally striped appearance.

The roof ridge of Fijian houses was in most parts strengthened by an extra binding of lianas and also two tree-fern stems (*Bala-Bala*) were attached slightly above the roof ridge, in a way that they projected from the roof. This gave the buildings a very typical, almost emblematic shape (Figs. 43, 44, 45, and 46).

Fijian houses can be built by only using stone tools, as no complicated or precise joints have to

Architecture of Fiji, Fig. 45 Inner roof structure of a house in Navala village (Source: Josef Schuller)

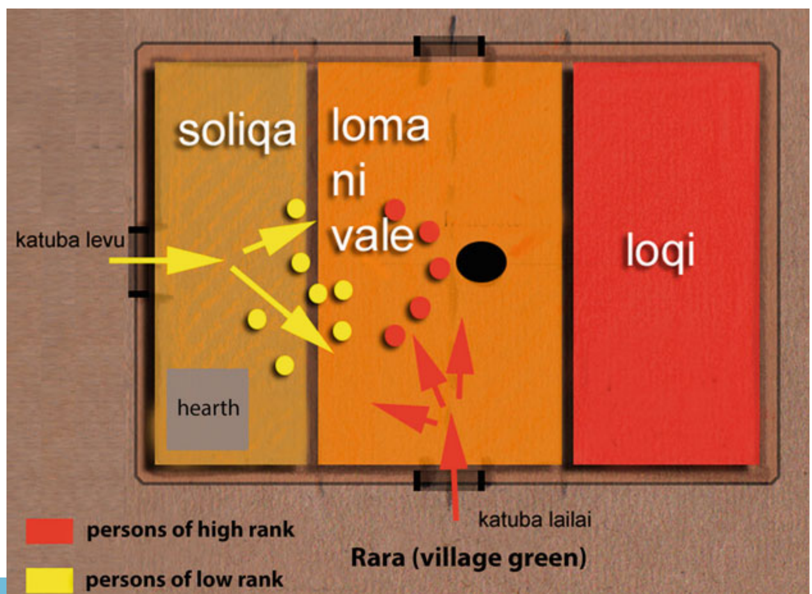
be cut into the wooden elements, nor do they have to be shaped (e.g., squared) very much. Before the advent of the Europeans, Fijians used stone knifes and adzes or bone tools like tortoise-shell adzes. After European contact first simple iron blades, later European style tools became common (Figs. 28, 29, 30).

The House As Ordered Space

Fijian society is strongly hierarchical, and the use of the inner space within a house reflects this. People are seated during ceremonies according to their rank within the community and also where a particular person enters the building is regulated according to status. The house itself is divided into three zones (there are no physical barriers present, and the zonation is purely existing in custom and people's perceptions). The back part of the building is called *Loqi*, and is private. Here people sleep and guests usually do not enter this area. People who step into the house either use the *Katuba Lailai* (small door) which is situated on the long side of the building and as a rule looks onto the Rara, the village green or they use the *Katuba Levu* (big door) which is situated on the shorter end of the building. The Katuba Lailai has high status and is only used by members of the community with high rank, while everybody can use the Katuba Levu. In former times, when a building used to have only one door, it was at the same position as the Latuba Lailai is now. On the right side, when entering through the Katuba Lailai, the private end of the house (Loqi) can be found; on the left is the public end (Soliqa). Thus having entered the building one is standing in the *Loma ni Vale* area, which is not private anymore, and also not open to all guests – only high ranking persons or persons well known to the family may sit here. The Soliqa can be directly accessed through the "low rank" door (Katuba Levu). If there is a hearth to be found in the building, then it will usually be located at the public end, in the right hand corner when entering through the Katuba Levu. Some buildings also have a door opposite the Katuba Lailai, but this door is seldom used as it is basically a back door to the Loma ni Vale, and thus ceremonially not as important as the much more prominent access from the Rara via the Katuba Lailai. In the Were Rausina the inner space was ordered somewhat differently, in a way that the hearth, which is in rectangular buildings in a low-ranking area, was situated behind the middle post right opposite the only entrance of the house, and thus within the Loma ni Vale, the higher ranking restricted part of the building. It is not clear why it was not situated in the Soliqa area. Otherwise the Were Rausina seems to have been used with a similar division (Loqi-Loma ni vale – Soliqa) as the rectangular buildings (Fig. 47).

In pre-Christian times deceased people used to be buried below their house in the house mound or platform (*Yavu*) (Roth, 1953, p. 10). This might be also the reason why house mounds have special importance and are regarded almost as sacred (Ravuvu, 1983, p. 14). The missionaries abolished the practice, and only chiefs were allowed to be buried within the village. If by any means chiefs or other high-ranking persons

Architecture of Fiji, Fig. 46 Thatching the house. As the roof ridge is most exposed to the weather and thus could be damaged, it is strengthened by being wrapped with lianas. Navala village (Source: Josef Schuller)



Architecture of Fiji, Fig. 47 Hierarchy of space within a Fijian house

Architecture of Fiji, Fig. 48 Grave of a Chief on Bau island. Above the grave a platform was created, on top of which a stone or concrete monument was erected in the approximate shape of a house

were not buried in the settlement, a mound was raised over the gravesite and usually a house built over it (Williams, 1858). A good example for this practice is the grave site of chief Cakombau in Bau, were a stone monument very much resembling a house has been erected over the burial platform (Fig. 48).

References

Birks, L. (1973). *Archeological excavations at Sigatoka dune site*. Suva, Fiji: Bulletin of the Fiji Museum No. 1, The Fiji Museum.

Clark, G., & Anderson, A. (2011). *The early prehistory of Fiji*. Canberra, Australia: ANU E Press.

Fison, L. (1884). The Nanga Cult. *Journal of the Anthropoligical Institute of Great Britain and Ireland, XIV*, 29.

Freeman, S. (1986). The center-poled houses of western Viti Levu. Suva. *Domodomo, Fiji Museum Quarterly, IV-1,* 2–19.

Joske, B. A. (1886). The Naga of Viti Levu. *Journal of the Anthropoligical Institute of Great Britain and Ireland, XVI*, 255–271.

Kirch, P. V. (1997). *The Lapita peoples – Ancestors of the oceanic world*. Cambridge, MA: John Wiley & Sons.

Kleinschmidt, T. (1879). Theodor Kleinschmidt's Reisen auf den Viti- Inseln. *Journal des Museum Godeffroy, 14*, 249–283.

Kooijman, S. (1978). Continuity and change in houses and house construction: The case of the Lau Islands, Fiji. In *Baessler – Archiv, Neue Folge, Band, XXVI*. Berlin: Verlag von Dietrich Reimer.

Lehner, E. (1995). *Südsee Architektur: traditionelle Bauten auf Hawaii, Tonga, Samoa*. Wien, Austria: Neuseeland und den Fidschi – Inseln. Phoibos Verlag.

Parry, J. T. (1977). Ring – Ditch fortifications, ring – Ditch fortifications in the Rewa Delta, Fiji: Air photo interpretation and analysis. *Bulletin of the Fiji Museum*, *3*, Suva.

Parry, J. T. (1981). Ring – Ditch fortifications II, ring – Ditch fortifications in the Navua Delta, Fiji: Air photo interpretation and analysis. *Bulletin of the Fiji Museum, 7*, Suva.

Parry, J. T. (1997). The North Coast of Viti Levu Ba to Ra air photo archeology and ethnohistory. *Bulletin of the Fiji Museum Vale ni I yaya Maroroi*, *10*, Suva, Fiji.

Ravuvu, A. (1983). *The Fijian way of life*. Suva, Fiji: Institute of Pacific Studies of the University of the South Pacific.

Roth, G. K. (1953). *Fijian way of Life*. Melbourne, Australia/London/Wellington, New Zealand: Geoffrey Cumberlege/Oxford University Press.

Roth, G. K. (1954). Housebuilding in Fiji. *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, 84, Parts 1&2.

Seeman, B. (1862). *Viti: An account of a government mission*. Cambridge: Macmillan.

Thomson, B. (1908). *The Fijians: A study of the decay of custom*. London: William Heinemann.

Tipett, A. R. (1968). *Fijian material culture* (B. P. Bishop Museum Bulletin, Vol. 232). Honolulu, HI: Bishop Museum Press. (Chapter five "A Case Study of Fijian House Types" pp.141–172).

Tischner, H. (1961). *Beiträge zur Ethnographie des Alten Viti Levu und Vanua Levu nach Unveröffentlichten Notizen und Zeichnungen Theodor Kleinschmidts aus den Jahren 1875–1878* (Veröffentlichungen des Museums für Völkerkunde zu Leipzig, Vol. 11, pp. 665–681). Berlin, Germany: Akademie-Verlag.

Tischner, H. (1966). *Theodor Kleinschmidt's Ethnographische Notizen aus den Jahren 1877/78 über die Bergbewohner von Viti Levu* (pp. 359–401). Baessler Archiv, NF 13 (1965). Berlin, Germany: Verlag von Dietrich Reimer.

Williams, T. (1858). *Fiji and the Fijians vol. 1, the Islands and their inhabitants*. Fiji Museum reprint 1982. Suva, Fiji Museum.

Zámolyi, F. (2004). *Traditionelle Fidschianische Architektur – Konstruktion-Funktion-Symbolik*. Wien, Austria: Unveröffentlichte Diplomarbeit, Tu-Wien.

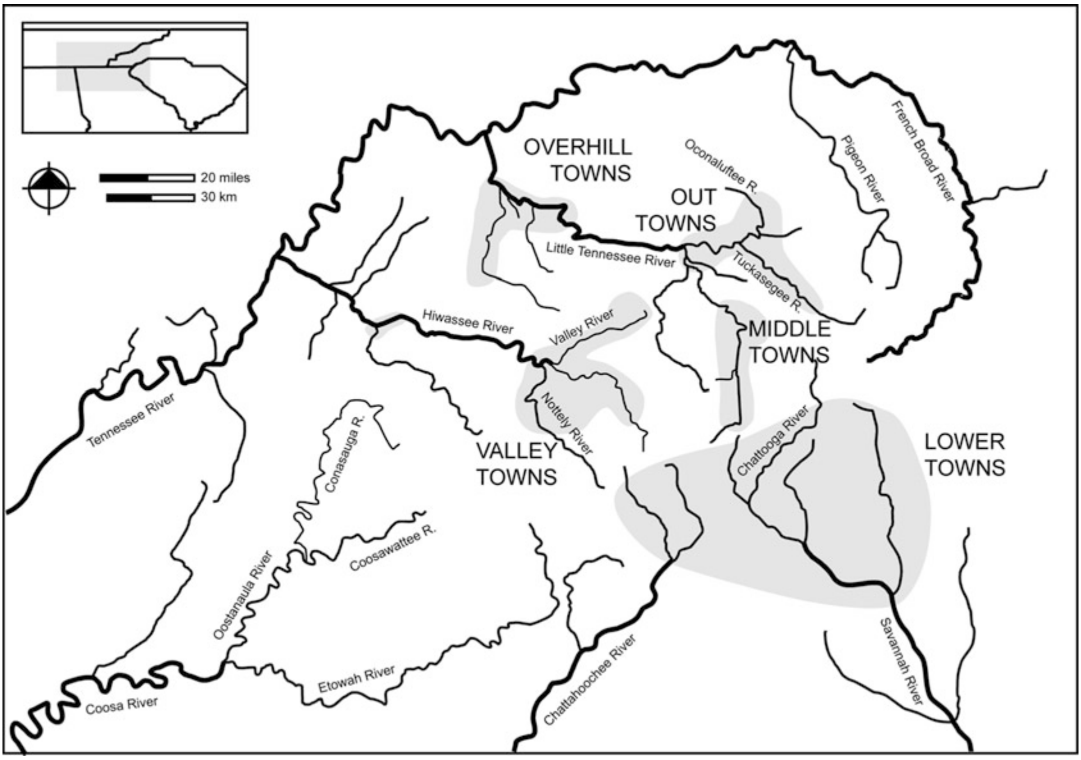
Architecture of the Cherokee

Christopher B. Rodning
Department of Anthropology, Tulane University, New Orleans, LA, USA

Several groups of Cherokee towns were present in the southern Appalachians during the period of early European contact in southeastern North America (Fig. 1). Different dialects of the Cherokee language were spoken in these discrete areas, although Cherokee town groups were connected by kinship and shared language and tradition. The Lower Cherokee towns were located in northeastern Georgia and northwestern South Carolina, along the headwaters of the Savannah and Chattahoochee rivers. The Middle Cherokee towns were situated along the headwaters of the Little Tennessee River in southwestern North Carolina. The Out Towns were located along the Tuckasegee River, and the Valley Towns along the upper reaches of the Hiwassee River, both in southwestern North Carolina. The Overhill Cherokee towns were located along the lower Little Tennessee and Tellico rivers in eastern Tennessee. Spanish conquistadores probably did not enter the heart of Cherokee country during explorations of the southeastern US during the sixteenth century A.D., but members of colonial expeditions led by Hernando de Soto and Juan Pardo did interact with people from Cherokee towns while traversing the southern Appalachians (Hudson, 1976, 1997, 2005). English colonists and traders from Virginia and South Carolina developed trade relations with Cherokee towns during the early eighteenth century, and the history of the deerskin trade and the Native American slave trade significantly impacted Cherokee and other Native American towns across the American South. These changes altered the spatial layouts of Cherokee towns, the locations of Cherokee towns on the landscape, and the kinds of architecture present in Cherokee towns and in rural areas between towns.

Archeological and documentary evidence from sites and sources dating from the 1500s through the 1700s indicate that Cherokee towns included public structures known as townhouses, large outdoor plazas adjacent to townhouses, and domestic structures and activity areas placed around those plazas (Riggs, 2008; Rodning, 2001a, 2002a, 2011a, 2015; Schroedl, 1978, 1986b, 2001). Cherokee towns typically included between 10 and 60 households, encompassing some 100–600 people. Cherokee groups traced descent through matrilines, and they typically practiced matrilocal postmarital residence, meaning that households typically included a woman, that woman's parents and perhaps siblings, one or more men who had married into the family, and children. Some towns in some areas may have been enclosed by log stockades, but not all, and log stockades are more the exception than the rule during the eighteenth century. Not all households lived within towns, and some people lived in small farmsteads situated in areas between major town centers (Cable, O'Steen, Raymer, Loubser et al., 1997; Shumate, Riggs, & Kimball, 2005).

Townhouses were square with rounded corners, or octagonal, in shape, ranging from 14 to 18 m in diameter (Rodning, 2011a; Schroedl, 1986b, 2000, 2001). They were built to accommodate all or nearly all of the people within each town at some community events, although some events that took place inside townhouses included smaller numbers of people. These structures were built on cleared surfaces, and the earth generated from clearing those surfaces or digging the basins in which townhouses were then built served as raw material for earthen embankments, walls, and roofs. Townhouses were built with log posts placed vertically in the ground forming the framework for walls made of wood and earth. Narrow vestibule entryways cut through earthen embankments, forming passageways connecting outside and inside. Log roof beams and large roof support posts supported roofs made of bark, thatch, and earth, with openings in the centers of those roofs forming smokeholes that let out smoke from the fires that were kept burning constantly inside townhouse hearths. Smaller townhouses typically had four roof support posts, placed in square patterns around central



Architecture of the Cherokee, Fig. 1 Locations of the Lower, Middle, Out, Valley, and Overhill Cherokee towns in the southern Appalachians

hearths. Larger and later townhouses often included eight roof support posts. It is not known how often Cherokee townhouses were renovated and rebuilt, but given the environment and climate of the southern Appalachians, and given the perishable raw materials with which townhouses were built, renovation, maintenance, renewal, and rebuilding were probably relatively common community-wide events and efforts. They probably necessitated significant community-wide investment in labor and the accumulation of wood, bark, thatch, and other materials. Broadly comparable public structures were present at sites in the greater southern Appalachians dating from the 1400s and 1500s (Hally, 2008; Polhemus, 1987; Schroedl, 1998; Sullivan, 1987). Townhouses were architectural symbols of the status of local households as a town. They were settings for town council deliberations and other public events, including periodic community feasts and dances. After European contact, townhouses were venues for diplomatic events involving leaders of Cherokee towns, people from other Native American towns and villages elsewhere in eastern North America, and colonial traders and agents of colonial governments.

Clay hearths at the centers of townhouses were settings for fires that imparted light and warmth and that were symbolic of the vitality of towns themselves. Community members, often male elders, were responsible for maintaining constant fires in townhouse hearths. The fires kept in townhouse hearths were sources of fire for kindling the fires in the hearths of domestic structures and household dwellings, and in some cases, the fires of townhouses in important Cherokee towns were carried to other towns. The constant or perpetual fires in Cherokee townhouse hearths symbolized the vitality and longevity of Cherokee towns and the Cherokee people. These fires were periodically put out during community renewal rituals, and ashes and embers from townhouse hearths were carefully discarded in carefully chosen pits or heaps in the vicinity of townhouses themselves.

Many townhouses were built and rebuilt in place, forming architectural sequences (Knight Jr, 2006), and, sometimes, townhouses were built on the summits of earthen platform mounds that were originally built during late prehistory, before European contact in the southern Appalachians. Similar long-term sequences of townhouses (and domestic structures) were present at sites dating from late prehistory through the early eighteenth century (Polhemus, 1987). Such long-term emplacement of structures and entire settlements became less common as households and entire towns became more and more mobile during the history of European contact and colonialism in the Americas (Marcoux, 2012). Some townhouses are known to have been built on the summits of platform mounds that were originally built during the late prehistoric period, including the mound at the sacred Cherokee town of Kituhwa (Riggs & Shumate, 2003). Written descriptions of Cherokee towns also note the presence of some Cherokee townhouses placed on the summits of precontact earthen mounds during the eighteenth century, including the townhouse that is known to have stood on the large earthen mound at Nequassee. That was recorded in written accounts of expeditions by colonial militias to Cherokee country in 1761 (Duncan & Riggs, 2003; King & Evans, 1977). During the late eighteenth century, the Quaker naturalist, William Bartram, visited Cherokee towns in the southern Appalachians. Bartram described a townhouse on the summit of the earthen mound at Cowee in 1775, and he also noted the ruins of abandoned townhouses on the summits of mounds at abandoned Cherokee town sites in northeastern Georgia and the western Carolinas (Rodning, 2002c).

Beside townhouses were rectangular ramadas, or porticos, that had roofs but not walls. These rectangular ramadas – often referred to as “summer” townhouses, situated beside “winter” townhouses, paired structures that were particularly important during those different seasons of the year – were approximately 16 by 16 m. Beside townhouses and townhouse ramadas were outdoor plazas, covering up to one hectare, and sometimes covered with clay or sand.

Households lived in domestic structures that were comparable in design and materials to townhouses, except that dwellings were much smaller than public structures. Just as there were townhouses and adjacent rectangular ramadas, so also were there square or octagonal “winter” houses and rectangular “summer” houses (Faulkner, 1978), and household dwellings were composed of a winter house paired with an adjacent summer structure (Schroedl, 2000). Winter houses ranged from seven to eight meters in diameter, and summer houses were roughly four meters wide by ten meters long. Winter houses typically included four roof support posts placed around central hearths, as in the case of townhouses (Rodning, 2009b; Schroedl, 1986b). These structures represent the same form of domestic architecture present at many late prehistoric Native American (Mississippian) sites in the greater southern Appalachians.

At sites dating from late prehistory through the seventeenth century, burials were often placed inside and beside public and domestic structures (Dickens, 1976; Hally, 2008; Rodning, 2001b, 2011b, 2012; Rodning & Moore, 2010; Ward & Davis, 1999). Houses and townhouses therefore marked the placements of burials and deceased ancestors. Building and rebuilding houses and townhouses in place kept living generations of Cherokee households and towns close to preceding generations and close to those structures themselves, and the increasing mobility of Cherokee households and entire towns during the course of trade and warfare in the eighteenth century probably diminished those close associations between people and particular places within the southern Appalachian landscape.

From late prehistory through the seventeenth century, dozens of Native American dotted the cultural landscape of the greater southern Appalachians. At most town sites, there were dense concentrations of houses and domestic activity areas, and some sites were very large. Beginning in the late seventeenth century, several large town sites were abandoned (Hatley, 1989), some

Cherokee towns moved to new locations (Smith, 1979), some Cherokee groups formed small settlements in remote areas (Marcoux, 2010), and architecture changed as seasonal movements related to hunting and the deerskin trade became more prevalent. These developments led to changes in regional settlement patterns (Goodwin, 1977), and town layouts became more spatially dispersed than they had been before, although townhouses and mounds continued to serve as focal points for spatially dispersed towns (Greene, 1999).

By the late eighteenth and early nineteenth century, traditional architectural forms were increasingly replaced by cabins and farm outbuildings that were broadly comparable to structures at Anglo-American settlements and farms. The traditional pattern of Cherokee towns surrounded by fields and farmsteads was replaced by a pattern of rural farmsteads spread along river valleys. By this point, some towns that encompassed houses, farms, fields, and woodlands spread across many miles of countryside, without the clear community centers in the form of Cherokee townhouses and plazas that were present through much of the eighteenth century.

Despite the "Europeanization" of the Cherokee landscape (Pillsbury, 1983) and the increasingly close resemblances between Cherokee and Anglo-American farmsteads in the southern Appalachians, some forms of traditional architecture persisted. Small, circular structures known as *asi*, or *osi*, "hot houses" associated with cabins and other forms of household dwellings were prevalent in the Cherokee landscape through the 1700s and 1800s. These "hot houses" preserved the post-in-ground wattle-and-daub architecture that was typical of Cherokee public and domestic architecture in the past. Meanwhile, townhouses were still built, including the townhouse at New Echota, the capital of the Cherokee Republic during the early nineteenth century, and at some other sites. That said, whereas each town formerly had its own townhouse, this architectural form was now built at only a relatively small number of sites.

From the period before European contact in the Americas through the early nineteenth century, the architecture of Cherokee towns and farmsteads in the southern Appalachians demonstrates both adaptability and cultural conservatism. At the point of Spanish contact in the 1500s, native towns in the southern Appalachians included public structures and plazas, surrounded by compact arrangements of domestic houses and activity areas. At the point when English trade networks reached Cherokee towns in the early 1700s, townhouses and plazas still marked the hubs of public life in Cherokee towns, and for much of the eighteenth century, public and domestic architecture included pairs of "winter" and "summer" structures. New forms of domestic architecture were developed in the 1700s and early 1800s as Cherokee groups adapted to cycles of trade, diplomacy, warfare, and other forms of entanglement among native and colonial societies in eastern North America. Those changes aside, there was stability and conservatism in some aspects of Cherokee architecture, including the townhouses, "hot houses," and earthen mounds that still dotted the southern Appalachian landscape in the early nineteenth century, just before the Cherokee Removal period and the forced movement of many Cherokee and other Native American people from the American South to Oklahoma.

At the end of the nineteenth century, earthen mounds and townhouses were no longer built, but mounds like those at Kituhwa, Cowee, Nequassee, and other Cherokee towns were still visible, and there was still knowledge of and cultural memory about building mounds and townhouses. The Smithsonian Institution ethnologist, James Mooney (1891, 1900), recorded a great many Cherokee oral traditions and created a compendium of Cherokee placenames based on his interactions with Cherokee elders in western North Carolina during the late nineteenth century. One of the "historical myths" documented by Mooney, "The Mounds and the Constant Fire: The Old Sacred Things" (Mooney, 1900, pp. 395–397) refers to the practices of building a mound and a townhouse, first by clearing a ground surface, burying one or several recently deceased chiefs and making other offerings and deposits in the ground, creating an earthen summit by bringing in many basketloads of earth, and building a townhouse on the summit of that mound. Mooney and other sources (e.g., Gearing, 1962, p. 23) refer to the importance of keeping the fire within the central hearths of townhouses burning constantly, an activity taken on primarily by male elders within Cherokee towns. It is said that those fires still burn today in some of the earthen mounds in Cherokee country, including the mounds at towns such as Kituhwa, Cowee, and Nequassee. The Eastern Band of the Cherokee Indians currently owns the land on which the Kituhwa and Cowee mounds are located, and the Nequassee mound is situated within a public park and a greenway along the Little Tennessee River. These and other mounds are vestiges of ancestral Cherokee architecture; other architectural remnants are present in the southern Appalachians buried underground, and some mounds and Cherokee town sites (Chauga, Estatoe, Seneca, Keowee, and others) are partly or entirely inundated by artificial lakes along the headwaters of the Savannah River.

Acknowledgments Thanks to Andrew Springer and David Watt for editorial assistance.

References

Anderson, D. G. (1994). *The Savannah River chiefdoms: Political change in the late prehistoric southeastern United States*. Tuscaloosa, AL: University of Alabama Press.

Baden, W. W. (1983). *Tomotley: An eighteenth-century Cherokee village. Report of Investigations 36*. Knoxville, TN: University of Tennessee, Department of Anthropology.

Boulware, T. (2011). *Deconstructing the Cherokee Nation: Town, region, and nation among eighteenth-century Cherokees*. Gainesville, TN: University Press of Florida.

Cable, J. S., O'Steen, L., Raymer, L. E., Loubser, J. H. N., Leigh, D. S., Joseph, J. W., Reed, M. B., Danielsson-Murphy, L., McEvoy, U., Murphy, T., Bonhage-Freund, M. T., & Wallsmith, D. (1997). *"A Picture Unsurpassed": Prehistoric and historic Indian settlement and landscape, Brasstown Valley, Towns County, Georgia*. Report submitted by New South Associates, Incorporated, to the Georgia Department of Natural Resources, Atlanta.

Chapman, J. (1985). *Tellico archaeology: 12,000 years of native American history*. Knoxville, TN: University of Tennessee Press.

Dickens, R. S., Jr. (1967). The route of Rutherford's expedition against the North Carolina Cherokees. *Southern Indian Studies, 19*, 3–24.

Dickens, R. S., Jr. (1976). *Cherokee prehistory: The Pisgah phase in the Appalachian Summit*. Knoxville, TN: University of Tennessee Press.

Dickens, R. S., Jr. (1978). Mississippian settlement patterns in the Appalachian Summit area: The Pisgah and Qualla phases. In B. D. Smith (Ed.), *Mississippian settlement patterns* (pp. 115–139). New York: Academic.

Dickens, R. S., Jr. (1979). The origins and development of Cherokee culture. In D. H. King (Ed.), *The Cherokee nation: a troubled history* (pp. 3–32). Knoxville, TN: University of Tennessee Press.

Dickens, R. S., Jr. (1986). Toward an explanation of Cherokee origins in east Tennessee. In D. G. Moore (Ed.), *The conference on Cherokee prehistory* (pp. 122–138). Swannanoa, NC: Warren Wilson College.

Duncan, B. R., & Riggs, B. H. (2003). *Cherokee heritage trails guidebook*. Chapel Hill, NC: University of North Carolina Press.

Ethridge, R. (2010). *From Chicaza to Chickasaw: The Spanish invasion and the transformation of the Mississippian world, 1540–1715*. Chapel Hill, NC: University of North Carolina Press.

Faulkner, W. H. (1978). The origin and evolution of the Cherokee winter house. *Journal of Cherokee Studies, 3*(2), 87–94.

Fogelson, R. D. (2004). Cherokee in the East. In R. D. Fogelson (Ed.), *Smithsonian handbook of North American Indians, volume 14: Southeast* (pp. 337–353). Washington, DC: Smithsonian Institution.

Gearing, F. O. (1962). *Priests and warriors: Structures for Cherokee politics in the eighteenth century. Memoir 93*. Menasha, WI: American Anthropological Association.

Gilbert, W. H., Jr. (1937). Eastern Cherokee social organization. In F. Eggan (Ed.), *Social anthropology of the North American tribes* (pp. 285–338). Chicago: University of Chicago Press.

Gilbert, W. H., Jr. (1943). *The Eastern Cherokees. Bureau of American ethnology bulletin 133* (pp. 169–413). Washington, DC: Smithsonian Institution.

Goodwin, G. C. (1977). *Cherokees in transition: A study of changing culture and environment prior to 1775. Research paper 181*. Chicago: University of Chicago, Department of Geography.

Greene, L. K. (1999). *The archaeology and history of the Cherokee out towns* (Volumes in historic archaeology, Vol. 40). Columbia, SC: South Carolina Institute of Archaeology and Anthropology.

Hally, D. J. (1986). The Cherokee archaeology of Georgia. In D. G. Moore (Ed.), *The conference on Cherokee prehistory* (pp. 95–121). Swannanoa, NC: Warren Wilson College.

Hally, D. J. (2002). "As caves beneath the ground": Making sense of aboriginal house form in the protohistoric and historic Southeast. In C. B. Wesson & M. A. Rees (Eds.), *Between contacts and colonies: Archaeological perspectives on the protohistoric Southeast* (pp. 90–109). Tuscaloosa, AL: University of Alabama Press.

Hally, D. J. (2008). *King: The social archaeology of a late Mississippian town in northwestern Georgia*. Tuscaloosa, AL: University of Alabama Press.

Harmon, M. A. (1986). *Eighteenth century Lower Cherokee adaptation and use of European material culture* (Volumes in historic archaeology, Vol. 2). Columbia, SC: South Carolina Institute of Archaeology and Anthropology.

Hatley, T. (1989). The three lives of Keowee: Loss and recovery in eighteenth-century Cherokee villages. In P. H. Wood, G. A. Waselkov, & T. Hatley (Eds.), *Powhatan's Mantle: Indians in the colonial Southeast* (pp. 223–248). Lincoln, NE: University of Nebraska Press.

Hatley, T. (1993). *The dividing paths: Cherokees and South Carolinians through the era of revolution*. Oxford: Oxford University Press.

Hatley, T. (2006). Cherokee women farmers hold their ground. In Waselkov, G. A., Wood, P. H., & Hatley, T. (Eds.), *Powhatan's Mantle: Indians in the colonial Southeast* (*revised and expanded edition*, pp. 305–335). Lincoln, NE: University of Nebraska Press.

Hill, S. H. (1997). *Weaving new worlds: Southeastern Cherokee women and their basketry*. Chapel Hill, NC: University of North Carolina Press.

Hudson, C. (1976). *The Southeastern Indians*. Knoxville, TN: University of Tennessee Press.

Hudson, C. (1986). Some thoughts on the early social history of the Cherokees. In D. G. Moore (Ed.), *The conference on Cherokee prehistory* (pp. 139–153). Swannanoa, NC: Warren Wilson College.

Hudson, C. (1997). *Knights of Spain, warriors of the sun: Hernando de Soto and the South's ancient chiefdoms*. Athens, GA: University of Georgia Press.

Hudson, C. (2005). *The Juan Pardo expeditions: Explorations of the Carolinas and Tennessee, 1566–1568*. Tuscaloosa, AL: University of Alabama Press.

Keel, B. C. (1976). *Cherokee archaeology: A study of the Appalachian Summit*. Knoxville, TN: University of Tennessee Press.

Kelly, A. R., & de Baillou, C. (1960). Excavation of the presumptive site of Estatoe. *Southern Indian Studies, 12*, 3–30.

Kelly, A. R., & Neitzel, R. S. (1961). *The Chauga mound and village site in Oconee County, South Carolina. Report 3*. Athens, GA: University of Georgia, Laboratory of Archaeology.

King, D. H. (1979). Introduction. In D. H. King (Ed.), *The Cherokee nation: A troubled history* (pp. ix–xix). Knoxville, TN: University of Tennessee Press.

King, D. H., & Evans, E. R. (1977). Memoirs of the Grant expedition against the Cherokees in 1761. *Journal of Cherokee Studies, 2*(3), 272–337.

Knight, V. J., Jr. (2006). Symbolism of Mississippian mounds. In Waselkov, G. A., Wood, P. H., & Hatley, T. (Eds.), *Powhatan's mantle: Indians in the colonial Southeast* (Revised and Expanded Edition, pp. 421–434). Lincoln, NE: University of Nebraska Press.

Marcoux, J. B. (2010). *Pox, empire, shackles, and hides: The Townsend site, 1670–1715*. Tuscaloosa, AL: University of Alabama Press.

Marcoux, J. B. (2012). *The Cherokees of Tuckaleechee Cove* (Memoir 52). Ann Arbor, MI: University of Michigan, Museum of Anthropology.

Martin, J. W. (1994). Southeastern Indians and the English trade in skins and slaves. In C. Hudson & C. C. Tesser (Eds.), *The Forgotten Centuries: Indians and Europeans in the colonial South, 1521–1704* (pp. 304–324). Athens, GA: University of Georgia Press.

Mooney, J. (1891). *Sacred formulas of the Cherokee* (Bureau of American ethnology annual report 7, pp. 302–397). Washington, DC: Smithsonian Institution.

Mooney, J. (1900). *Myths of the Cherokee* (Bureau of American ethnology annual report 19, pp. 1–576). Washington, DC: Smithsonian Institution.

Moore, D. G. (2002). Pisgah phase village evolution at the Warren Wilson site. *Southeastern Archaeological Conference Special Publication, 7*, 76–83.

Oatis, S. J. (2004). *A colonial complex: South Carolina's frontiers in the era of the Yamasee War, 1680–1730*. Lincoln, NE: University of Nebraska Press.

Perdue, T. (1998). *Cherokee women: Gender and culture change, 1700–1838*. Lincoln,NE: University of Nebraska Press.

Persico, V. R., Jr. (1979). Early nineteenth-century Cherokee political organization. In D. H. King (Ed.), *The Cherokee nation: A troubled history* (pp. 92–109). Knoxville, TN: University of Tennessee Press.

Pillsbury, R. (1983). The Europeanization of the Cherokee settlement landscape prior to Removal: A Georgia case study. In R. W. Neuman (Ed.), *Historical archaeology of the eastern United States* (Geosciences and man, Vol. 23, pp. 59–69). Baton Rouge, LA: Louisiana State University.

Pillsbury, R. (2006). Cherokee settlement. In R. Pillsbury (Ed.), *The new encyclopedia of Southern culture, volume 2: Geography*. Chapel Hill, NC: University of North Carolina Press.

Polhemus, R. R. (Ed.). (1987). *The Toqua site: A late Mississippian Dallas phase town* (Report of investigations, Vol. 41). Knoxville, TN: University of Tennessee, Department of Anthropology.

Polhemus, R. R. (1990). Dallas phase architecture and sociopolitical structure. In M. Williams & G. Shapiro (Eds.), *Lamar archaeology: Mississippian chiefdoms in the deep South* (pp. 125–138). Tuscaloosa, AL: University of Alabama Press.

Ramsay, W. L. (2008). *The Yamasee War: A study of culture, economy, and conflict in the colonial South*. Lincoln, NE: University of Nebraska Press.

Riggs, B. H. (1997). The Christie Cabin Site: Historical and archaeological evidence of the life and times of a Cherokee Métis Household (1835–1838). In R. S. Brunk (Ed.), *May we all remember well: A journal of the history and cultures of Western North Carolina* (pp. 228–248). Asheville, NC: R. S. Brunk Auction Services.

Riggs, B. H. (2008). *A synthesis of documentary and archaeological evidence for early eighteenth century Cherokee villages and structures: Data for the reconstruction of the Tsa-La-Gi ancient village, Cherokee Heritage Center, Park Hill, Oklahoma*. Report on file at the Research Laboratories of Archaeology, University of North Carolina, Chapel Hill, NC.

Riggs, B. H., & Shumate, M. S. (2003). *Archaeological testing at Kituhwa: 2001 investigations at 31SW1, 31SW2, 31SW287, 31SW316, 31SW317, 31SW318, and 31SW320*. Report submitted to the Eastern Band of Cherokee Indians, Office of Cultural Resources, Cherokee, NC.

Rodning, C. B. (2001a). Mortuary ritual and gender ideology in protohistoric southwestern North Carolina. In J. M. Eastman & C. B. Rodning (Eds.), *Archaeological studies of gender in the Southeastern United States* (pp. 77–100). Gainesville, FL: University Press of Florida.

Rodning, C. B. (2001b). Architecture and landscape in late prehistoric and protohistoric Western North Carolina. In L. P. Sullivan & S. C. Prezzano (Eds.), *Archaeology of the Appalachian highlands* (pp. 238–249). Knoxville, TN: University of Tennessee Press.

Rodning, C. B. (2002a). The townhouse at Coweeta Creek. *Southeastern Archaeology, 21*(1), 10–20.

Rodning, C. B. (2002b). Reconstructing the coalescence of Cherokee communities in southern Appalachia. In R. Ethridge & C. Hudson (Eds.), *The Transformation of the Southeastern Indians, 1540–1760* (pp. 155–175). Jackson, MS: University Press of Mississippi.

Rodning, C. B. (2002c). William Bartram and the archaeology of the Appalachian Summit. In C. B. Wesson & M. A. Rees (Eds.), *Between contacts and colonies: Archaeological perspectives on the protohistoric Southeast* (pp. 67–89). Tuscaloosa, AL: University of Alabama Press.

Rodning, C. B. (2009a). Mounds, myths, and Cherokee townhouses in southwestern North Carolina. *American Antiquity, 74*(4), 627–663.

Rodning, C. B. (2009b). Domestic houses at Coweeta Creek. *Southeastern Archaeology, 28*(1), 1–26.

Rodning, C. B. (2010). Architectural symbolism and Cherokee townhouses. *Southeastern Archaeology, 29*(1), 59–79.

Rodning, C. B. (2011a). Cherokee townhouses: Architectural adaptation to European contact in the southern Appalachians. *North American Archaeologist, 32*(2), 131–190.

Rodning, C. B. (2011b). Mortuary practices, gender ideology, and the Cherokee town at the Coweeta Creek site. *Journal of Anthropological Archaeology, 30*(2), 145–173.

Rodning, C. B. (2012). Late prehistoric and protohistoric shell gorgets from southwestern North Carolina. *Southeastern Archaeology, 31*(1), 33–56.

Rodning, C. B. (2013). Architecture of aggregation in the southern Appalachians: Cherokee townhouses. In J. A. Birch (Ed.), *From prehistoric villages to cities: Settlement aggregation and community transformation* (pp. 179–200). London: Routledge.

Rodning, C. B. (2015). *Center places and Cherokee towns: Archaeological perspectives on Native American architecture and landscape in the southern Appalachians*. Tuscaloosa, AL: University of Alabama Press.

Rodning, C. B., & Moore, D. G. (2010). South Appalachian Mississippian and protohistoric mortuary practices in southwestern North Carolina. *Southeastern Archaeology, 29*(1), 80–100.

Rudolph, J. L. (1984). Earth lodges and platform mounds: Changing public architecture in the southeastern United States. *Southeastern Archaeology, 3*(1), 33–45.

Russ, K. C., & Chapman, J. (1983). *Archaeological investigations at the eighteenth-century Cherokee town of Mialoquo* (Report of investigations, Vol. 37). Knoxville, TN: University of Tennessee, Department of Anthropology.

Schroedl, G. F. (1978). Louis-Philippe's journal and archaeological investigations at the eighteenth-century Overhill Cherokee town of Toqua. *Journal of Cherokee Studies, 3*(4), 206–220.

Schroedl, G. F. (1986a). Toward an explanation of Cherokee origins in east Tennessee. In D. G. Moore (Ed.), *The conference on Cherokee prehistory* (pp. 122–138). Swannanoa, NC: Warren Wilson College.

Schroedl, G. F. (Ed.). (1986b). *Overhill Cherokee archaeology at Chota-Tanasee* (Report of investigations, Vol. 38). Knoxville, TN: University of Tennessee, Department of Anthropology.

Schroedl, G. F. (1998). Mississippian towns in the eastern Tennessee Valley. In R. B. Lewis & C. Stout (Eds.), *Mississippian towns and sacred spaces: Searching for an architectural grammar* (pp. 64–92). Tuscaloosa, AL: University of Alabama Press.

Schroedl, G. F. (2000). Cherokee ethnohistory and archaeology from 1540 to 1838. In B. G. McEwan (Ed.), *Indians of the greater southeast: Historical archaeology and ethnohistory* (pp. 204–241). Gainesville, FL: University Press of Florida.

Schroedl, G. F. (2001). Cherokee archaeology since the 1970s. In L. P. Sullivan & S. C. Prezzano (Eds.), *Archaeology of the Appalachian highlands* (pp. 278–297). Knoxville, TN: University of Tennessee Press.

Shumate, M. S., Riggs, B. H., & Kimball, L. R. (2005). *The Alarka farmstead site: Archaeological investigations at a mid-seventeenth-century Cherokee winter house/summer house complex, Swain County, North Carolina*. Report submitted by the Appalachian State

University Laboratories of Archaeological Science to National Forests in North Carolina, Asheville.
Smith, B. A. (1979). Distribution of eighteenth-century Cherokee settlements. In D. H. King (Ed.), *The Cherokee nation: A troubled history* (pp. 46–60). Knoxville, TN: University of Tennessee Press.
Smith, M. T. (1987). *Archaeology of aboriginal culture change in the interior Southeast: Depopulation during the early historic period*. Gainesville, FL: University Press of Florida.
Sullivan, L. P. (1987). The Mouse Creek phase. *Southeastern Archaeology, 6*(1), 16–29.
Sullivan, L. P. (1995). Mississippian household and community organization in eastern Tennessee. In J. D. Rogers & B. D. Smith (Eds.), *Mississippian communities and households* (pp. 99–123). Tuscaloosa, AL: University of Alabama Press.
Ward, H. T., & Davis, R. P. S., Jr. (1999). *Time before history: The archaeology of North Carolina*. Chapel Hill, NC: University of North Carolina Press.
Waselkov, G. W. (1994). The Macon trading house and early European-Indian contact in the colonial Southeast. In D. J. Hally (Ed.), *Ocmulgee archaeology, 1936–1986* (pp. 190–196). Athens, GA: University of Georgia Press.
Waselkov, G. A., & Holland, K. E. H. (Eds.) (1995). *William Bartram on the Southeastern Indians*. Lincoln, NE: University of Nebraska Press.
Wilms, D. C. (1974). Cherokee settlement patterns in nineteenth-century Georgia. *Southeastern Geographer, 14*(1), 46–53.
Wilms, D. C. (1991). Cherokee land use in Georgia before Removal. In W. L. Anderson (Ed.), *Cherokee removal, before and after* (pp. 1–28). Athens, GA: University of Georgia Press.

Architecture of the Maori People

Michael Linzey

The most striking fact about Maori architecture is that it is a living presence in the traditional heart of the community. When a New Zealand Maori orator stands to speak in front of a meetinghouse, he (or sometimes soon it may be she) addresses the house directly and in the same breath also addresses the assembled people. This fundamental understanding that the *wharenui* (meetinghouse) is a living presence is richer than any mere simile, it is beyond the idea of a metaphor or a representation in the European sense (Mead, 1984). The house is not *like* an ancestor, it *is* the ancestor. Maori people conceive of cosmogenesis as an evolution in three parts: *te kore* is a nothingness condition of endless possibility, *te po* is a long night that is rich in potentiality, and *te ao marama* is the world of light which is to say the actuality of the real world. These three fundamental states of existence are represented on the door lintels of traditional architecture (Simmons, 1985, pp. 43–47). This traditional understanding resembles the triadic cosmogony of Peirce (1992, v. 1, pp. 285–297); it may not be entirely surprising therefore that the idea of an interconnected life-force, *mauri*, pervades the physical world of the Maori, and that architecture is included in this universal embrace.

I am not talking here about the precontact condition of Maori architecture [about which anyway very little is known (Phillipps, 1952)]. What is more significant is that the Maori comportment toward architecture has survived within a predominantly European ambience of New Zealand life, perhaps indeed it developed more pronouncedly within the clash of cultures that was the introduction of colonialism and the rise of nationalism during the nineteenth and twentieth centuries. Modern Maori are not isolated from the majority culture, just as in New Zealand nothing European can claim to be isolated from the Maori presence. But whereas we sometimes lament the loss of meaning within European architecture, and some even go so far as to say that architecture is dead, the architecture of the Maori by contrast is radically alive. It is a living example of the scientific condition that Peirce called "objective idealism," in which the material world itself is understood to be fundamentally alive.

In the confines of this short article three aspects of the living meaning of Maori architecture are addressed. They are its *faciality*, its ornament, and an aspect of its *space*. Relevant terms in the Maori language are *mataihi*, *whakairo*, and *kauhanga*. These are not general terms; they have meanings that are quite specific to architecture. In particular the *wharenui* is often also called (and addressed as) *whare whakairo*, meaning a house that is adorned with pattern. *Mataihi* specifically means the gable-end (the front) face of the *wharenui*, and *kauhanga* or *kauwhanga* is the interior space down the middle of the *wharenui* specifically when it is in a *tapu* or highly potent state. Necessarily these three aspects of architecture have to be addressed separately in this article, but they are not separate, not even interrelated concepts. Rather they are three valences that together go to make up the single meaning of addressing the *mauri* or life force in Maori architecture. If I may follow Peirce for a little bit longer, this triadic situation can be compared to an ordinary street sign. A street sign also *faces* us, *points* out a direction in the world, and *tells* us something about what is happening in that direction. The three valences *together* make up the whole meaning of the sign. A reader may be advised to take in what follows here, necessarily in the sequential order of the text, and then to think about it again in a few days time. Perhaps then some small appreciation may be gained about the liveliness of Maori architecture as a whole triadic sign.

Faciality, *Mataihi*

In Maori, as in most of the Austronesian languages, *mata* is a word that signified the leading part or the growing tip of something. It does not indicate a direction, but a frontal *sense* of direction. As well as meaning a person's face, *mata* can also be a prominent geographical point, like a headland, or a rock which marks the leading boundary between fishing grounds. The prefix *mata-* is used in words that mean a first appearance, for example *mataika* is the first person slain in a battle. *Mataaho* is the window of a house, metaphorically perhaps we could think of it as the "eye" of the house. *Mataihi* is the gable-end "face" of the meetinghouse. In the *Williams Dictionary of the Maori Language*, the word *mataaho* was recorded as early as the first Edition (1844). *Mataihi* appeared for the first time only in the fifth edition (1917). This is not to say that *mataihi* was not a traditional word, but its architectural meaning was perhaps less obvious to early lexographers than *mataaho* was.

Internationally, the ornamental *mataihi* of the *wharenui* is the best-known icon of Maori architecture, comparable to the full *moko* tattooing of the chiefly face. As often as not it is the stately face of Te Tokanganui-a-noho that has carried this image of Maori architecture to the wider world. Te Tokanganui-a-noho is one of the oldest extant meetinghouses. It was built and reconstructed and relocated over a period of years from 1873 to 1882 under the supervision of a visionary leader of the time, who was also the founder of the Ringatu Church, named Te Kooti Arikirangi Te Turuki (Binney, 1995, pp. 272–281). The design of this house not only reaffirmed traditional values in a time at which Maori were experiencing all sorts of upheavals, it was also without doubt the most innovative house of this period and it started many trends that were taken up in later meetinghouses. In particular Roger Neich (1993, pp. 175–185) notes that most of the carvings on the gable-end face of this meetinghouse (with the notable exception of the carved door lintel and doorposts) were brilliantly delineated with polychrome paint; naturalistic flowers and religious symbols were painted on the vertical boards inside the porch, and naturalistic portraits of historic personages were on the door panels.

Almost all modern (postrenaissance) meetinghouses in New Zealand now adopt the traditional gable-end form. However the rectangular plan of the *wharenui* and the characteristic gable-end porch is not the only form in which Maori architecture has ever been expressed. A very traditional *whare wananga* or house of learning named Miringa Te Kakara was first built probably in the 1860s and destroyed by fire in the 1980s. This beautiful work had a distinctive cross-shaped plan and four *mataihi* facing the directions of four mountain ranges. Another memorable image is that of the circular "beehive" shaped assembly house named Hiona which was built early in the twentieth century by Rua Kenena (Binney, 1996). An awkward-seeming scaffold, platform and staircase were constructed to one side of Hiona which may have been a necessary substitution for faciality in the form of this work. Many Maori churches too do not display the traditional *mataihi* form. In the case of one early church, Rangiatea, completed in 1851 by the famous chief Te Rauparaha, it is recorded that the Reverend Samuel Williams played an important role in its design when after a dispute and in the middle of the night he cut a 10 ft length off the ridge pole. It is interesting to speculate that the dispute may have been related to a perceived conflict between the more traditional Maori expression of faciality, which would have required the extended ridge pole (*tahu*) to support a gable-end porch, and the shorter inward-looking Christian church form that was eventually adopted.

In the case of the pan-tribal meetinghouse Te Hono-ki-Hawaiki which was recently incorporated in the Museum of New Zealand Te Papa Tongarewa in Wellington, the meetinghouse almost seems to be reduced to a pure expression of *mataihi* or face (http://www.tepapa.govt.nz/virtualhighlight/Marae_english.html). The designer Cliff Whiting comments that this was partly a result of compromises that were necessary to develop a pantribal *kawa* (protocol). The Maui family group was adopted to embrace the widest possible sector of the population including Maori and Pacific Island people. Te Ati Awa and Ngati Toa, as *tangata whenua*, the local hosts, were made responsible for figures on the *amo*, the two side posts of the meetinghouse, while many other figures on the gable-end have yet to be named at all. Whiting remarks that *iwi* (tribal groups) from all other parts of the country can opt to "come into it" or not as they wish. In this sense the *kawa* of Te Hono-ki-Hawaiki is in a state of incompleteness, like the incomplete, yet to be negotiated political *kawa* of biculturalism in New Zealand. Its *mataihi* signifies a dynamic temporal sense of "facing the future" and of going forward with political intent. It has often been remarked that the classical Maori body "faced" the past and had its back to the future, and the front of a meetinghouse more often represents a region of timeless myth and legend (Neich, 1993, p. 232). This modern version of *mataihi* at Te Papa in effect employs the myth of Maui in a bicultural context in order to "face" an unformed future.

Ornament, *Whakairo*

Whakairo means to adorn with a pattern, to give direction, to form and inform aspects of any artistic construction whatsoever. The word was recorded in the first Edition (1844) of the *Williams Dictionary* but with only the limited meaning of "carved, carving, to carve." The prefix *whaka*-, meaning "toward, in the direction of," first appeared in the third Edition (1871). A 1915 version (which was not a separate Edition) of the *Dictionary* extended the meaning of *whakairo* to include "carve, adorn with carving." Two years later this was replaced with the fuller meaning, "ornament with a pattern, used of carving, tattooing, painting, weaving." Today the meaning of *whakairo* has been further extended to also embrace such activities as sculpture, printmaking and spatial design. Thus a *whare whakairo* may not necessarily be a *carved* meetinghouse at all. The decorative scheme of Rongopai, for example, a beautiful 1887 meetinghouse, comprises "a magnificent statement of tribal identity and joyous optimism" (Neich, 1993, p. 192) that is expressed predominantly through painted figures and patterns rather than through woodcarving.

The architectural meaning of *whakairo* "giving direction" and constructing an orientation for people in the world is expressed in every meetinghouse through the orientation of the *tahu*, the long imposing horizontal ridge pole which is sometimes also called *tahuhu*. The *tahu* or *tahuhu* is normally painted with distinctive *kowhaiwhai* patterns in the interior and carved where it joins with the exterior scheme of the *mataihi* under the roof of the porch. What is however a more fundamental aspect of *whakairo* of the *tahu* is its horizontal *orientation*, its direction in the world.

We might say that Te Kooti was the principal architect not only of the Ringatu Church but also of the meetinghouse in its modern form. Te Kooti adopted the meetinghouse form as a way to subvert the intention of the Christian mission church, or to transform the Christian message according to Maori protocols. In place of the tall closed box and the spire pointing upward to heaven, which was a form of church architecture already familiar in Maori villages throughout New Zealand, Te Kooti emphatically reasserted the authority of the *wharenui* form, and in particular the horizontal *tahu* that points to a real horizon.

Roger Neich (1993, pp. 229–234) describes how the *tahu* not only marks the place of the *marae* (the village and its formal gathering place) as a specific location in the world but also describes a direction within and across this place. Referring specifically to a Ringatu meetinghouse named Tutamure at Omarumutu *marae* near Whakatane, Neich identifies multiple layers of interconnected narratives through which the *tahu* points out and constructs a meaningful direction in the world. Firstly Neich writes it points to the openness of the *marae* forecourt in front of the *wharenui*, and to closure at the rear. Then it points to the ocean and the land, the sea and the forest (pointing out that the technoeconomic resources of the local people are found in front of and behind the house, respectively). The ridgepole of the meetinghouse also points to Hawaiki and New Zealand (as directions in front and behind in cosmological space), and to the canoe immigrants (in this case the Mataatua and Nukutere canoes) and the Tino-o-Toi aborigines (directions of arrival, confrontation and retreat in the sociological space of tribal history).

Almost every *marae* has stories similar to this associated with the horizontal pointing form of the *tahu* of the *wharenui*. The "point" of the meetinghouse is this fundamental *whakairo* gesture. It is interesting to note that the Anglican Holy Trinity Cathedral in Auckland recently extended the nave with a strong *wharenui*-like horizontal gesture, but that the church authorities did not see fit to build a vertical campanile (contrary to the advice of the architect).

Space, Kauhanga

Kauhanga is a term that means the interior space of the meetinghouse specifically when it is *tapu*. There are other words also that refer to interior space, for example *tara iti* is the space on the inside left of the *wharenui* and *tara nui* is that on the right (as one enters the house from the front.) Literally *tara* refers to the side walls of the house as well as meaning the inside spaces. Whenever a new *wharenui* is constructed a great deal of negotiation takes place to decide which ancestors and stories should be represented and the most appropriate spatial relationships. Naturally, as with any architectural design, the interior space becomes charged with potential meanings far in excess of what is actually built. The highly potent *tapu* condition of a new meetinghouse is dissipated in ritual processes called *whakanoa*.

The *tapu* space is often implicated in what might be called prophetic lore or *kupu whakaari* that is associated with the opening of meetinghouses. One famous example is a prediction or warning that Te Kooti is said to have made when he attended the reopening of Te Tokanganui-a-noho in 1883. It is recorded that Te Kooti said "The day will come when the God of the Pakeha will whistle in these places,. . . entering right into the porch of the house and coming straight through the back of it. . .." (Binney, 1995, p. 278). Te Kooti also said of another meetinghouse, Ruataupare, that ". . . one wall is arguing against the other, and the door against the back wall." (Binney, p. 328). This is not the place to enter into the interpretation of these prophetic sayings. What is significant is the fact that the *kauhanga* space of the meetinghouse is implicated in them.

Since Maori architecture is alive and its meaning is alive, therefore it is appropriate to speak to the *wharenui*, and also on occasion to speak as it were *through* the *wharenui*, to allow the architecture of the house to structure and guide what is said. Even on some occasions of *whaikorero* or formal talking it is appropriate that the *wharenui* itself speaks. As Hohepa Kereopa succinctly expressed it, "The whaikorero is based on the idea of how a whare is built" (Moon, 2003, p. 113).

References

Binney, J. (1995). *Redemption songs, a life of Te Kooti Arikirangi Te Turuki*. Auckland, New Zealand: Auckland University Press.

Binney, J. (1996). *Mihaia: The Prophet Rua Kenana and his community at Maungapohatu*. Auckland, New Zealand: Auckland University Press.

Mead, H. (Ed.). (1984). *Te Maori, Maori art from New Zealand collections*. Auckland, New Zealand: Heinemann.
Moon, P. (2003). *Tohunga Hohepa Kereopa*. Auckland, New Zealand: David Ling.
Neich, R. (1993). *Painted histories, early Maori figurative painting*. Auckland, New Zealand: Auckland University Press.
Peirce, C. S. (1992). In N. Houser & C. Kloesel (Eds.), *The essential Peirce, selected philosophical writings, volume 1 (1867–1893)*. Bloomington, IN: Indiana University Press.
Phillipps, W. J. (1952). *Maori houses and food stores* (Dominion museum monograph no. 8). Wellington, New Zealand: Government Printer.
Simmons, D. (1985). *Whakairo, Maori tribal art*. Auckland, New Zealand: Oxford University Press.
Williams, H. W. (1971). *A dictionary of the Maori language* (7th ed.). Wellington, New Zealand: Government Printer.

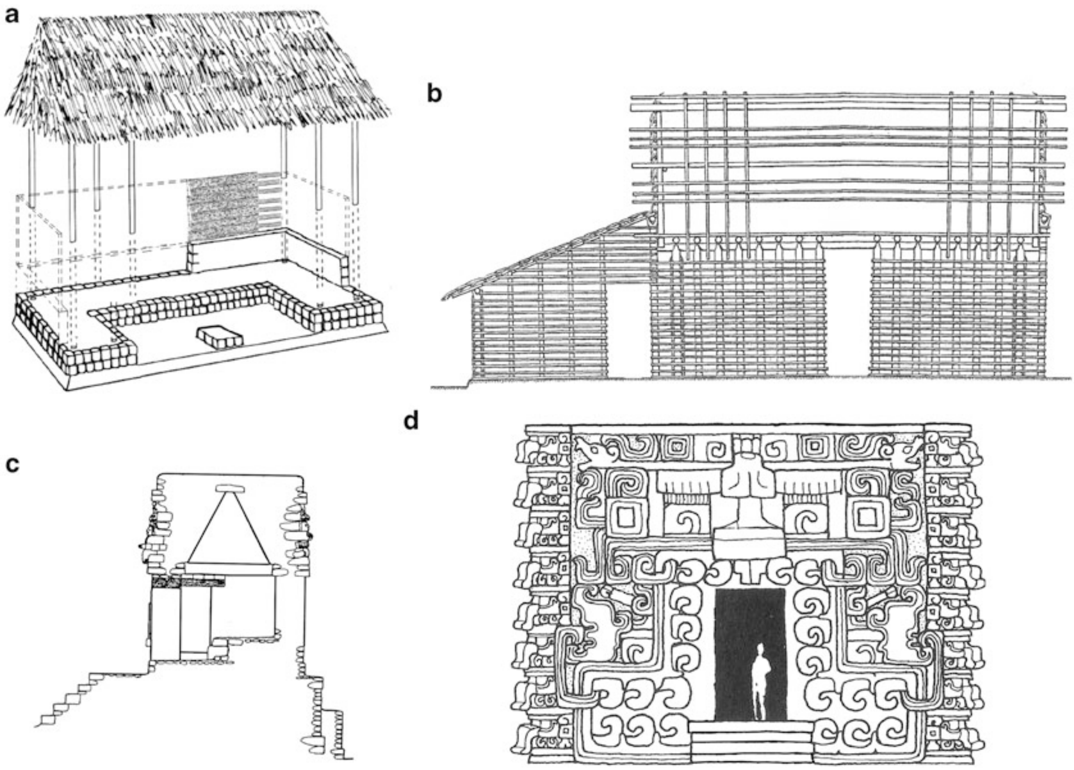
Architecture of the Maya

Kevin Schwarz
ASC Group Inc., Columbus, OH, USA

The Pre-Columbian Maya of southern Mexico and Central America had one of the most developed architectural traditions among indigenous cultures of the Americas. The Maya building tradition originated in the Preclassic period (2000 B.C.–A.D. 100) and reached an apogee of development in the Classic period (A.D. 200–A.D. 850). The Classic Maya Collapse (A.D. 800–1000), Spanish Conquest (A.D. 1521–A.D. 1697), and subsequent Colonial period (until A.D. 1821) affected Maya civilization in various ways, and this included their architecture. The Maya abandoned many of their urban civic-ceremonial centers in certain regions. Buildings crumbled and were covered by forests. The construction of large temples and carved stone stelae decreased and then ceased. Some Maya remained and built smaller-scale civic-ceremonial centers, however. Architectural traditions continued in the Postclassic period (A.D. 1000–A.D. 1525) although the Maya transformed certain aspects of their architecture (Schwarz, 2013). Smaller temples and shrines emerged and new building types such as open halls became common (Fig. 1a). After the Spanish Conquest, the Maya only continued some of their pre-Columbian building traditions. They adapted to the new cultural setting as they found themselves becoming peasants in the developing colonies and Central American states and Mexico.

Archaeologists spent much of the late nineteenth and early twentieth century rediscovering and reconstructing pre-Columbian Maya centers and buildings. The overall emphasis was on determining architectural function and on restoring the buildings themselves. These tasks continue (Fig. 2). However, archaeologists increasingly have studied the cultural processes by which the Maya created architecture, such as their architectural technology (Abrams, 1994) and their process of design (Schwarz, 2013). They also have researched how the Maya conceptualized the built environment (Houston, 1998) and dwelt within it (Hutson, 2010). Another topic of interest is identifying how building programs corresponded to political and dynastic histories. Also, increasingly sophisticated analyses of architectural plans (Ashmore & Sabloff, 2002), coupled with better iconographic analyses and decipherment of Maya hieroglyphs, mean that now an appreciation is developing of the symbolic and semiotic aspects of Maya architecture and use of space.

With these themes in mind, this article focuses on Maya architectural design, architectural technology, and architectural symbolism and semiotics. What archaeologists had presented as a static view of a Stone Age culture of builders is now resolved to such a degree that we can see the innovation, consensus, freedom, and play inherent in the creation and modification of these buildings (Schwarz, 2013). Through the study of architecture, archaeologists can reconstruct, to some extent, the kinds of constraints and opportunities Maya architects and builders faced. And they can posit realistic reconstructions of how the Maya actively changed their buildings over time, from the royal precincts of the largest classic civic-ceremonial centers to the huts of the



Architecture of the Maya, Fig. 1 Maya Buildings. (**a**) Postclassic open hall, Quexil Islands, Guatemala (From Schwarz, 2013); (**b**) twentieth-century Maya pole-framed house, Coban, Guatemala (Adapted from Wauchope, 1938); (**c**) vaulted residential structure 9 N-82C, Copán, Honduras (Adapted from Abrams, 1994); (**d**) temple at Tabasqueño, Mexico. The entire frontal facade is a god mask (Adapted from Schele, 1998)

Architecture of the Maya, Fig. 2 Step pyramid being reconstructed at Xunantunich, Belize, in 2001. On the *right side*, the building facade is collapsed while on the *left* is a partially restored structure modern Lacandon people. The Maya changed their architecture and innovated as their needs changed and as they responded to the social and environmental challenges they faced.

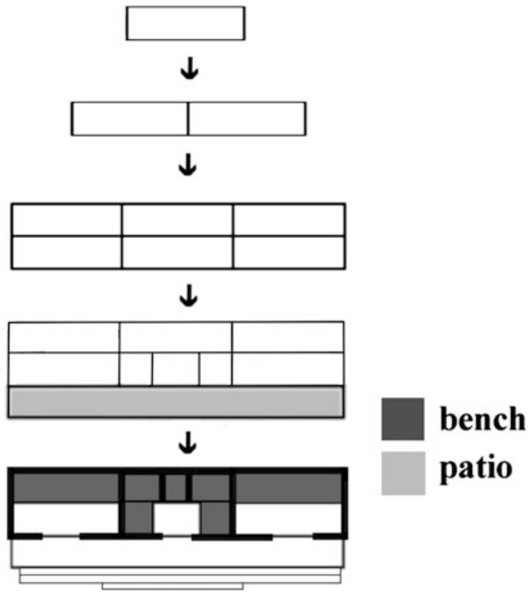
Architectural Design

The art historian George Kubler (1961) wrote that Maya architecture derives from several basic forms, including the hut, the platform, and the path. All of these forms can be found in any Maya village from the Preclassic period until today. To this list, Mary Ellen Miller (1998) adds a fourth element, the stairs, which connect platforms. Or as the Maya elaborated upon the hut or house form throughout the eventful course of Maya history, stairs led to elevated palaces or temples. A few other distinctive forms can be mentioned and are described below, including ballcourts and observatories.

Elaboration and embellishment of basic forms resulted in a variety of building types and styles. There is a cultural logic evident in Maya building on the basis of several actions, including the subdivision of rectilinear built spaces and replication of single-room cells (Fig. 3) used in buildings (Schwarz, 2004). Arrangements of these cells can form larger multiroom structures (Fig. 4). Most such Maya buildings maintained certain symmetries, particularly bilateral symmetry.

Maya buildings are massed together into distinctive arrangements of positive spaces (e.g., rooms enclosing spaces) and negative or open spaces (voids). Most generally, pre-Columbian builders positioned buildings in relation to principles of cardinal directionality. Particularly, they were oriented to the path of the sun and other celestial bodies. East is associated with the rising sun while west is associated with the setting sun. The Maya identified structures in the north and south positions of architectural groups with the mythic heavens and underworld (Ashmore & Sabloff, 2002).

The arrangement of these built and open spaces formed groups of buildings and precincts



Architecture of the Maya, Fig. 3 Example of Maya residential building from Tikal. Design of the structure can be conceived of partly as a series of replications and subdivisions of a rectangular cell (Adapted from Schwarz, 2013)

(groups of groups). Most notably, Maya buildings from the Preclassic and Classic period established a pattern whereby groups of buildings were generally arranged around broad, paved open spaces, or plazas (Fig. 5).

The Maya today make use of outdoor space, for example, the Yucatecan *solar*, or walled courtyard, where outdoor space is as integral as the building to the design and use of social space (Hanks, 1990). This indoor-outdoor integration of spatial practice apparently has great antiquity. Use-patterning at archaeologically identified residences indicates spaces in plazas, and around and behind buildings were used and segregated into activity areas (Robin, 2002).

Integration of architecture and spatial practice perhaps has its most spectacular and notable development in the Maya Classic period (A.D. 200–850) civic-ceremonial centers, such as Tikal, Copán, and Palenque. Architectural expression framed the creation of meaning and prestige. Studies of architecture, iconography, and Maya hieroglyphs in civic-ceremonial centers have

Architecture of the Maya, Fig. 4 Range structure, Tikal, Guatemala

Architecture of the Maya, Fig. 5 Domestic plaza group. Domestic structures around an open plaza at Copán, Honduras

demonstrated that elite precincts, which were the provinces of Maya divine kings, nobles, and priests, became superlatively charged semiotic environments. The architecture, arrangement of monuments, and placement of iconography and hieroglyphic texts on architectural media supported political displays of power and sacred rituals (Miller, 1998; Schele, 1998; Tate, 1992). The result was a designed or built environment that communicated the ideological values of the Maya elites, inculcated political views, fostered social control and appropriate behaviors, and expressed deeply held religious meanings. The Maya were both the creators and users of this semiotic system, and it acted upon them.

The Maya house (Yucatec *nah*) is the most common architectural form. Generally, it is but one room or two (Fig. 1b). The low thatched roof hut of both today's Maya village and the pre-Columbian past is at base an enclosure that

Architecture of the Maya, Fig. 6 Hieroglyphic Bench at the House of the Scribes, Copán, Honduras. At Copán, benches were inscribed with texts that have cosmological and political statements, aligning the elites with the ruler and the gods

screens off interior space from the outdoor space (Kubler, 1961; Miller, 1998). The house may contain a kitchen, shrine, agricultural storage, and sleeping quarters. These elements may be parts of a single building or form a small cluster of individual buildings. The focal point of the house was often a bench-altar or, in the modern context, a table altar. At Classic Copán, Honduras, elite scribes and lineage patrons had bench-altars inscribed with texts that presented cosmological and political statements, aligning the elites with the divine king and the gods (Fig. 6) (Noble, 1999). In essence, house altars centered the household in its politico-religious setting.

Multiroomed palaces can be conceived of as elaborated designs where single rooms have been replicated and added on in a patterned fashion (Fig. 3). These multiroomed buildings, termed range structures, were prevalent in Classic civic-ceremonial centers. They were generally single-room deep sets of rooms arranged side by side along a plaza (Fig. 4). Stairs and elevated patios provided access to elevated structures and a frontal space for approaching the building and for social interaction between visitors and occupants. Range structures had highly repetitive and impressive frontal facades and exhibited the bilateral symmetry common to Maya architecture. Archaeological clearance of rooms in these buildings usually yields little evidence of what activities the Maya carried out there. Most archaeologists think these range structures were elite palaces for housing the nobles, priests, officials, and retainers of the Maya royal courts. A related idea is that they were administrative buildings.

Maya houses or house shrines were often the sites of burials of ancestors (McAnany, 1995). Burials can take a variety of forms including tombs, crypts, or cists. Sometimes the Maya placed burials within the hearting of an elevated structure or below benches or stairways. In some cases, shrines were separate structures within a familial compound.

In Classic civic-ceremonial centers, there were elevated burial shrines associated with the ruler or related elites. Many shrines were physically closely related to elite houses. In other cases, they were associated with the civic-ceremonial core of the urban center, although the attendant concept of the house still applies (see below). Step pyramids became common in the Late Preclassic period and were the premier ceremonial temple form of Classic centers in addition to having sepulchral functions. That is, the Maya buried divine kings or their direct kin in tombs in such structures, such as the temples at Tikal, Guatemala (Figs. 7 and 8). Rites and ceremonies were performed at these temples as well.

Step pyramids sometimes were surmounted by a small temple or throne room (Fig. 7). These structures were elaborate single-room (or at most two or three rooms) stone buildings, set atop the step pyramids. Tedlock (2005, p. 197) reports that the Quiche Maya called a step pyramid with a temple on it *Kaq Ja*, "red house," indicating an explicit association of this structure type with houses. In some cases, step pyramids exhibited radial symmetry (Fig. 9), i.e., symmetry is expressed on all four sides of the structure. It is believed that the radial design of four stairs leading to the central temple relates to a quatrefoil form in Maya iconography. The quatrefoil references several mythological and astronomical figures, such that the radial architectural form metaphorically encloses the archetypal three stone hearth central to all Maya houses (Taube, 1998).

Architecture of the Maya, Fig. 7 Temple II. Tikal, Guatemala

Architecture of the Maya, Fig. 8 Temple I. Tikal, Guatemala

The Maya both built buildings on platforms and utilized the platforms themselves as useful spaces. At sites such as Tikal, Guatemala, relatively frequent building and rebuilding over many centuries resulted in the creation of elevated architectural spaces. The built monumental space became so impressive that they are termed acropoli by Mayanists after the Greek usage. Excavations often yield evidence of prior building episodes of temples and palaces buried within the architectural mass of stone and earth as the temple and palace complex (Fig. 10) was remodeled and expanded repeatedly.

Lest Maya civic-ceremonial architecture seems overly forbidding, dominated by temples atop steep step pyramids (Fig. 7), it should be said that low platforms adorn Maya sites at plaza level as well. These include oratories, round temple platforms (Fig. 11), and presentation palaces. Though archaeological investigation is often inconclusive, these low structures are sometimes

Architecture of the Maya, Fig. 9 Castillo, Chicheń Itzá, Mexico. Temple pyramid exhibits radial symmetry

Architecture of the Maya, Fig. 10 North Acropolis, Tikal, Guatemala

thought to have been used for religious and political events and rituals that would have been viewed by the public.

Raised, paved pathways/roads (Yucatecan *sacbeob* or "white ways") were built up into networks that connected Classic civic-ceremonial centers, smaller satellite centers, and even other centers. The sites of Cobá, Mexico, and Caracol, Belize, are famous for radial networks of these elevated *sacbeob*, which tied together the extensive territories that these centers controlled. Most of the *sacbeob* led to the civic-ceremonial center. Cobá also is connected to the neighboring center of Yaxuna by a *sacbe* that is over 100 km in length. *Sacbeob* sometimes connected precincts or groups of buildings within large sites such as Tikal.

Ballcourts along with observatories (described in greater depth below) reference pan-Mesoamerican influences. They occur in Highland Central Mexico as well as in the Maya region. Ballcourts were alley-like masonry

Architecture of the Maya, Fig. 11 Round platform. Seibal, Guatemala

Architecture of the Maya, Fig. 12 Ballcourt, Tikal, Guatemala

constructions in which the Maya played a sport with a natural rubber ball. The sport involved two opposing teams in a competition that had both mythological and war associations. In the Classic period of Petén, Guatemala, most ballcourts were simple masonry alleys with angled sidewalls and elevated viewing platforms for spectators (Fig. 12), while at Chicheń Itzá, Mexico, a larger I-shaped ballcourt had iconography on tall, straight-sided walls. Ballcourts are no longer built today.

Architectural Technology

Maya building has utilized a variety of materials including stacked cut stone; cut stone veneer with a rubble core; and earth, adobe, and wood. Use of multiple materials in a single building was common in the pre-Columbian period and is common today. Cut stone is frequently limestone, particularly in the karstic lowlands, while sandstone and igneous stones were also used in some settings, such as the Usumacinta Valley, Mexico, and

A

Architecture of the Maya, Fig. 13 Post-and-lintel structure

Architecture of the Maya, Fig. 14 Corbelled vault at Labna, Mexico. The facade is decorated in the famed Puuc style (Photo courtesy of Edy Barrios)

Maya Highlands of Mexico and Guatemala. Lime stuccos and plasters were common surface treatments, particularly in the pre-Columbian period.

A fundamental challenge that architectural technology addresses is the problem of spanning or development of roofed spaces to protect occupants and possessions from the elements and provide enclosure for controlled social interaction. The Maya had multiple technologies for spanning, including thatched roofs with lightly framed pole rafters (Fig. 1b), wooden post-and-lintel structures, stone post-and-lintel (or beam) structures (Fig. 13), and the corbelled vault (Figs. 1c and 14). The use of the corbelled vault emerged sometime in the Preclassic period (Hansen, 1998) and was widely employed by the Early Classic period in the heartland of the lowland Maya civilization, the Petén of Guatemala. This method has sometimes been called the false arch, because weight is transferred laterally rather than to a vertically oriented keystone bearing weight overhead (as in the Old World arch). The corbelled vault served the Maya well enough, however. The result was that, in order to sustain the lateral forces, the Maya built relatively narrow roofed rooms in corbelled vault

Architecture of the Maya, Fig. 15 Puuc style facade at Las Monjas group, Uxmal, Mexico (Photo courtesy of Edy Barrios)

buildings and exterior walls had to be massive and made of stone and earth. In comparison to the Classic period massive vaulted stone structures, during the Postclassic and later periods, post-and-beam structures were more common. These are much more lightly built. Some Postclassic structures had partially or wholly wooden superstructures and thatched roofs (Fig. 1a).

The use of thatched roofs with native palms and grasses is known from the archaeological excavations at El Cerén, El Salvador, and in the present day. According to the author's informants, thatched roofs are preferred in Petén, Guatemala, a region with high rainfall. The natural thatching can last a long time, up to 10–30 years, if prepared properly (Wauchope, 1938). Thatched roofs seldom leak. However, corrugated aluminum roofs are more common today because of the lower labor outlay. They are much hotter for their inhabitants than traditional thatching. Wattle and daub was and continues to be a common wall fabric, particularly for houses and other small structures.

Studies have shed light on how ancient Maya buildings were built and how much labor actually was involved. From cutting stone blocks in a quarry without metal tools, to making lime plaster, to gathering palm thatch, and to assembling the actual building, a number of procurement and construction activities were very labor intensive. This has led to theorization of what kinds of labor organization were utilized to build the Classic civic-ceremonial centers with their temples, palaces, and monuments. Corvée labor, feudal relations, and other obligatory systems have been put forward to explain how Maya elites commanded so much labor. Abrams (1994, p. 55), however, calculated how much labor actually would have been needed, for example, to build palaces and elite houses at Copán, Honduras, based on experimental data. For example, he estimates vaulted palace structure 10L-22 to have required 24,705 person-days to construct, while a vaulted roof elite house structure, 9N-82C, required 8,567 person-days (Fig. 1c). Structure 9N-83, a post-and-beam residence, required 5,893 person-days of labor. A person-day is the labor of one adult for one work day of 5–8 hours, depending on the task. However, he notes the long time horizons during which the Maya built many of these structures. Some were expanded and remodeled over decades and even centuries. Considering these long time spans for construction, labor outlays by commoners in the Copán kingdom may have been as little as a few days or weeks per year to account for the mass of buildings at the civic-ceremonial center of Copán.

Architecture of the Maya, Fig 16 Puuc style facade at Kabah, Mexico. Repeated geometrical designs and tenoned god masks characterize this style (Photo Courtesy of Edy Barrios)

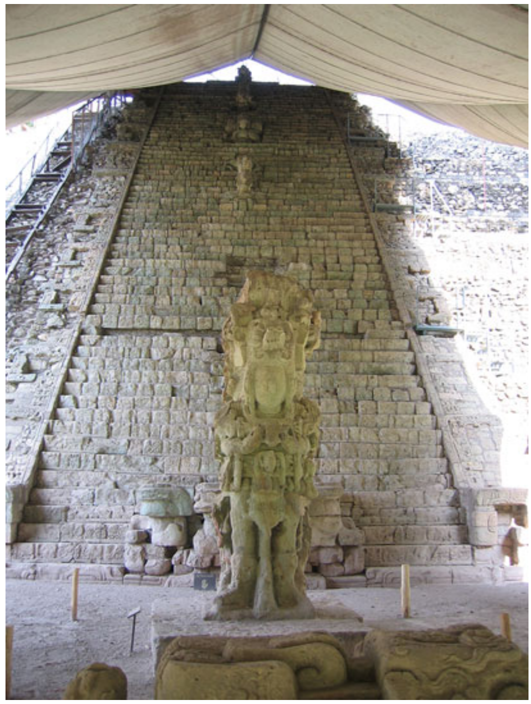
Architecture of the Maya, Fig. 17 Palenque, Mexico. Palenque building facades preserve many reliefs displaying religious and political iconography. Also, Palenque has a unique square three-story tower (Photo courtesy of Edy Barrios)

Architecture in Politico-religious Contexts: Symbolic and Semiotic Systems

Pre-Columbian Maya architecture was, as Miller (1998) explains, designed to impart meaning, mostly political and religious messages. This sort of communication utilizes architectural signs created by architects, builders, and, importantly, sponsors. The architectural messages were received by building occupants, visitors, and other recipients (Schwarz, 2004; 2013). Effectively, architecture was a semiotic system, a means of communication with built forms, messages in stone. Architecture communicated messages important enough to invest the considerable sums of labor and materials described above and justified the pursuit of long-term construction programs by sponsors and their subjects. And architecture and the iconography were symbolic of deeply held beliefs and inculcated ideologies prevalent in Maya society, such as divine kingship.

Architecture across the Maya region had identifiable regional styles (Andrews, 1975), such as the Puuc style of central Yucatan, Mexico. Some civic-ceremonial centers' styles also referenced architecture from powerful highland Mexican neighbors like Teotihuacan and the later center of Tollan, home of the Toltecs. Styles apparently communicated identity, alliance, and similarity although it must be said that some cities, such as Copán, produced architecture and sculptural art so unique that they belie regional stylistic identification. They are exemplars in and of themselves. The Puuc style is noted for its repetitive, abstract facade designs punctuated regularly with masks of gods (Gendrop, 1983). These designs are of such stunning artistic quality that they compare favorably with abstract art anywhere (Figs. 1d, 14, 15, and 16).

Architecture of the Maya, Fig. 18 Relief panel at Palenque, Mexico



Architecture of the Maya, Fig. 19 Hieroglyphic stairway and stela depicting the 15th ruler of Copán, Honduras, and dynastic history

Three examples of architectural expression and communication indicate the achievements in composing enduring buildings, in creating innovative built forms, and in architectural messaging. Schele (1998) notes that Maya architectural facades were stage fronts for rituals and carried important messages, particularly at sites such as Palenque, Mexico (Figs. 17 and 18). Beginning in the Late Preclassic and taking on increasing sophistication during the Classic period, iconography and hieroglyphs were displayed that portrayed historical narratives, religious and creation imagery, and other subjects. God masks (Fig. 1d), flowers, snakes, sacred mountains, Maya kings, and other images adorned temples, bearing walls, freestanding stelae and altars, and a variety of other media. Such extensive integration of the hieroglyphic texts and architecture is perhaps comparable to Chinese integration of large-format calligraphy in public spaces. But the integration of pictorial hieroglyphs and a powerful and complex naturalistic iconography on architectural media is unique to the Maya. It is one of the reasons Maya architecture is so fascinating.

Fash (2000) refers to the hieroglyphic stairway at Copán as the great dynastic encyclical for this kingdom. This construction integrated the history of the Copán polity in a unique monument. Hieroglyphs and tenoned sculpture (Fig. 19) are arrayed on a stairway that leads to a temple on top, which is richly decorated with both Maya and Teotihuacan (Mexican) style texts and images. A large sculpted figure at every twelfth stair step depicts an important previous ruler of Copán. In this unique monument, inscriptions portray and link the fifteenth ruler of Copán with the dynastic history of the ruling house and symbolically link him to his powerful ancestors, to warrior imagery, and to the powerful Teotihuacan state.

The Caracol of Chicheń Itzá, Mexico, is the largest and most famous round tower of the Maya region (Fig. 20). Aveni (2001) believes that its openings (stone windows and stone building elements) are aligned with celestial bodies on the horizon during significant astronomical events.

Architecture of the Maya, Fig. 20 Caracol, Chicheń Itzá, Mexico. It is believed to be an ancient observatory (Photo courtesy of Edy Barrios)

Several smaller observatories, mostly in the Yucatan peninsula, are also known although these are not well studied. At Chicheń, the Caracol is thought to preserve alignments matching the most northerly declination of Venus at sunset, the sunset at the day of its zenith passage, and the summer solstice sunrise. These alignments, if intentional, would provide good evidence for the degree to which the Maya observed the heavens and then oriented their lives and buildings in accordance with important celestial events. Certainly, Aveni's evidence is strong though circumstantial, and the celestial alignments at Chicheń Itzá and other sites fit with our knowledge of Maya astronomy and astrology in written bark-paper codices and the quite accurate solar, lunar, and Venusian elements of the Maya calendar.

References

Abrams, E. M. (1994). *How the Maya built their world: Architecture and energetics*. Austin, TX: University of Texas Press.

Andrews, G. M. (1975). *Maya cities: Placemaking and urbanization*. Norman, OK: University of Oklahoma Press.

Ashmore, W., & Sabloff, J. (2002). Spatial orders in Maya civic plans. *Latin American Antiquity, 13*(2), 201–216.

Aveni, A. F. (2001). *Skywatchers*. Austin, TX: University of Texas Press.

Fash, W. L. (2000). *Scribes, warriors and kings: The city of Copan and the ancient Maya* (Rev. Ed.). London: Thames & Hudson.

Gendrop, P. (1983). *Los Estilos Río Bec, Chenes, Y Puuc en la arquitectura maya*. México, DF: Universidad Nacional Autónoma.

Hanks, W. (1990). *Referential practice: Language and lived space among the Maya*. Chicago, IL: University of Chicago.

Hansen, R. (1998). Continuity and disjunction: The pre-classic antecedents of classic Maya architecture. In S. D. Houston (Ed.), *Function and meaning in classic Maya architecture* (pp. 49–123). Washington, DC: Dumbarton Oaks Research Library and Collection.

Houston, S. D. (1998). Classic Maya depictions of the built environment. In S. D. Houston (Ed.), *Function and meaning in classic Maya architecture* (pp. 333–372). Washington, DC: Dumbarton Oaks Research Library and Collection.

Hutson, S. R. (2010). *Dwelling, identity and the Maya: Relational archaeology at Chunchucmil*. Lanham, MA: Altamira Press.

Kubler, G. (1961). The design of space in Maya architecture. In *Miscellanea Paul Rivet: octogenario dictata* (pp. 515–531). Mexico, DF: Universidad Nacional Autonóma.

McAnany, P. A. (1995). *Living with the ancestors: Kinship and kingship in ancient Maya society*. Austin, TX: University of Texas Press.

Miller, M. E. (1998). A design for meaning in Maya architecture. In S. D. Houston (Ed.), *Function and meaning in classic Maya architecture* (pp. 187–222). Washington, DC: Dumbarton Oaks Research Library and Collection.

Noble, S. (1999). *Maya seats and Maya seats-of-authority*. Doctoral dissertation, University of British Columbia, Vancouver

Robin, C. (2002). Outside of houses: The practices of everyday life and Chan Nóohol, Belize. *Journal of Social Archaeology, 2*(2), 245–268.

Schele, L. (1998). The iconography of Maya architectural façades during the late classic period. In S. D. Houston (Ed.), *Function and meaning in classic Maya architecture* (pp. 479–518). Washington, DC: Dumbarton Oaks Research Library and Collection.

Schwarz, K. R. (2004). *Understanding classic to postclassic household and community spatial transformation: The rural Maya of the Quexil-Petenxil Basins, Guatemala*. Doctoral Dissertation, Southern Illinois University at Carbondale

Schwarz, K. R. (2013). Architecture, materialization and the duality of structure: A Maya case study of structurally shaped innovation. *Cambridge Archaeological Journal, 23*(2), 307–332.

Tate, C. E. (1992). *Yaxchilan: The design of a Maya ceremonial city*. Austin, TX: University of Texas Press.

Taube, K. (1998). Centrality, rulership, and the classic Maya temple. In S. D. Houston (Ed.), *Function and meaning in classic Maya architecture* (pp. 427–478). Washington, DC: Dumbarton Oaks Research Library and Collection.

Tedlock, D. (2005). *Rabinal achi: A Mayan drama of war and sacrifice*. Oxford, UK: Oxford University Press.

Wauchope, R. (1938). *Modern maya houses: A study of their archaeological significance*. Washington, DC: Carnegie Institute of Washington.

Architecture of the Maya: Domestic Architecture

Leah McCurdy
University of Texas at San Antonio, San Antonio, TX, USA

Every society in the past has built and maintained some sort of domestic, or residential, architecture for the purposes of shelter, social gathering, activity space, and material storage. Environmental conditions, social structure, and cultural expression influence the type and style of domestic architecture developed by a society. Maya domestic architecture is typical of tropical or subtropical regions with abundant natural resources for building. Investigations of Maya domestic architecture provide insight into Maya social life, family structure and relationships, as well as daily activities and productive pursuits.

The two major sources of information on Maya domestic architecture are material remains of houses excavated by archaeologists and structures constructed by "modern Maya" people. Archaeological investigations of ancient Maya houses and related domestic architecture are a more recent development in the discipline. Most early archaeologists were attracted to the grandeur and mystery of Maya monumental buildings and public spaces. Current archaeological inquiry in the Maya region has expanded to fully include detailed study of domestic and residential space. The extraordinary discovery of the ancient Maya village of Ceren in El Salvador, called the "Pompeii of the New World," (Sheets, 2006) has been very influential in inspiring concentrated excavations of Maya households and domestic spaces. Ceren was buried and preserved in ash during a massive volcanic event. The field of household archaeology is closely tied to the Ceren discoveries and how much we have learned from the amazing preservation of Maya households at that site.

Studies of modern Maya houses and the domestic sphere of living people have also been very influential in our understanding of how ancient people lived and their daily households. The most famous of such studies was conducted by Robert Wauchope (1938) and provides extensive detail on how Maya people constructed houses and domestic areas, what domestic activities can be preserved in the archaeological record, and what materials were used for construction and daily life. Photographs from Wauchope's work significantly inform archaeological reconstructions of ancient Maya housing and other domestic structures.

Construction

Most Maya architecture is designed with two major components, substructure (also known as base, terrace, or platform) and superstructure. For domestic architecture, substructures are typically constructed of masonry and/or earth to form a solid foundation upon which living spaces can be organized. Superstructures are typically constructed of perishable materials, such as

Architecture of the Maya: Domestic Architecture, Fig. 1 View up into a modern roof structure at the archaeological site of Tikal showing perishable materials, supporting wooden members, and covering palm thatch

(Fig. 1) thatch, widely available and renewable in the tropical environments of the Maya region. The use of more permanent materials in substructures indicate that these were meant to last, while the superstructures composed of impermanent materials were not necessarily meant to last beyond a generation's occupation of a house. Archaeological evidence and explorations of modern Maya cultural practices suggests that the superstructures of Maya houses were renovated or rebuilt on a relatively consistent cycle.

Domestic building and rebuilding events have been informally studied in modern Maya communities. Elliot Abrams (1994) suggests that continual domestic rebuilding could have been sustained by a reciprocal labor system. Families and extended kin networks likely exchanged labor for rebuilding episodes over generations and developed relationships based on reciprocal labor. This type of communal labor system likely also extended to agricultural practices. Abrams (1994) also suggests that other labor systems existed in Maya society including tribute and/or corvée (forced) situations for public architectural construction.

Spatial Organization and Architectural Components

Patio Groups

Maya domestic spaces are typically arranged around a central patio (or courtyard) space. This open-air patio connects multiple domestic structures, serves as an activity area itself, and likely serves the practical need of staying cool in tropical and subtropical environments. Domestic patio groups are common throughout Mesoamerica. The patio area is typically elevated above the surrounding terrain through the construction of a substructure. Residential and other domestic structures are arranged around the patio, facing into the domestic compound. Principal buildings, such as those used for sleeping and eating, are typically located directly off the patio. Ancillary structures such as the kitchen or storage areas can be located behind the main structures or off the substructure entirely.

Structure Types

Current knowledge of Maya domestic structure types is greatly informed by work at Ceren in El Salvador (Sheets, 2006). The principal building located directly off the patio area is the domicile or living structure where sleeping, eating, and other daily activities take place. Domiciles are typically outfitted with elevated masonry benches designed for sleeping and use as a seating area. Mats of thatch or other materials would be used as cushions for sleeping on the bench surface. Domiciles typically do not have interior partitions or dividing walls but contain only single-roomed spaces. Doorways or entrances are typically short and not very wide with mechanisms for closure and security, such as curtains or sometimes wooden coverings. Activities such as household production, entertainment, and family ritual practice likely also took place in domicile structures. There is evidence at Ceren of child-rearing activities as well. Further, the use of both interior and exterior space indicates that domiciles and patio areas complemented each other as venues for domestic activities in Maya daily life.

Kitchen structures show evidence of the use of fire, certain types of ceramic vessels for cooking, and activities related to food processing and preparation. Kitchen structures typically feature walls with openings (such as between wattle sticks) that provide sufficient ventilation. Kitchen structures at Ceren are particularly informative with in situ evidence of what the householders were cooking the day of the volcanic explosion. A multitude of specialized ceramic vessels indicate the wide range of cooking practices employed by the Maya. Further, manos and metates are particularly significant features of Maya kitchen structures as they are used to grind maize, a staple of the Maya diet, for making tortillas and tamales.

Maya households also typically contain storage structures. Storages structures are typically constructed of masonry with securable doorways. As agriculturalists, Maya people would produce their own food along with a surplus for their own contingency use or for exchange. Storage areas would be paramount for such surplus storage as well as storing valuables and prized objects such as jewelry or ancestral items. Storage areas at Ceren, known as bodegas, exhibit a very wide range of items from ears of corn to ducks, water containers, and broken ceramic vessels. The contents of different bodegas, belonging to different family units at Ceren, reveal a great deal about differences among groups. For example, one family is known as the hoarders because they seemed to keep and store every broken ceramic vessel they ever used. Another family was known as the entrepreneurs, storing a multitude of items that were likely bartered or sold to other households. Some patio groups may not have had individual storage structures but used areas of the domicile to store their surplus and valuables.

Other domestic structures that may be present in or around a Maya household could include production areas or shrines associated with family ancestry. In all, the Maya household comprised of multiple, interrelated structures that could serve diverse needs of household members. Archaeologists have recently begun using the term "house lot" as inclusive of both the architectural patio group (with multiple structures and activity areas) and household gardens or larger agricultural plots (Lohse & Findlay, 2000; Sheets, 2006). Households at Ceren often had a nearby garden with medicinal plants and subsistence crops such as manioc and maize. It is also likely that larger agricultural fields were located nearby. All of these areas should be included in the understanding of Maya domestic space and life.

Learning About Maya Daily Life

Maya domestic architecture and space are key to the archaeological understanding of how Maya people lived everyday (Robin, 2013). Sleeping quarters can reveal details about the size of family units and how everyone in the family related to one another, over generations, for example. The daily productive activities of Maya farmers in their households can help us understand subsistence practices and access to resources in the environment. Further, we can understand how changes in environment affect the majority of the Maya population. Other productive activities such as ceramic production or textile weaving provide insight into the division of labor, gendered roles, and the social organization of family units. Production in every Maya household is also the backbone of the community economy. Questions of politics and economics can be understood through detailed investigations of household production and changes over time. Communities, as collections of households and domestic units, are increasingly important in Maya scholarship (Canuto & Yaeger, 2000). Communities have genealogical, productive, and ideological ties that can all be investigated through individual households and how they compare to others.

Domestic patio groups, and particularly domicile structures, are often marked as special through the internment of deceased relatives within the floor. The Maya often dug graves for their family members into the floor of their homes and then covered the burial with a new plaster floor. These dead family members became ancestors to protect the living family and serve as their connection to the spiritual realm. Excavations of domestic buildings often reveal a great deal of information about family history and ritual practices associated with reverence for the dead (Haviland, 1988).

Elite Versus Commoner Domestic Architecture

The discussion above relates to domestic architecture that archaeologists identify with

Architecture of the Maya: Domestic Architecture, Fig. 2 Eastern side of Central Acropolis at Tikal showing the remains of multiple elite domestic structures

"commoners," or those making up the majority with less political and economic power than the elite minority. Elite domestic architecture is distinct from commoner domestic architecture in several ways and is most often classified as public architecture (see ► Architecture of the Maya: Public Architecture). Elite residences were almost always located in or nearby public areas (such as ceremonial buildings and plaza spaces) where members of the public sometimes had access (Christie, 2003; Fig. 2). Elite domestic architecture is reflective of the social stratification embedded in the distinction of commoner versus elite. Prestige objects, hieroglyphic inscriptions, paintings, and elite burials are oftentimes associated with elite domestic architecture.

References

Abrams, E. (1994). *How the maya built their world: Energetics and ancient architecture*. Austin: The University of Texas Press.

Canuto, M. A., & Yaeger, J. (2000). *The archaeology of communities*. Oxon, UK: Routledge.

Christie, J. J. (Ed.). (2003). *Maya palaces and elite residences: An interdisciplinary approach*. Austin: The University of Texas Press.

Haviland, W. A. (1988). Musical hammocks at Tikal: Problems with reconstructing household composition. In R. R. Wilk & W. Ashmore (Eds.), *Household and community in the mesoamerican past* (pp. 121–134). Albuquerque: University of New Mexico Press.

Lohse, J. C., & Findlay, P. N. (2000). A classic maya house-lot drainage system in Northwestern Belize. *Latin American Antiquity, 11*(2), 175–185.

Robin, C. (2013). *Everyday life matters: Maya farmers at Chan*. Gainesville: University of Florida Press.

Sheets, P. (2006). *The ceren site: An ancient maya village buried by volcanic ash in Central America*. Belmont, CA: Thomson Higher Education.

Wauchope, R. (1938). *Modern maya houses: A study of their archaeological significance*. Washington, DC: Carnegie Institution of Washington.

Architecture of the Maya: Public Architecture

Leah McCurdy
University of Texas at San Antonio, San Antonio, TX, USA

Like many ancient peoples, the Maya were avid builders and invested a great deal of energy and resources to modify their environment. The result of changes to the environment made by people over time and as an expression of their lived experience is known as "the built environment." There are many components of the built environment, one of which is architecture and the construction of buildings. Architecture itself can be divided into many types, domestic and public, for example. Using this distinction, public architecture is typically understood to be larger in scale, grander in appearance, and more reflective of a large group of people or population rather than one family or subset of a population (see ► Architecture of the Maya: Domestic Architecture). The term "public" contrasts with "private" and is used in reference to architecture associated with the congregation of people beyond their own private, or domestic, sphere. Thus, public architecture refers to buildings and spaces that were used or occupied in connection with public activities.

Scholars also use another related set of contrasting terms: elite versus commoner. Typically, public architecture is associated with elite individuals more so than commoners, while commoners are most often tied to domestic, or residential, architecture within which they would have lived. This distinction does not necessarily reflect the history of buildings, as the construction of monumental public buildings requires a large number of laborers. Often, these laborers are of the commoner ilk. Beyond these sometimes problematic distinctions, public architecture reflects some important characteristics that distinguish it from other forms of architecture.

Centralization and Nucleation

Public architecture is most often found in a central, nucleated location with historic associations to groups with social and/or political power. Centralization and nucleation are the result of long-term settlement and population growth. Many scholars investigate the origin of cities as centralized places where large portions of a society or population focus their settlement. In this way, central places become nucleated wherein population density decreases as one moves farther away from the center. As ancient cities grew beyond the institutions of small villages, as political control developed and was sustained, and as hierarchies overtook egalitarian ways of life in a large portion of ancient societies, there was a need or demand for expressions of institutionalized social control and differentiation. In its many forms, public architecture enables such expressions and thus is most effective if present in areas of the highest population density. Further, public displays of power and/or authority are often erected in close proximity to those individuals who hold that power. Control over public architecture is often the prerogative of political leaders.

Monumentality

Public architecture is typically larger than domestic architecture and thus typically referred to as monumental. There is a general concept that architectural forms have increased in size over time since humans first started constructing buildings. The archaeological record typically bears this pattern out. Thus, monumentality is a development of architectural change and the result of changes in how people built structures over time. Building at a larger, monumental scale inevitably increases the scale of construction and requires more material resources, a larger labor force to carry out building tasks, and more preparatory planning before construction.

Monumentality can be understood as an intentioned invention or as an "unintended consequence" (Joyce, 2004) of behavioral accumulations over time. The long-held assumption of archaeologists is that ancient people desired to create enormous buildings and so invested more energy and time into construction with the result of building monumental public architecture. In this case, the intention to modify the environment would have been large scale and designed to make a large impact as a component of the built environment. From a different perspective, changes to the built environment may have been smaller but accretionary over time, continually building atop previous constructions. Over long periods of time, the consequence of accretionary building is the development of large structures (Joyce). This development may have been unintentional originally, but as the realization of the impact of monumental structures grew, intentional monumental construction continued.

There is much archaeological evidence that Maya public buildings were often built on top of previous constructions. In opposition to the practice of renovating existing structures for continued use, the Maya often used existing structures as the internal foundation for new construction. This practice results in buildings as onions, with nested phases of previous buildings inside more recent versions. Maya monumental public buildings are often an accumulation of constructions and thus may reflect a history of unintended monumentality rather than its spontaneous invention.

Political and Ideological Expression

When buildings are in the public eye, aesthetic appearance often becomes more premeditated and inclusive of politically charged expressions. When centrally located and monumental in scale, public architecture can serve as a billboard for the display of significant social or political ideas. Motivations for such display are varied and are often tied to political messages of divineness, spiritual belief, royal pedigree, military prowess, social control, and/or group relatedness. Political and ideological expression can take the form of architectural art or ritual performance that is facilitated by the layout and design of a building. Architectural art on Maya public buildings is immensely diverse. It can range from a simply painted surface to complex carved, stuccoed, and painted masonry with inset and projecting features.

It is important to recognize that not all public architecture must be centrally located, monumental, or expressive of ideological significance. These factors most often characterize Maya public architecture; however, there are exceptions to the rule. The long history of Maya architecture demonstrates a great diversity of form, function, and meaning.

Construction

Little research has been conducted on the processes of Maya architectural construction. Generally, scholars understand that large labor forces would have been required, although for most Maya buildings, construction crews likely did not range beyond thousands of workers at any one time (Abrams, 1994). Construction tasks varied considerably depending on the type and structural form of the building. Overall, tasks can be categorized as relating to procurement, transportation, manufacture, and construction (or assembly) (Abrams). Most Maya masonry construction is composed of rough enclosing masonry (construction pins), interior masonry or earth fill, and finished exterior blocks with varying degrees of cut precision (Fig. 1). Materials for public architecture range based on architectural style but often include limestone masonry, lime-based plaster or stucco, hardwood, palm thatch, and naturally derived pigments for painting. Where limestone is not present, Maya builders used other types of stones including granite and slate as masonry materials. Masonry materials typically far outweigh the amount of wood material incorporated into Maya public buildings.

Components of Maya Public Architecture

There are several architectural components commonly found in Maya public architecture (Loten & Pendergast 1984). In particular buildings, these components may vary to a high degree. Often, different expressions of these components are found to relate to distinct regional architectural styles. There are four widely recognized Maya architectural styles: Puuc, Chenes, Rio Bec, and Peten. These styles generally correlate to geographic regions.

Substructure

Maya architectural designs can often be divided into two major components: substructure and

Architecture of the Maya: Public Architecture, Fig. 1 View of poorly preserved masonry showing interior masonry fill and exterior finished stones in the ballcourt building of Copan, Honduras

superstructure. The substructure (also sometimes referred to as a base, platform, or terrace) is typically the largest and most massive component and serves as structural support for the smaller superstructure (Fig. 2). In pyramidal forms, substructures are typically multilayered with distinctive sections rising successively and offset from the previous edge. Substructural sections are typically battered, or sloped, as well. In combination, offsetting and battering result in the typical substructural form: broader at the base with a smaller horizontal surface area at the top. Some substructures, particularly those relatively low in height and without multiple layers, are simply battered in one plane rising from the base to the surface. On multilayered substructures, corners may be rectangular or inset. Various functional and aesthetic design elements are found on substructural walls. Moldings, or projections from the main surface plane, on substructural walls create a more detailed design and serve to keep water away from the base of each substructural section, where it might affect the foundation. Substructural walls can also incorporate carved masonry designs or decorative stucco panels (Fig. 3). The Maya often built new buildings on top of already existing buildings. Substructures of existing buildings were often incorporated into the expanded or heightened substructure of new constructions.

Staircases or sets of steps are typically integrated into a substructure (inset) or appended to it (outset). Stair treads and risers are typically constructed of the same masonry blocks used in the substructural sections and are often battered like substructural walls to ensure water runoff. Staircases can include balustrades or edge features that delineate and emphasize their verticality. Hieroglyphic stairways are rare but striking on Maya public buildings. These staircases contain masonry blocks that are carved with hieroglyphic inscriptions on the stair risers and sometimes treads (Fig. 4).

Superstructure

Superstructures sit atop substructures and can be composed of permanent or impermanent materials. Those constructed of impermanent materials are referred to as temporary and are known to be cyclically rebuilt. Temporary superstructures are constructed like a traditional Maya house (see ► Architecture of the Maya: Domestic Architecture). Large structural posts made of cut tree trunks would be secured into the substructural surface. (Postholes are the archaeological signature of these posts.) A roof structure of large timbers would be constructed atop these structural posts, interlocking with some components, and secured with vine lashings. Smaller wood members would be added to define the interior space and create a lattice roof structure onto which thatch covering would be applied. The Maya used particular palm species for thatching. Thatch is applied in overlapping layers to ensure water protection and total coverage.

Architecture of the Maya: Public Architecture, Fig. 2 Temple II of Tikal, Guatemala. The three substructural sections of Temple II support its single-roomed superstructure with massive roof combs

Walls can be constructed in many different ways. The Maya often used the wattle and daub wall construction method. Vertical wattle sticks are placed as the structure of a wall plane and covered with the mud and claylike mixture called daub. Daub could also be covered with lime plaster for added water protection. Walls could also be constructed of free-standing masonry and coated with lime plaster. Other methods include using only wattle sticks and lime plaster together without the daub layer. Superstructures of public buildings were likely always plastered and painted (or limewashed) to appear consistent with the plastered substructures. Temporary superstructures are often smaller than permanent versions and are more affected by fire damage.

Permanent superstructures are constructed of masonry with some wooden elements (Fig. 5). Masonry superstructures are composed of rooms with individual or multiple entrances. Maya rooms are typically small in comparison to other public architecture. Room interiors would have been quite dark as compared to the bright white or colorful exterior, open spaces of plazas. Room entrances, typically referred to as doorways, are often constructed through the use of wooden lintels (Fig. 6). Lintels span an opening, take the weight of the masonry above, and are integrated into the upper portions of the wall. Lintels can be plain, carved, plastered, and/or painted. In the absence of a lintel, doorways can be constructed as a corbel arch (Fig. 7) (see description of corbelling below). Evidence of doors is rare in Maya architecture. Instead, archaeologists have evidence that doorways were closed off by fabric panels or curtains, hung on rods that spanned the opening and fitted into curtain holders. Curtain holders were circular holes built into the threshold of a doorway opening. Some curtain holders are designed with a stick or vertical stone insert that serves as a place to tie a string, on which a curtain may have hung. Vaults and other

Architecture of the Maya: Public Architecture, Fig. 3 Carving on substructural wall on Structure 5D-43 at Tikal, Guatemala

components of superstructures are detailed below. Exterior walls of superstructures typically sport moldings similar to substructural walls that expel water and increase aesthetic appeal.

Interior stairways are not uncommon in Maya superstructures. Interior stairways typically serve to allow access to upper stories, concealed courtyards/plaza spaces, or roof combs. Corbel vaults are used to enclose interior stairways and integrate them into the superstructure masonry. Structural designs of corbel vaults above interior stairways are often creative to account for the changes in elevation (Fig. 8).

Vault

Vaults are constructed to enclose the upper sections of a room, in lieu of a ceiling (horizontal closure at the top of a room), through the creation of additional space above the floor area. The Maya are well known for the peculiar type of vaults they built to enclose their masonry rooms, called a corbel vault (Fig. 9). Distinct from a true arch vault, a corbel vault is built by corbelling wherein vault stones are successively projected into a vault space and rest only partially on the stone immediately below. The uppermost corbel vault stone, or keystone, is placed as a cap over the vault, on the centerline above the space the vault spans. Corbel vaults require supporting stones to lock the others in place and counteract the tendency of vault stones to fall into the space cavity. The spandrel sections of a corbel vault are integral to its structural integrity. The Maya made use of this structural requirement to create upper façade sections of their rectangular roof areas. Wooden beams are often present in Maya corbel vaults, spanning the shorter, lateral dimension. Scholars debate whether these beams are structural, meant to function for storage or hanging purposes in the room, or are purely aesthetic. Vault beams can be plain or carved.

Upper Façade

The upper façade is the exterior section of a building corresponding to the corbel vault section on the interior. As a structural component,

Architecture of the Maya: Public Architecture, Fig. 4 Hieroglyphic stairway of Temple 26 at Copan, Honduras

the upper façade is a masonry section that stabilizes the corbel vault. The Maya often took advantage of the exterior exposure of the upper façade to create prominent decorative panels that could contain carving, stucco installments, or painting. Upper façades typically contain large-scale architectural friezes that incorporate carved symbolic designs, hieroglyphic inscriptions, and occasional figural representations (Fig. 10).

Roof and Roof Combs

Almost all Maya roofs appear flat but in fact are gently sloped to ensure proper water runoff. Roof surfaces were protected with multiple coatings of lime plaster atop the masonry structure. Depending on the height of the building, roofs may have been designed as functional space. Political leaders may have taken advantage of the great height of Maya buildings and used roofs as platforms from which to present themselves as nearer to the spiritual realm than the rest of the population. Ceremonial buildings also often featured roof combs, or roof crests (see Fig. 2). These were masonry features of lattice-like construction erected on the roof surface to soar above the superstructure. Most roof combs sported elaborate decorations with ideological or political significance. Roof combs appear to be important to Maya architectural design because these elements are the closest to the spiritual realm (in the sky) and thus have an intrinsic connection to the deities and spirits that were thought to dwell there. Like the upper façade, roof comb designs often incorporate carved symbolic elements, hieroglyphic inscriptions, and figural representations.

Finishes and Treatments

Most Maya buildings, both public and domestic, were protected by coatings of lime plaster. Lime plaster is derived from naturally occurring limestone and marl (powdered limestone). Lime plaster provides a permeable but protective water barrier to building surfaces that increases the lifespan of masonry materials. Depending on the constituent limestone used, lime plaster is often a yellowish or grayish white color in its final state. Lime plaster is applied in multiple coats to ensure proper coverage and to gradually refine the coat quality toward the surface. Maya public buildings were almost always treated with a limewash to seal the final coats of plaster. Other treatments to plaster include painting and coloration using naturally derived pigments. Limewashes can be colored to resemble paint. Several colors were often used to decorate Maya public buildings with red and black as the most frequent. Lime plaster and paint requires a great deal of maintenance and care.

Types of Maya Public Architecture

Ceremonial Architecture

Ceremonial buildings of the Maya have been labeled as temples, pyramids, or shrines.

Architecture of the Maya: Public Architecture, Fig. 5 Eastern half of the Great Plaza at Tikal, Guatemala, showing the superstructure of Temple I (foreground) and superstructures of the Central Acropolis. This view shows the great variety of height and form that superstructures can take even in Maya buildings at the same site

Architecture of the Maya: Public Architecture, Fig. 6 Doorway with lintel in Mundo Perdido complex at Tikal, Guatemala

The term pyramid has enjoyed widespread use because Maya ceremonial buildings often have a pyramidal shape, rising from a broad substructure to a relatively compact superstructure in layers (see Fig. 1). However, Maya ceremonial buildings can also be mostly rectangular in form with vertical sides and flat roofs. Ceremonial architecture is associated with rituals and ceremonies Maya elite would perform or conduct for both public and private audiences. Ceremonial buildings are often designed to facilitate ideologically significant rituals or performances and may be tied to specific ritual paths or processions. Ceremonial architecture is often the most

Architecture of the Maya: Public Architecture, Fig. 7 Doorway with corbel arch at Cahal Pech, Belize

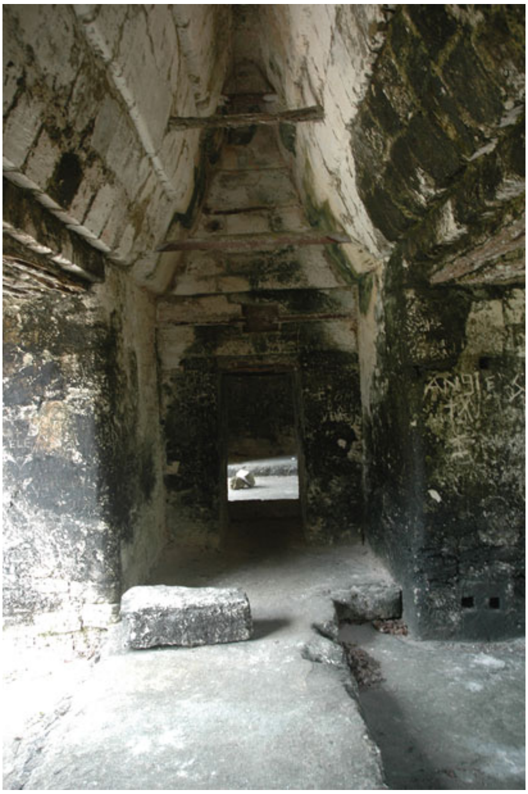
Architecture of the Maya: Public Architecture, Fig. 8 Corbel vaulted interior stairway at Cahal Pech, Belize

richly and elaborately decorated type of public architecture, with distinct symbolic references or schemes that reflect the significance of the structure itself or the individual who commissioned it. Ceremonial buildings typically have interior spaces with ritual significance and that had restrictions of access related to this significance. Like most Maya buildings, interior spaces of ceremonial architecture are small and dark. Scholars suggest that the juxtaposition of a monumental, pyramid-like building and small, dark interior space reflects that natural relationship of mountain and cave. Both mountains and caves were very ideologically significant to the Maya, representing portals to the Underworld and access to otherworldly experiences. Funerary architecture can be considered a subset of ceremonial architecture. Buildings constructed to honor the dead and/or house their remains are often associated with rituals or ceremonies to commemorate death, ancestral relationships, and the spiritual relationships of elite individuals.

One type of common and very unique Maya ceremonial architecture is known as a ballcourt (Fig. 11). Ballcourts were used for the ceremonial ball game which involved a rubber ball and handless passing between teammates to facilitate "scoring" the ball in a variety of ways. Ballcourts consist of three main components: two largely identical masonry sides constructed parallel to one another and a long, level alley surface between the buildings. Ballcourt buildings have a frontal sloping ramp that may have been used during the game or as a seating location for audience members. Elaborate ballcourt buildings also have a superstructure (see Fig. 11) with interior rooms and upper façade decoration that would have sheltered either audience members or participants.

Administrative Architecture

Administrative buildings functioned as spaces for meetings, social control, and politically related housing in public places with varying degrees of



Architecture of the Maya: Public Architecture, Fig. 9 Corbel vault and room interior in the Plaza of the Seven Temples at Tikal, Guatemala, showing plastered surfaces, floor elevations, and vault beams

accessibility. Scholars have suggested that elite individuals who worked to sustain a political administration would have conducted business related to taxation, political decision making, judgment, and/or military control in administrative buildings. Administrative buildings are typically found in groups and are often arranged around or in front of ceremonial buildings. These multiroomed administrative buildings may have also served to protect ceremonial spaces and restrict access to them. Administrative buildings of this type are often called *audiencias* (Fig. 12). A special type of administrative building, known as a council house (or *popol nah*), has larger interior spaces and probably functioned as a meeting place for elite leaders and decision makers. Administrative buildings are typically rectangular and less decorated with shorter substructures than ceremonial architecture.

Architecture of the Maya: Public Architecture, Fig. 10 Reconstruction of macaw carved decoration on the upper façade of one ballcourt building at Copan, Honduras

Administrative buildings typically contain more rooms than ceremonial architecture because room interiors were used on a more regular or more utilitarian basis. Room interiors often contain different elevated floor levels and features known as benches (Fig. 13). Benches in administrative buildings are typically at sitting height, as opposed to lower benches in domestic contexts that were probably used for sleeping.

Plaza Spaces

Spaces that lack buildings and are generally open often provide venues for public activities and so should be involved in an understanding of public architecture. In the Maya world, open spaces linked to public buildings are known as plazas. Archaeological evidence indicates that these plaza spaces were used for public gatherings, feasts, and ceremonies associated with politically powerful groups. Plaza spaces often contain stelae that represent important figures or events significant to the centralized place or region (Fig. 14). Stelae are monumental carved stone blocks erected upright, sometimes plastered and painted. While often flat and planar, plaza spaces may also contain stairs, elevated areas, drainage systems, and temporary structures for shade or display. Some scholars also suggest that certain plaza spaces surrounding Maya public buildings would have been used as marketplaces

Architecture of the Maya: Public Architecture, Fig. 11 Western half of ballcourt at Copan, Honduras

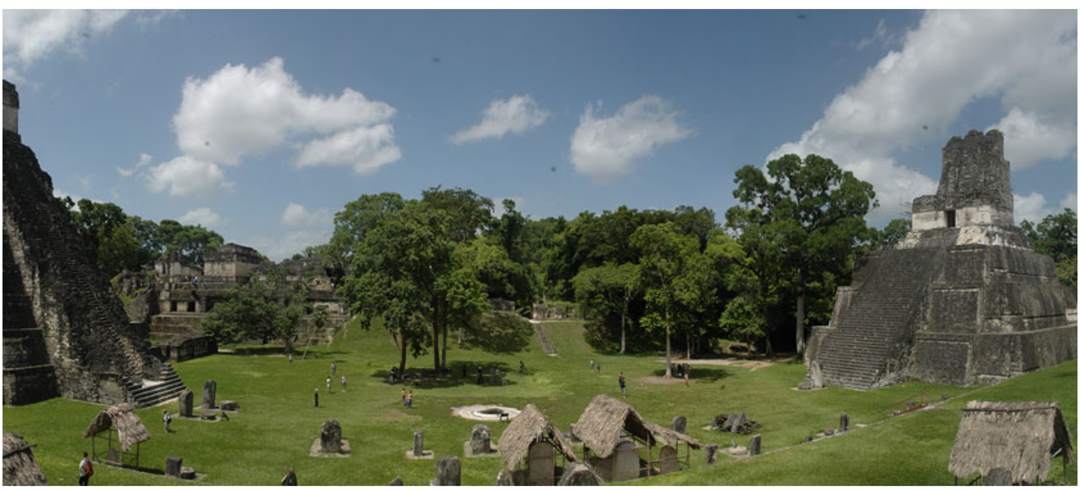
Architecture of the Maya: Public Architecture, Fig. 12 East façade of structure A-2 at Cahal Pech, Belize. This multiroomed building is considered an *audiencia* as it funnels and restricts access to the more private plaza to the west

(Cap, 2011) with subdivisions of space used for distinct vendors or merchandise. Plaza spaces also serve a connective or transitory function to link distinct areas, such as ceremonial and administrative areas. Much current research is concerned with better understanding the public functions of plaza spaces and their connections to adjacent and nearby public buildings.

Architecture of the Maya: Public Architecture, Fig. 13 Room interior at Cahal Pech, Belize, showing corner bench

Elite Domestic Architecture

Despite the tension between the labels of domestic and public, in the Maya culture the residential structures of elite people (often referred to as or palaces) served some public functions. Elite domestic architecture was incorporated into public space and the built environment of city centers. Archaeologists have determined that access to such "public" structures was restricted to certain people or for certain events. If only occasionally public, elite domestic architecture must be included in this category. Beyond domestic functions (see ► Architecture of the Maya: Domestic Architecture), elite residences were part of the public image of ruling and administrative elite people. These buildings likely displayed representations of the occupants' elite status and superiority and housed rituals associated with rulership and spirituality. Like administrative buildings, elite domestic buildings often contain benches that probably served multiple functions including sleeping surfaces, sitting/conversing surfaces, and storage areas. Benches vary in size and height. Some benches were constructed with



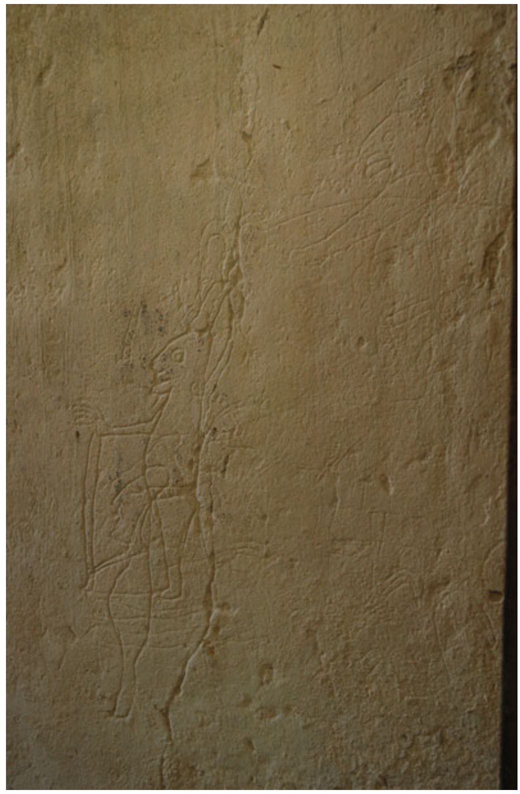
Architecture of the Maya: Public Architecture, Fig. 14 Great Plaza of Tikal, Guatemala, showing stelae placed in the open plaza space armrests and are referred to as thrones. Thrones are typically located directly opposite a doorway opening and look out into a plaza space or other open area.

Service Architecture

Service buildings are an oft forgotten component of public spaces that can be very instructive in understanding daily activities and significant events, such as feasting. Maya service architecture appears to resemble domestic architecture (see ► Architecture of the Maya: Domestic Architecture) in the use of permanent masonry substructures and impermanent wooden and thatch superstructures. Service buildings are typically situated on the edge of royal compounds or plazas but are hidden from the view of people in the ceremonial, administrative, or domestic areas. Service areas are most often associated with elite domestic buildings and probably represent the housing and workspace of servants to the elite occupants. Service architecture has much poorer preservation than other forms of public architecture. Poor preservation is likely due to the impermanent nature of most service buildings, disuse and abandonment of service areas over time, as well as the lack of prestige associated with the occupants.

Sacbeob

Most Maya city centers are associated with at least one sacbe (singular of sacbeob) or paved walkway/road (also referred to as causeways). Sacbeob are often elevated, are plastered, and can stretch over 100 km long. Most sacbeob connect related elite cities, villages, and natural features such as caves. Sacbeob were often large-scale constructions that required large labor forces and material resources. As a travel route, sacbeob were necessarily public. Sacbeob also served ritual functions as people attending ceremonies or rituals held in city centers would use sacbeob to enter the ritual space. Further, sacbeob were often used as procession routes and venues for traveling ceremonies. Sacbeob can integrate stairways but are typically level pathways constructed of masonry with plastered surfaces that slope for water runoff.



Architecture of the Maya: Public Architecture, Fig. 15 Figural graffiti incised into interior plaster in Structure 5D-96 of the Plaza of the Seven Temples at Tikal, Guatemala

Activities in and Among Public Buildings

Public architecture of many types offers a view into Maya public life. Archaeologists are very keen to better understand the functions and histories of public buildings because they reflect what ancient Maya people did, what they thought, and how those things changed over time. Each public building has its own construction and occupational history that provides evidence about the specific individuals who lived in or used the structure at different periods of time. Activity areas within structures and individual rooms provide details on specific activities that took place in public architecture. One striking indication of use is graffiti incised into wall plaster in room interiors (Fig. 15). Depictions in graffiti can expose the meaning of activities or rituals that took place within specific rooms. Artifact assemblages and any other decorative elements within rooms of public architecture provide further evidence for activities that occurred there over time.

References

Abrams, E. (1994). *How the Maya built their world: Energetics and ancient architecture*. Austin, TX: University of Texas Press.

Cap, B. (2011). Investigating an ancient Maya marketplace at Buenavista del Cayo, Belize. *Research Reports in Belizean Archaeology*, *8*, 241–253.

Joyce, R. (2004). Unintended consequences? Monumentality as a novel experience in formative Mesoamerica. *Journal of Archaeological Method and Theory, 11*(1), 5–29.

Loten, S., & Pendergast, D. (1984). *A lexicon of Maya architecture*. Toronto, ON: Royal Ontario Museum.

Architecture of the Moluccas

A. Dwi Eva Lestari
Watampone – South Sulawesi, Indonesia

Introduction

Seram Island is located to the north of Ambon Island, Maluku Province, Indonesia. It extends 340 km from east to west and 70 km from north to south. Markele mount and Binaiya mount are the highest peak at Seram Island with elevation 3027 meters above sea level they having dense forest. The Kanikeh, a humble and well-maintained indigenous society, live on the Binaiya mountainside. The main settlement is a village surrounded by luxuriant forest, a river, and steep hills that have become borders separating the traditional villages from people living outside of the mountain range. Days of walking are required to reach Kanikeh village, where we carried out this piece of architectural research (Fig. 1).

We examined how the vernacular architecture of the Kanikeh people took form through detailed observation of the physical and nonphysical visual aspects of every architectural building. The result of this study is a typology of house characteristics and features in Kanikeh village.

Our observations led to the discovery of two types of houses: the *Rumah gantong* and *Rumah tanah*. However, according to the local people, the earliest house type in the village was the grandstand house type *Rumah gantong*, while the *Rumah tanah* developed later from the *Rumah gantong* shape.

Rumah Gantong

The *Rumah gantong* is a house on a platform with one front door and a small rear door. The wall was made using a dried Sagu tree extract called *gaba-gaba*. Its floor was made of sliced bamboo, while for the roof the leaves or *rumbia* of the Sagu tree were used. The height of the foundation is about 8,090 cm above ground level. A small window, for air ventilation and also to provide light, was usually placed at the front of the house at the height of a seated person. It also provided a view outside of the house.

The house has a simple inner room, with a large kitchen for cooking and preparing dishes which also functioned as a bedroom for the owner of the house. There is also a smaller kitchen for food and clean water storage (warehouse) (Fig. 2).

As can be seen on the façade, there are height differences between the right and left sides of the *Rumah gantong* house and the middle part of the house is about 10–15 cm higher which made these houses unique. This height difference is associated with the main room or the large kitchen and is supposed to be a place to sit or to place a bed. This was not adapted to the *Rumah tanah*. Most of the *Rumah gantong* houses are inhabited by elderly people and their grandchildren. Younger villagers prefer to build the *Rumah tanah* house type.

Rumah Tanah

Rumah tanah shapes are different to those of the *Rumah gantong*, the houses being both wider and larger, but they are nevertheless a development of the *Rumah gantong*. The *Rumah tanah* house type does not have a floor height difference inside the room as did the *Rumah gantong*.

Architecture of the Moluccas, Fig. 1 Research location on a map

Architecture of the Moluccas, Fig. 2 (**a**) Rumah gantong gaba-gaba. (**b**) Rumah tanah gaba-gaba

The *Rumah tanah* has a parlor, a dining room, and an additional bedroom. Referred to Kanikeh's spiritual figure, the *Rumah tanah* houses are easier to collapse or break-up as opposed to *Rumah gantong*, as *Rumah gantong* are constructed using embedded foundations for their pillars, while the *Rumah tanah* house types only use above-ground foundations such as the house's columned poles. These are attached to each other and roped together using bamboo rope or forest plant root.

Kanikeh's traditional houses mostly use materials taken from the forest for their structures. Among those materials are wood used for the pillars of the traditional houses. The owner would have collected wood from deep inside the jungle to make the house's poles. The diameter of the wood is about 5–10 cm, straight and strong. These poles were inserted into the ground and then tightened into the floor's structure until a mutually reinforcing structure is achieved (Fig. 3).

The inserted poles have additional cantilevers made of pine wood set in a diagonal position. The purpose of these additions is to increase the stability of the poles and make them strong enough to hold both a vertical and horizontal weight force (Fig. 3).

The floors are made of split bamboo sliced according to the room length inside the house. *Rumah gantong*, the original house form, has an elevation gap between the left/right flank

Architecture of the Moluccas, Fig. 3 *Left*: Installing the pillars; *Right*: pine wood in a diagonal position

Architecture of the Moluccas, Fig. 4 *Left*: House floors; *Middle and Right*: elevation gap between left/right flank of the house

and the median of the house. The gap is continuous up to the kitchen. The house owners used to spit when they chewed *sirih pinang* inside the house and for this they made a small hole in the floor.

The walls of the traditional houses are made from an arrangement of Sagu tree midribs. In the local language these midribs are called *gaba-gaba*. This arrangement can be vertical or horizontal. Wider midribs (5–6 cm) are used to make the horizontal arrangements while the smaller (4 cm) ones are used for the vertical arrangements. The horizontal arrangement uses a midrib pile up installation system while in the vertical arrangement they are installed adjacent to each other.

Architecture of the Moluccas, Fig. 5 *Left*: A structure formed of connected single poles; *Middle*: connected walls; *Right*: connected floor

Architecture of the Moluccas, Fig. 6 *Left*: Door; *Middle*; window for the semipublic room; *Right*: window for the private room

Every single pole, wall, and floor structure is connected by rope made from bamboo leather or roots so that they are attached to each other without using nails (Fig. 5).

Walls, windows, and doors are made using a dry *Sagu* midrib arrangement. The door's width is about 60–80 cm while its height is about 150 cm. They made the doors and windows in such a way that they do not cover the whole frame. These gaps provide air ventilation and light. The *Rumah gantong* house type always has a small window placed at the height of a seated person. In contrast, the *Rumah tanah* house types have inclined wider and bigger windows in their parlor (semipublic); some are coverless or wide open without security. The bedroom (private) utilizes *gaba-gaba* covers (Fig. 6).

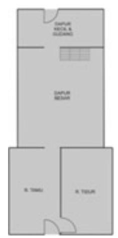
Presentation of Data

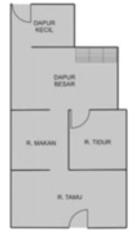
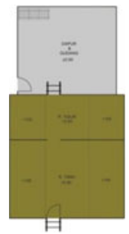
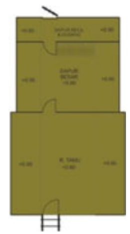
Table 1 presents similarities between façades, functions, and distinctions of the rooms in some Kanikeh houses.

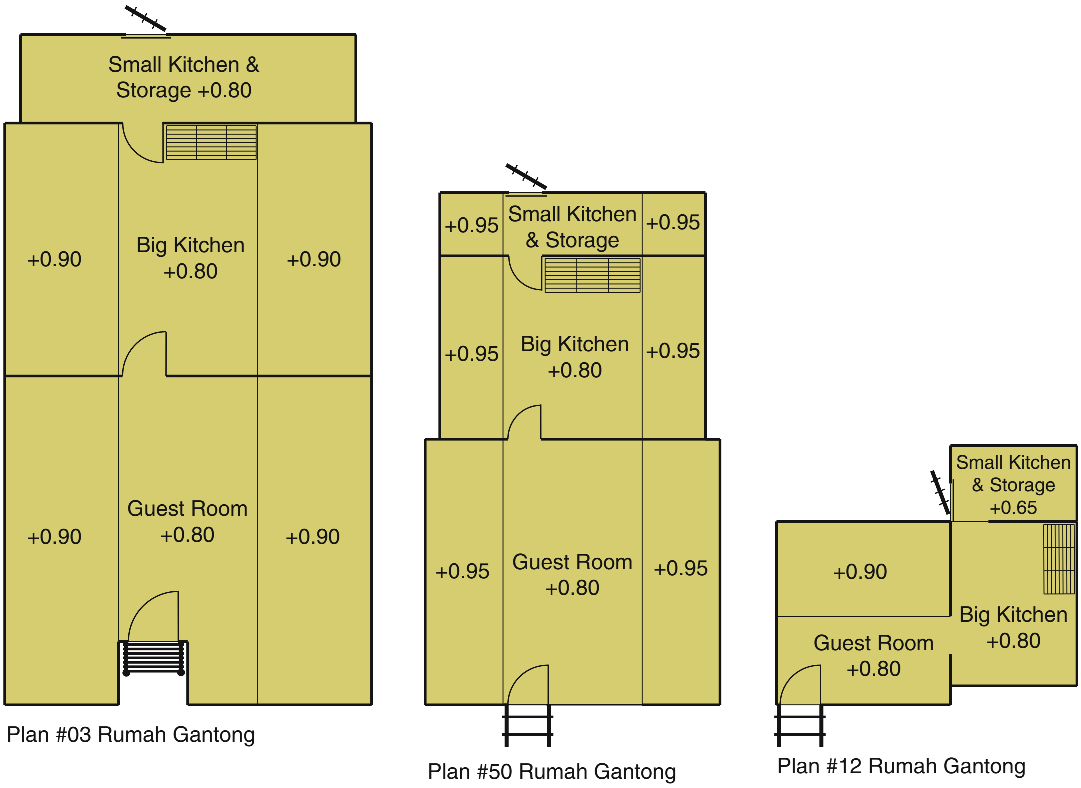
There are three types of Kanikeh vernacular architecture: *Rumah gantong*, *Rumah tanah*, and a combination of both types, *Rumah gantong dan tanah*.

Rumah gantong are further classified into three sizes: original/common, large, and small. Although there are various sizes, the functions and types of room are similar, including the main room (guest room) as a multipurpose room, rest room, recipient room, and bedroom; the large kitchen used for cooking, as a bedroom and as a dining room; and a small kitchen or

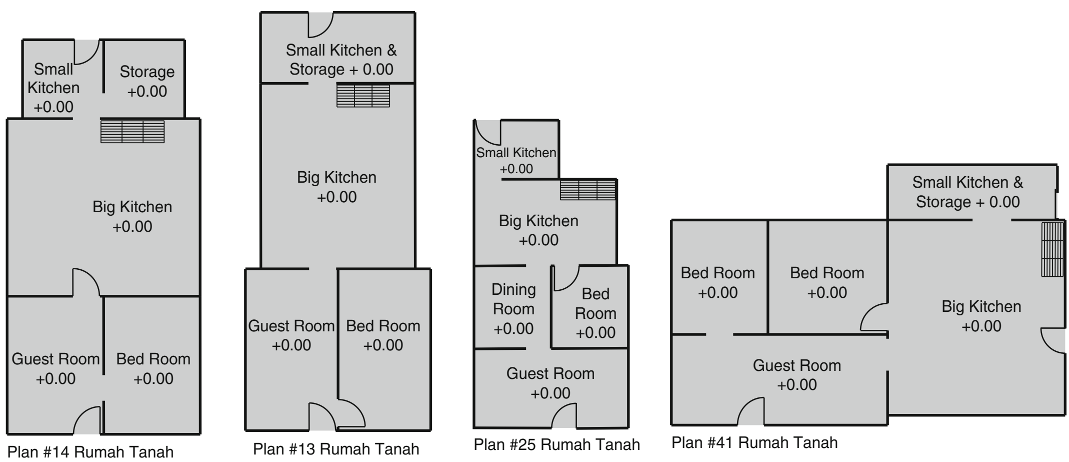
Architecture of the Moluccas, Table 1 Table Identification

Number of house	Type of house	Photos	Sketch	Plan	Name of room	Room function
03	Rumah Gantong				1. Guest room	1. Multi function room, sitting, guest room, sleeping
					2. Big kitchen	2. Cooking, sleeping, eating
					3. Small kitchen	3. Food storage and drinking water
12	Rumah Gantong				1. Guest room	1. Multi function room, sitting, guest room, sleeping
					2. Big kitchen	2. Cooking, sleeping, eating
					3. Small kitchen	3. Food storage and drinking water
13	Rumah Tanah				1. Guest room	1. Multi function room, sitting, guest room
					2. Bed room	2. Sleeping
					3. Big kitchen	3. Cooking, sleeping, eating
					4. Small kitchen	4. Food storage and drinking water

25	Rumah Tanah				1. Guest room	1. Multi function room, sitting, guest room
					2. Bed room	2. Sleeping
					3. Living room	3. Eating
					4. Big kitchen	4. Cooking, sleeping
					5. Small kitchen	5. Food storage and drinking water
32	Rumah Gantong and Tanah				1. Guest room	1. Multi function room, sitting, guest room, sleeping
					2. Sleeping room	2. Eating, sleeping
					3. Kitchen	3. Cooking, food storage and drinking water
50	Rumah Gantong				1. Guest room	1. Multi function room, sitting, guest room, sleeping
					2. Big kitchen	2. Cooking, sleeping, eating
					3. Small kitchen	3. Food storage and drinking water



Architecture of the Moluccas, Fig. 7 Plan view of Rumah Gantong

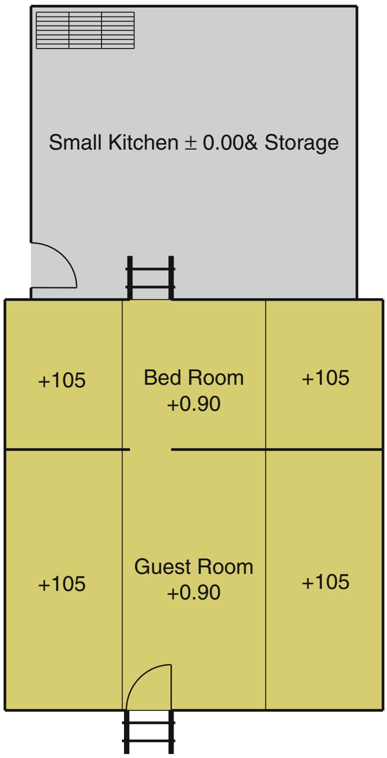


Architecture of the Moluccas, Fig. 8 Plan *Rumah Tanah*

storage kitchen as a place to keep food/ingredients and clean/drinking water (Fig. 7).

Rumah tanah are usually large in size: the front room is bigger than the room after it and the rear room is the smallest. It is usually had one or even more separate rooms that functioned as a room for the house owner or as a guest bedroom.

Although there is still some variation, the *Rumah tanah* preserves the *Rumah gantong*'s main rooms such as the guest room, large kitchen,



Plan #32 Rumah Gantong/Tanah

Architecture of the Moluccas, Fig. 9 Plan Rumah Gantong and Tanah

and the small kitchen/warehouse. The large kitchen is still used as a bedroom for the house owner and as a place to cook and prepare dishes (Fig. 8).

The house variation *Rumah gantong and Tanah* combines both types of house, the *Rumah gantong* and *Rumah tanah*. There are only two such hybrid units, both of them are front-side *Rumah gantong* (parlor) and rear-side *Rumah tanah* (large kitchen and storage room). The inner room of the hybrid unit is similar to the *Rumah gantong*. The distinction is that the back rooms are same with the large kitchen and storage kitchen at *Rumah Tanah* which was used to cook in and as a sleeping place for homeowners. The cooking function is carried out in the storage kitchen which is at the rear of the house as in the *Rumah tanah* (Fig. 9).

The architecture of the living houses in Kanikeh village reflects local characters by optimizing and utilizing surrounding local materials.

Acknowledgments Our greatest thanks go to SATU BUMI for conducting “Architecture Research of Kanikeh Land” within the 2013 Binaiya Karst Exploration program. Thanks to all SATU BUMI’s members, the Executive Committee, Expedition Athletes/Representatives, Kanikeh Villagers, and all other institutions helping with this research. Special thanks also to Prof. Zamolyi Ferenc for the recommendation and Helaine Selin as editors helping with the publication of these “travel notes.”

References

Baroncini Turricchia, G., & Benassi, A. (2012). *Report citation: Cave and Karst prospecting within Seram Island (Maluku Province)*, taken from http://www.circolospeleologicoromano.it/csr/wpcontent/uploads/2014/01/Seram2012.pdf

Oliver, P. (1987). *Dwellings: the house across the world*. Oxford: Phaidon.

Architecture: El Morro of Puerto Rico

Mohammad Gharipour[1] and
Jacqueline Stephens[2]
[1]Morgan State University, Baltimore, MD, USA
[2]Indiana State University, Terre Haute, IN, USA

El Castillo de San Felipe del Morro, known as El Morro, is the second fort built on the islet of San Juan, Puerto Rico. It is a six-level citadel rising 140 ft and covering over 70 acres above the northwestern point of the islet named in honor of Philip II, the son of King Charles V. “El Morro” means a promontory or headland. The Spanish began to build this second fort quickly after completion of La Fortaleza, San Juan’s first fort. Because La Fortaleza was placed inside the harbor, critics pointed out, approaching enemies would believe the island was unprotected.

The construction of El Morro started in 1539, with a vaulted masonry tower about 60 ft above sea level, midway up the cliff, with bracing for four cannons. At this time, only three cannons were mounted in the tower. In the early 1580s, with English freebooters like Sir Francis Drake and Sir John Hawkins pilfering the Spanish Caribbean, Philip II sent two defense experts:

Field Marshal Juan de Tejeda, a military veteran, and Juan Bautista Antonelli, an Italian engineer-architect, to inspect Spain's American ports. In September 1587, Tejeda and Antonelli, back from their inspection tour, proposed that the Crown fortifies ten key ports, one of which was San Juan, Puerto Rico. In March 1589, with Philip's approval, Tejeda and Antonelli returned to San Juan with artisans, stonecutters, masons, and blacksmiths. They also used local laborers and slaves.

Antonelli's new design for El Morro consisted of shelter for 3,000 people, guardhouses, magazines for munitions, plus structures that military engineers call "hornwork." The hornwork was comprised of two half-bastions with a straight wall, known as a curtain, between them. For the additional appearance of height and protection against an assault, a narrow moat was dug in front of the curtain wall and half-bastion walls. A drawbridge for crossing the moat was located at the center of the curtain wall in front of the gate for entering the fort. Just inside the gate were guardhouses provided for shelter from the weather since the hornwork was a basic parapet, which provided no shelter. In order to shield the gate and drawbridge a ravelin, small fortification of two embankments that are shaped as an arrowhead pointing toward the larger defensive area was built with a cannon placed within the embankments to cover the approach.

Antonelli's design, plus additions made by his successors, was tested in 1595, when Sir Francis Drake attacked San Juan. Drake's men were unable to take the fort by surprise, and after an hour of fighting, the English ships left El Morro. While waiting for the funds to repair El Morro's defenses after Drake's attack, a much reduced garrison of 176 men was able to ward off another attack by Sir George Cumberland on June 17, 1598. The city of San Juan surrendered to Cumberland the next morning, but El Morro was not taken until July 1, after Cumberland blockaded the fort and ordered continuous cannon fire. Cumberland and his men withdrew after 6 weeks, leaving San Juan and El Morro in ruins.

Puerto Rico's new governor, Captain Alonso de Mercado, rebuilt the fort, and his preparations were tested on September 25, 1625, when Dutch admiral Boudewijn Hendricksz attacked the harbor. Hendricksz was able to sail past El Morro's cannons and enter the San Juan harbor. Governor Mercado gathered his supplies and soldiers into the fort, allowing Hendricksz to take the city. Three days later, Hendricksz attacked El Morro with his heavy Dutch guns. But El Morro's artillery, plus the efforts of Puerto Rican militiamen outside the fort, forced the Dutch back to their ships.

This successful sidestepping of El Morro brought new construction and repairs. A new barrier wall was begun which encircled the whole city following along the contours of the land. These new reinforcements stood against attack for over 100 years.

In 1765, Spanish engineers updated the fort and other city defenses, increasing its firepower from 3 to 37 cannon, building an 18-ft thick wall and enlarging the interior spaces. In 1843, Puerto Rico's first lighthouse was built atop El Morro. Except for a few pirate raids, San Juan stayed peaceful until the USA attacked on May 12, 1898, in the Spanish-American War. After bombing El Morro all day long, the USA managed to damage the tip of the Santa Barbara Bastion. In 1908, the US Navy built a lighthouse atop El Morro, which still stands today.

During World War II, the USA added a concrete sentry tower to the Santa Barbara Bastion, as well as hidden command and communication centers, and underground bunkers. In 1961, the US Army turned El Morro over to the jurisdiction of the US National Park Service to be preserved as a museum. The United Nations declared the site a World Heritage site in 1983. Today it is the most visited tourist attraction in Puerto Rico.

References

Buisseret, D. (1980). *Historic architecture of the Caribbean*. London/Exeter, NH: Heinemann.

Crain, E. E. (1994). *Historic architecture in the Caribbean Islands*. Gainesville, FL: University Press of Florida.

National Park Service. (1996). *Forts of old San Juan: San Juan National Historic Site*. Washington, DC: Division of Publications, National Park Service.

Architecture: La Citadel of Haiti

Mohammad Gharipour
Morgan State University, Baltimore, MD, USA

Located in northern Haiti, the impressive fort Citadel Laferrière sits at 3,000 ft (over 900 m) on the Bonnet-à-Lévêque, a mountain overlooking Haiti's northern plain, near the village of Milot. The city of Cap Haitian is about 25 miles (40 km) away. An important symbol of Haitian independence, the fort was recognized as a World Heritage Site by UNESCO in 1981. The location of the fortress offers a panoramic view to the entire northern region of Haiti and to the Caribbean Sea and the eastern side of Cuba.

There are few archival sources on the architects and builders of the Citadel. The fortress is said to have been designed in 1805 by a Haitian, Henri Barre or Besse, and other sources attribute its completion to a Scottish architect named Ferrier. Other accounts say it was designed by a French architect named Laferrière. None of this has been documented, however. Stretched across the mountain peak incorporating three sheer cliffs, the fort has four irregular sides, a long triangular jetty and a high rounded bastion. Its walls are up to 130 ft tall and its stone foundation is directly laid into the mountain, covering an area of 108,000 ft^2, roughly four acres. The Citadel has large cisterns and storehouses to enable its residents to store food and water for 1,500 defenders for up to 3 years. The plan of this fortress included living quarters for the king and his family, kitchens, bakery, foundry, dungeons, bathing quarters, and powder magazines.

Construction lasted from 1805 to 1817 and is said to have involved more than a 100,000 workers, who hoisted half-a-million pounds of rock to the site, as well as 275 brass cannons. Limestone, molasses, and the blood of local cows and goats were used to fasten stones together. Eleven small brick and tile workshops supplied materials for the fortress. It is said that more than 20,000 workers lost their lives during the construction process.

The Citadel Laferrière was built to defend Haitian independence, proclaimed on January 1, 1804. It was commissioned by Henri Christophe, one of the ex-slave generals who had led the Haitian Revolution, but who had refused to accept the leadership of a republican state based in Port-au-Prince. Seceding to develop his own northern Kingdom of Haiti, Christophe controlled what had been France's most valuable plantation zone and major colonial port. Most European states as well as the United States refused to recognize Haiti's independence and Christophe was deeply concerned that France might attempt to retake its former colony.

Though it overlooks the northern coast, the Citadel is about 9 miles (15 km) from the sea, too far for its cannons to reach naval attackers. Instead, it was part of a network of interior forts Haitian leaders built to protect the country's high interior plateau. In the war for Haitian Independence, French armies had controlled the coastal zones and sugar plantation areas, but had been unable tame the mountains. In the lowlands, thousands of soldiers newly arrived from Europe had died of malaria and yellow fever for which they had no antibodies. The Citadel would have allowed the Haitians to redeploy this strategy, in the event of a foreign attack.

The Citadel was only the most spectacular of Henri Christophe's building projects, which may have included as many as 9 royal residences and 15 forts. The second most impressive of these structures is the palace of Sans Souci, built at the foot of the Citadel. Though partially destroyed by an earthquake in 1842, considerable ruins remain at the town of Milot, including a striking circular chapel 82 ft (25 m) in circumference. In this large and elegant palace, with its running water, marble statutes, extensive gardens, and circular chapel, the King held court from its completion in 1813 until his death in 1820, at which time his Kingdom was dissolved. In 1825, Haiti signed a treaty with France, ending the threat of invasion.

References

Mangonès, F. (1992). The citadel as site of Haitian memory. *Callaloo, 15*(3), 857–861.

Trouillot, M.-R. (1995). The three faces of Sans Souci. In *Silencing the past: Power and the production of history* (pp. 31–69). Boston: Beacon.

Wilson, V.-E. R., & Van Baelen, J. (1992). The forgotten eighth wonder of the world. *Callaloo, 15*(3), 849–856. Summer.

Architecture: Nomadic Architecture of Inner Asia

Ferenc Zámolyi
Department of History of Architecture and Building Archaeology, Vienna University of Technology, Vienna, Austria

The Sinor Research Institute for Inner Asian studies defines the term *Inner Asia* as follows:

> Inner Asia, or the interior of the Eurasian landmass, comprises in historical terms the civilizations of Central Asia, Mongolia, and Tibet, together with neighbouring areas and peoples that in certain periods formed cultural, political, or ethnolinguistic unities with these regions. In the past the Inner Asian world was dominated by pastoral nomadic communities of the great Eurasian steppe, and its history was shaped by the interaction of these societies with neighbouring sedentary civilizations. (Website of the Sinor Research Institute, Indiana, Bloomington).

Thus, Inner Asia is not only a geographic term but even more a cultural-historical term for defining the broader region which led to the emergence of different nomadic populations in Asia. These civilizations and peoples were and are mostly inhabiting the arid steppe areas in the interior of the continent. Their economy was mostly based on cattle herding; the ecology of the steppe made it necessary to move the animals at certain intervals to avoid overgrazing. This frequent change of location together with the requirements and benefits of animal husbandry led to the emergence of certain specific dwelling forms, several of which endure and are still used even in our modern age. The fact that these buildings are still present may be a proof of their sophistication and adaptation to local climate and prevailing lifestyle. However, as everywhere, in many Inner Asian countries, the lifestyles and economy of the people are changing, and these changes lead in many places to sedentarization and the abandonment of nomadic habits.

Types of Nomadic Dwellings

Historically, we can discern several types of nomadic dwellings, which were used in Inner Asia:

- Tents with a load-bearing inner structure
- The yurt (Turkic) or *ger* (Mongolian), a trellis tent with a load-bearing inner structure and felt covering
- Carts with tents attached to them
- The black tent, a very special tent form made out of black goat hair or yak hair
- Different tents, usually for very temporary purposes and not intended for permanent dwelling

At present, only the trellis tent (the so-called yurt or ger) and the black tent are still in use among Inner Asian nomads for permanent dwelling. Tents with a load-bearing inner structure (the precursors of trellis tents) and carts with attached tents are only of historical significance. While the more permanent nomadic structures remain in one place usually for a period from 2 to 3 weeks to several months, according to the environment and time of the year, various simple tent types, usually made of light materials, are used for a few days' stay during hunting, traveling or attending festivities.

While in Mongolia the harsh climate makes agriculture a not very viable alternative to animal husbandry, in many Central Asian countries there is an option, especially with the advent of modernization, to switch to agriculture. Especially in those countries formerly part of the USSR, this change was forcedly introduced. Thus, it is not always clear to what extent the nomadic lifestyle is still a living tradition. In Mongolia, gers and people living a nomadic life are still dominant in

Architecture: Nomadic Architecture of Inner Asia, Fig. 1 Mongolian nomad camp

the countryside (Fig. 1), and many trellis tents can also be found in the suburbs of the main cities. In other countries, the amount of nomadic trellis tents still used is supposedly far less. However, the success of the trellis tent can be only estimated if one realizes that approximately 50 years ago, some people as far as central Anatolia and other parts of Turkey were still living in them. Nowadays, on the other hand, they have become extremely rare or maybe even do not exist anymore in the same region. Anatolia of course can only be counted as part of Inner Asia in a very broad cultural sense, but it shows that certain types of nomadic dwellings were used in a very broad geographic area, usually due to historic migrations of certain steppe people.

Tents with a Load-Bearing Inner Structure

Such tents had an inner frame of wooden sticks supporting a covering made out of textile or felt and thus may have functioned somewhat similar to a Native American teepee. There are also hints that in certain regions, mobile huts with curved wooden poles were in use. These dwellings can be considered the predecessors of the more sophisticated trellis tent. A better-documented ancient historical example for a tent with an inner frame might be the Sarmatian tent as there have been paintings showing such tents found, while a contemporary example is the dwelling of the reindeer-herding minority of Tuva people living in Mongolia (Fig. 2).

Trellis Tent

The trellis tent has walls made of a wooden lattice bound together with rawhide stripes. There are many variants in size or number of these lattice wall elements used. The trellis tent has a wooden roof ring (roof wheel) which in certain areas may be supported by columns.

Architecture: Nomadic Architecture of Inner Asia, Fig. 2 Tent with load-bearing wooden inner structure, N-Mongolia

The wooden roof wheel and the walls are connected by wooden poles (roof struts). The wooden frame is usually strengthened by ropes wound around the perimeter of the wall (girths) and also through the roof structure. The trellis tent is usually covered by layers of felt made of sheep wool. In case of Turkic variants also, a decorated reed mat (cane screen) is put up along the wall before it is covered with the wall felt. Nowadays, trellis tents do have a proper door; formerly, only a more makeshift door frame was made and the entrance covered with a piece of felt. According to Andrews, the trellis tent was invented supposedly around the eighth century AD by Turkic tribes. At the time of Ghenghis Khan, it seems to have been used side by side with nontrellis tents of a similar form, as passages in the *Secret History of the Mongols* (dating from approximately 1240) suggest (Andrews, 1999) (Fig. 3).

Tents on a Cart

Models of four-wheeled wagons dated to 600 BC were found in Kerch in East Crimea, and several authors of classical antiquity mention nomadic people of their time living in felt-covered tent cars. Some mention structures resembling wickerwork attached to these wagons (Andrews, 1999, pp. 13–17). Apparently later there was a shift to two-wheeled cars. Cuman (Polovtsy) people fleeing from Mongols are depicted in two-wheeled carts with steep tents in the thirteenth-century Radziwill Chronicle. Also dwellings which could be taken from the cart and placed on the ground seemed to have been introduced with time.

Szalay (2009) remarks that in the Chinese chronicles of the Heida Shilue (1237), the Chinese envoys Peng Daya and Xu Ting from the Sung Dynasty write about the form of life of a nation they call ”Black Tartars”:

> Their dwellings are felt tents which have no [solid] walls or beamed rooms.[. . .] On the day for travelling when the camp is broken up, cows, horses and camels are used to pull the cabins on carts in which one can sit or lie down. These are called tent carts.
>
> The yurt [qionglu] is of two kinds. The Yenjing style uses willow sticks as a structure which is like lattice work of the south and is collapsible. [. . .] They are carried on horses. The grassland style uses willow sticks to weave a rigid enclosure and across its diameter felt is used to pull it taut; these are not collapsible and are carried on carts.

In the seventeenth century, the Noghay are reported to have been living in similar tents. These dwellings did not have a trellis yet; however, there is a photograph from the beginning of

Architecture: Nomadic Architecture of Inner Asia, Fig. 3 Trellis tent being erected. Mongolia

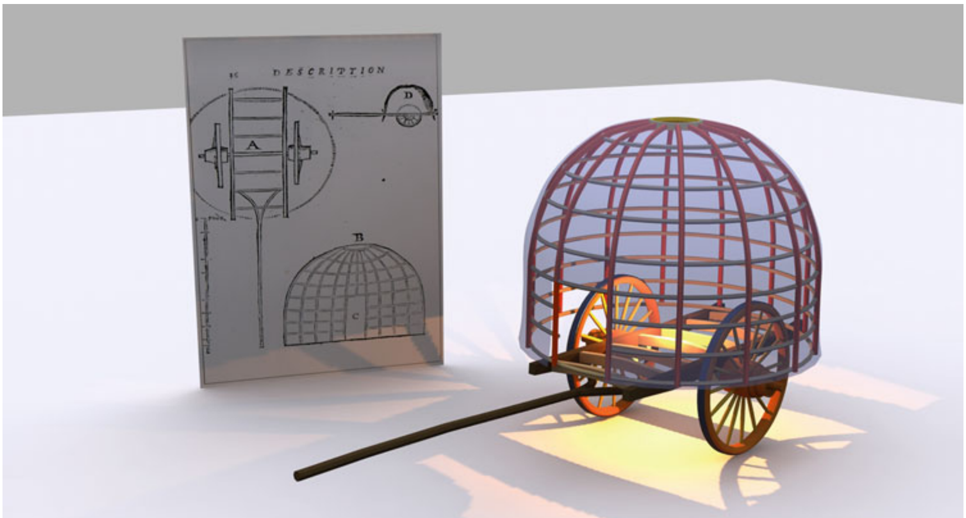
Architecture: Nomadic Architecture of Inner Asia, Fig. 4 Noghay tent-cart, after Andrews (1999)

the twentieth century showing a Noghay tent cart with a tent apparently having a fixed trellis (Andrews, 1999) (Figs. 4 and 5).

Black Tent

There are two regions of Inner Asia where nomads use black tents as dwellings: Tibet and Baluchistan. If Inner Asia is meant in a very broad definition, there would be other areas (e.g., parts of Iran, Anatolia - Fig. 7) where black tents are in use. For a detailed description of black tents, see Andrews (1997) or Ambrosch (2005) or Pfeifer (formerly Ambrosch 2015). In this article, only the Tibetan and the Baluchistan tents will be described.

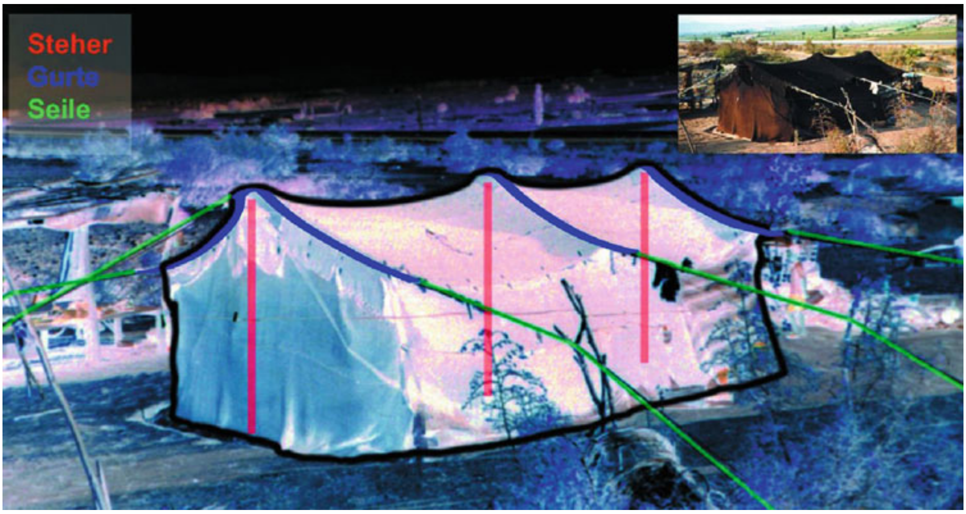
The Tibetan tents can be divided according to Ambrosch (2005) into three types. All these three are made of Yak hair, which is different to other types of black tents, which are made of goat hair. The shape of Tibetan tents is extraordinary, as they are all quite low, and one of their variants is almost domelike in appearance, as most of the supporting



Architecture: Nomadic Architecture of Inner Asia, Fig. 5 Noghay tent-cart, after Andrews (1999)

Architecture: Nomadic Architecture of Inner Asia, Fig. 6 Black tent in Ladakh (Source: Gisela Hayfa, Helga Zimpel-Erler, Ulrich Zimpel)

wooden poles are arranged outside the tent itself and are higher than the ridge. Thus, the ropes first go upward and are redirected via the poles to the ground. The appearance of this tent is much like a spider sitting on the ground with its legs being the guy ropes. The form of the tent itself, however, is very similar to modern tent forms used by mountaineers, which is of course an adaptation to strong winds and the cold climate. The short roof ridge of the tent is held up by two poles, and at the apex, an opening can be found where the smoke of the fire can exit (Figs. 6 and 8). The other types of Tibetan tents do not have such a spectacular form. The second type uses no high wooden poles for the guy ropes, but they are directly staked to the ground, and a low stone circle is put up around the tent. The third type is similar in appearance but incorporates a low stone wall into its design. Tibetan tents are cold as the fabric does not insulate well. People have adapted to these conditions and have to be able to bear very low temperatures.



Architecture: Nomadic Architecture of Inner Asia, Fig. 7 Different parts of a Yörük (Turkish) *black* tent. *Red*: wooden posts under pressure, *blue*: fabric under tension, *green*: guy ropes under tension (Source: Ambrosch, 2005)

Architecture: Nomadic Architecture of Inner Asia, Fig. 8 Tibetan tent (Source: http://enjoyingindia.com)

Baluchi tents are made of goat hair, and they have an inner frame of arches made of willow wood. However, this frame is not capable of supporting itself without the tent fabric, and the structure needs guy ropes to stand. Most other black tent types which can be found in Arabia, northern Africa, or Asia Minor do have straight poles supporting the tent fabric, thus the Baluchi tent can be regarded as an unusual construction. It is not only used in Baluchistan but in a few other neighboring regions of Afghanistan (Ambrosch, 2005, pp. 79–81).

Tents for Temporary Use

A variety of tents for short trips, hunting or using at festivals were known to nomadic people.

Architecture: Nomadic Architecture of Inner Asia, Fig. 9 Mongol tent of the Maixan type (Source: Birtalan, Rákos, Tartsák, & Zámolyi, 2009)

Architecture: Nomadic Architecture of Inner Asia, Fig. 10 Mongolian trellis tent (ger)(Source: Birtalan et al., 2009)

To illustrate the topic, Szilágyi's description of Mongolian tent types will be cited:

> Asar. This is a generic term for several tent types, such as cacar (one without vertical walls) and cačir (one with vertical fabric walls). The word asar means "tent, tent palace, pavilion", and one can find references to it written as early as in the Mongolian times. It is usually used at great festivals or to welcome visitors. The size of an asar can vary from small (for one or two persons) to large capable of hosting 500 people. In his account of the enthronement of Güyüg khan (1246), Plano Carpini, the Franciscan friar, reports about a giant tent that could hold two thousand people, and the support pillars of which were adorned in gold. In later times, the plans of several Mongolian Buddhist temples were designed after cačir. (Szilágyi, 2009).

The Mongols use other tent types, for example, the Maixan, which is a tent with an inner structure of two forked vertical poles and a ridge pole laid across them. The tent cloth is held up by this roof ridge and has to be fixed with ropes and stakes. These variants, as the other temporary tents, need the tensile strength of the tent fabric to stand. Trellis tents and tents with a load-bearing wooden structure, which are usually used by Inner Asian nomads as dwellings, are

Architecture: Nomadic Architecture of Inner Asia, Fig. 11 Uzbek trellis tent (Source: Erich Lehner)

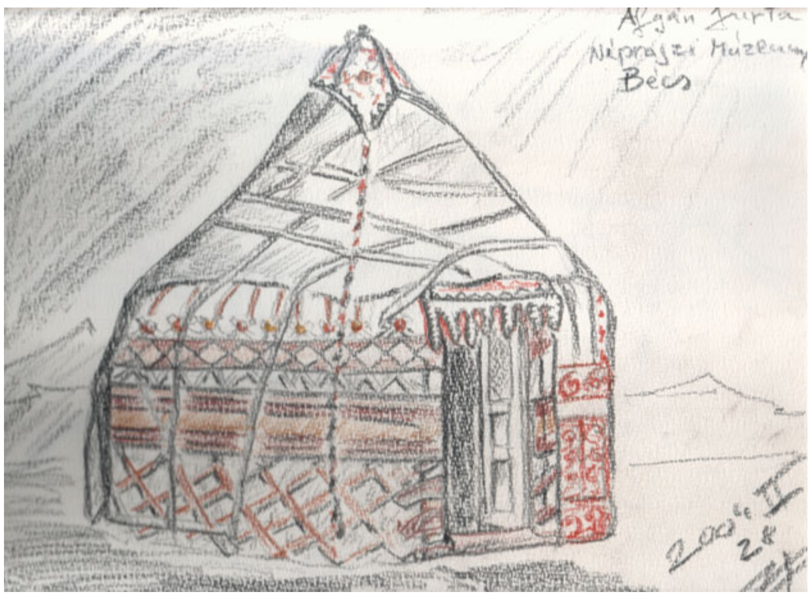
Architecture: Nomadic Architecture of Inner Asia, Fig. 12 Kirgiz trellis tents (Source: Gisela Hayfa, Helga Zimpel-Erler, Ulrich Zimpel)

capable of standing by themselves without their covering or any guy ropes. According to Szilágyi (2009), at festivals an ornate version of the maixan (*ugaljtai maixan*), mostly of blue color, is erected, which is decorated with the patterns of "endless knot" (*öljī utas*) and "longevity" (*pūj*) (Fig. 9).

Difference Between Turkic and Mongolian Trellis Tents

Although there is quite a large variety of Turkic trellis tent types (yurts), in this article only the Mongolian ger will be described in detail. The basic characteristics of trellis tents are similar

Architecture: Nomadic Architecture of Inner Asia, Fig. 13 Kirgiz trellis tents (Source: Gisela Hayfa, Helga Zimpel-Erler, Ulrich Zimpel)



Architecture: Nomadic Architecture of Inner Asia, Fig. 14 Afghan trellis tent at the Anthropological Museum Vienna, sketched by the author

everywhere and will be discussed when describing the Mongolian ger. For a detailed account on Turkic trellis tents, please refer to Andrews (1999), which is the best and most comprehensive work available.

There are certain basic differences between Turkic and Mongolian trellis tents:

- The roof wheel of Turkic yurts is not supported by columns.
- Usually, the roof wheels of Turkic yurts are made of one piece of wood, which is steamed and bent in a circle, while the roof wheels of the more common type of Mongolian ger is assembled out of several parts carved in a curved shape.

A

Architecture: Nomadic Architecture of Inner Asia, Fig. 15 Decorated cane screen of a Kirgiz tent (Source: Vidák István)

Architecture: Nomadic Architecture of Inner Asia, Fig. 16 Felt rugs of a Kirgiz tent (Source: Vidák István)

- The roof struts of Turkic yurts are usually bent to form a dome-like shape.
- The roof of Turkic yurts is definitely steeper than that of gers.
- The roof struts of Mongolian gers are usually heavier and thicker than those of Turkic yurts.
- The trellis laths of Turkic yurts are also bent, often in elegant curves to form somewhat

Architecture: Nomadic Architecture of Inner Asia, Fig. 17 Traditionally the ger was either packed onto camels or transported on two-wheeled carts when nomads moved from one grazing area to the next with their herds

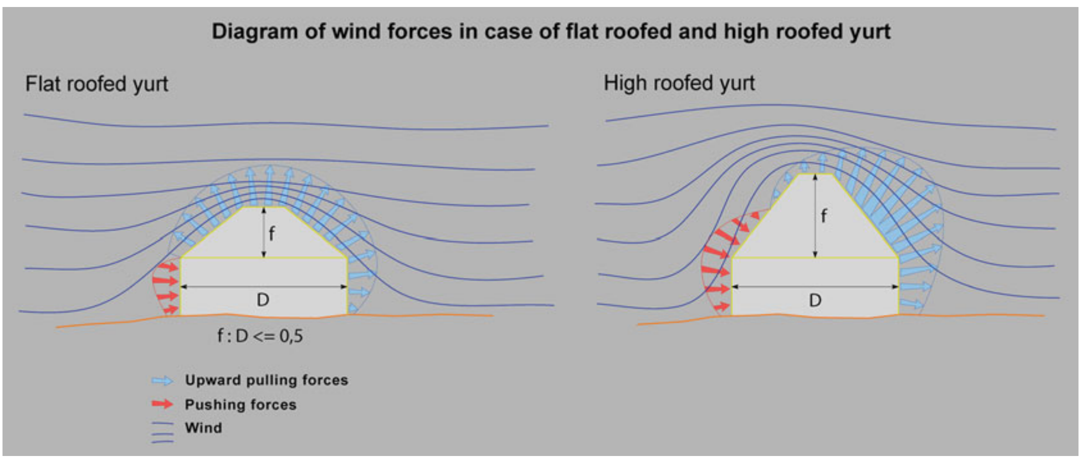
Architecture: Nomadic Architecture of Inner Asia, Fig. 18 Transport of a ger by modern means on a truck

spherical walls (the trellis laths of Mongolian gers are only bent minimally).

- Turkic yurts usually have a (decorated) cane screen around the trellis walls, which Mongolian gers only very seldom have.
- Turkic yurts have more and elaborately decorated felt rugs inside the dwelling. Usually the floor is covered in such rugs, while in the Mongolian ger it is not. Also Mongolians decorate their felt rugs in a somewhat different technique.

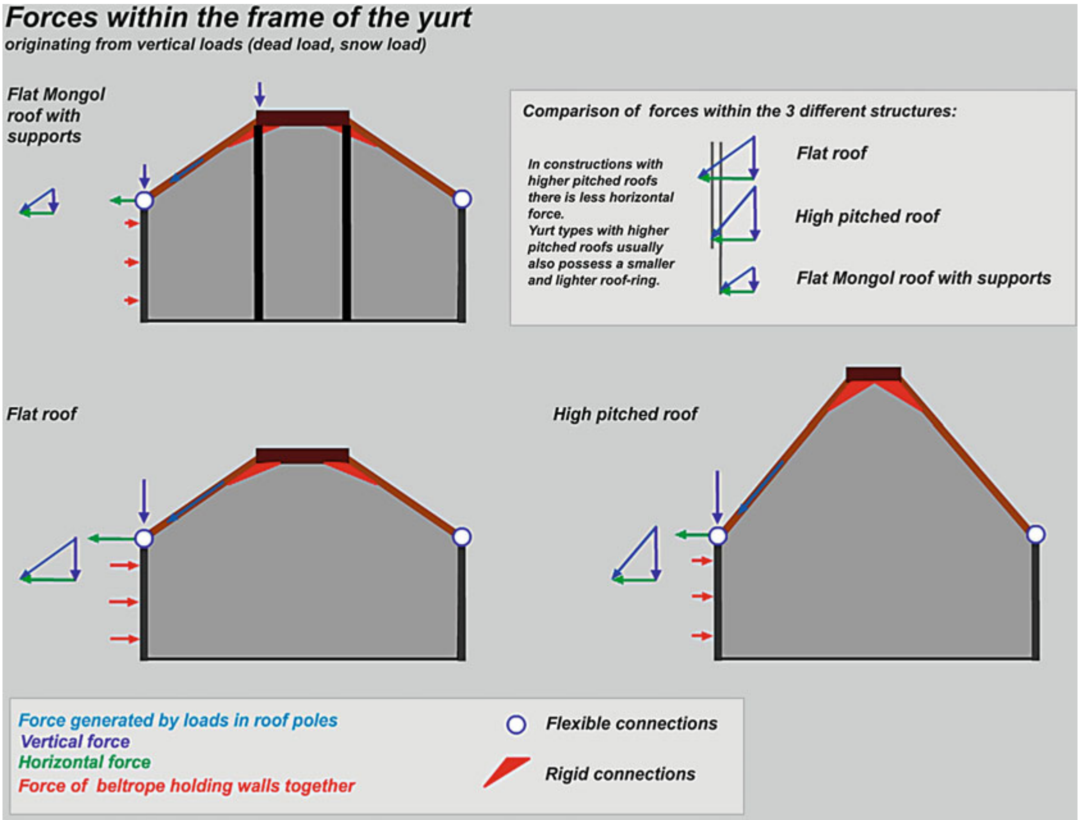
A

Architecture: Nomadic Architecture of Inner Asia, Fig. 19 The ger in winter. It is optimised to loose as little heat as possible, but its light structure cannot take snow loads. Thus as soon as snow falls, it has to be scratched from the roof (Source: Kevin Tierney)



Architecture: Nomadic Architecture of Inner Asia, Fig. 20 In strong winds trellis tents with high pitched roofs are in danger of being toppled, those with low pitched roofs are in danger of being “lifted” by the slipstream. Thus the roof structure of the Mongolian ger is low, comparably heavy, and in case of a storm extra weight is attached to the roof wheel to hold the dwelling down

- Turkic yurts tend often (but not always) to be more decorated on the outside than Mongolian gers, which have a plainer appearance.
- In Mongolian gers sometimes roof wheels and roof struts are painted elaborately with different symbolic designs. Often also the door is painted similarly.
- In spring Mongolian people often have to take newly born lambs or other animals into the ger, as the weather can still be very harsh at that time. Thus a small pen is set up near the entrance for that purpose. In Turkic yurts this measure is usually not necessary.
- While Turkic yurts are usually put up facing east, Mongolian gers are always erected facing south with their entrance (Figs. 10, 11, 12, 13, 14, 15, and 16).



Architecture: Nomadic Architecture of Inner Asia, Fig. 21 Forces in a Mongolian ger (*low roof*) as opposed to some Turkic yurts (*higher roof*)

The Mongolian Ger as an Example of a Nomadic Dwelling

The yurt, or as the Mongolian nomads call it, the ger, was designed to function as a mobile dwelling used all year round in a climate which in winter is extremely cold and stormy but is comparably arid. Although snow is a typical phenomenon during the Mongolian winter, high precipitation is not; the climate can be described as continental.

The location of a ger is altered very frequently; a camp is abandoned depending on surrounding resources for 2–3 weeks (Gobi region) to 2–3 months (in the more northern parts of Mongolia).

This means that well-designed heat insulation and an easy possibility of heating are essential for the inhabitants to survive the winter. As heating material (in this case animal dung) is scarce, it has to be used very effectively.

Mobility is another defining factor of nomadic architecture. People must be capable of disassembling the building into parts and load it on animals or carts in a comparably short time and with a minimum of effort involved. For transport, it has to be as light as possible and should occupy only a small space. After transport, the dwelling has to stand as soon as possible.

The criteria mentioned above define most structural properties of the yurt. It is a dwelling with a very light but strong wooden frame, which is covered with layers of felt for insulation and for protection against storm and rain. However, it is only in ethnographical terminology that the yurt is called a “trellis tent,” “round tent,” or “felt tent.” From the architect’s point of view, it is more related to a house, as it has a wooden

Architecture: Nomadic Architecture of Inner Asia, Fig. 22 Kirgizian craftsman building a yurt with hand tools (Source: Vidák István)

frame, which stands by itself without any supports or need of guying. Real tents do not stand without their textile skin, which takes an active part in carrying loads and tensile forces. A tent always needs guy ropes, which fix the construction to the ground, while a yurt does not. In the case of the yurt, the felt provides protection against wind, rain, and snow. It has no significant structural function.

It seems that in former times mobility was even more important than it is today, as ancient nomadic tribes are reported to have moved around mainly in tents or yurts fixed permanently to carts. However, nowadays these solutions have disappeared, and the dwellings are always dismantled when transported. Today, if no motorized transport is available, the yurt is still packed on animal-driven carts pulled by yaks, oxen, or camels. If the terrain is rugged, everything is loaded on camelback. A camel can carry approximately 300 kg on short distances and 200 on longer ones. This means a yurt and household items can be transported by three to four camels (Figs. 17 and 18).

When assembled, the pieces of the yurt, which themselves are small and light (and in case of the wall elements even foldable), form an optimized spatial structure. The form of the yurt is favorable for several reasons: firstly, the dome or flat cone-shaped interior with the low wall section offers a maximum of free inner space while using a minimum of construction material; secondly, the form is almost half dome shaped. The sphere has the smallest surface area–to–enclosed volume ratio of all geometric bodies. The loss of heat energy is directly proportional to the surface area.

This means that a half-dome-shaped house loses less energy than all other forms. Thus, the form of the yurt is optimized to lose as little heat as possible. Additionally, its comparably low structure, which integrates well into the surrounding landscape, offers as little surface to wind forces as possible. Usually, the emerging forces are pulling the structure upward. That is why in case of stormy weather usually a weight is attached to a central rope, which hangs from the roof wheel. The roof structure of the Mongolian yurt is also heavier than the roofs of other yurt types. This could be also an adaptation to strong winter storms, as the heavy roof ring and the roof poles attached to it are not easily susceptible to being dragged away. Also in case of low cone-shaped roofs no pushing forces appear. Pushing forces are more dangerous than pulling forces as they can lead to toppling of the structure (Figs. 19, 20, and 21).

As the Mongolian ger roof does not have a high pitch and the roof ring is heavy, it is necessary to support it with posts. Other yurt types that possess higher roofs and lighter rings do not need any supports.

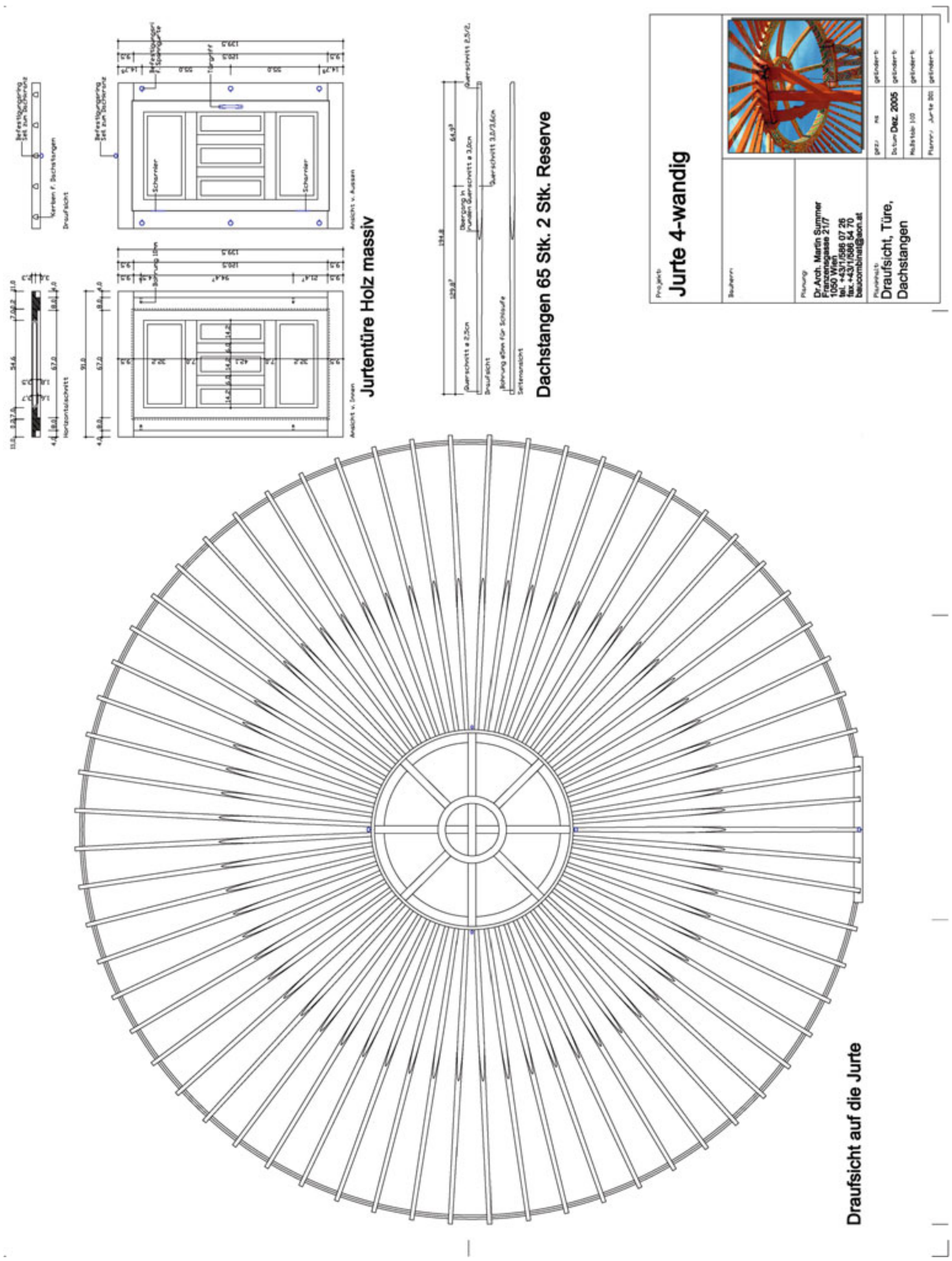
The pitch of the roof essentially determines the forces submitted by the roof poles to the wall construction, thus pushing it outward. The lower the roof pitch, the larger the outward pushing

Architecture: Nomadic Architecture of Inner Asia, Fig. 23 Feltmaking: The horse is dragging rolled up new felt over the steppe to compress it (Source: Jillian Van Ells)

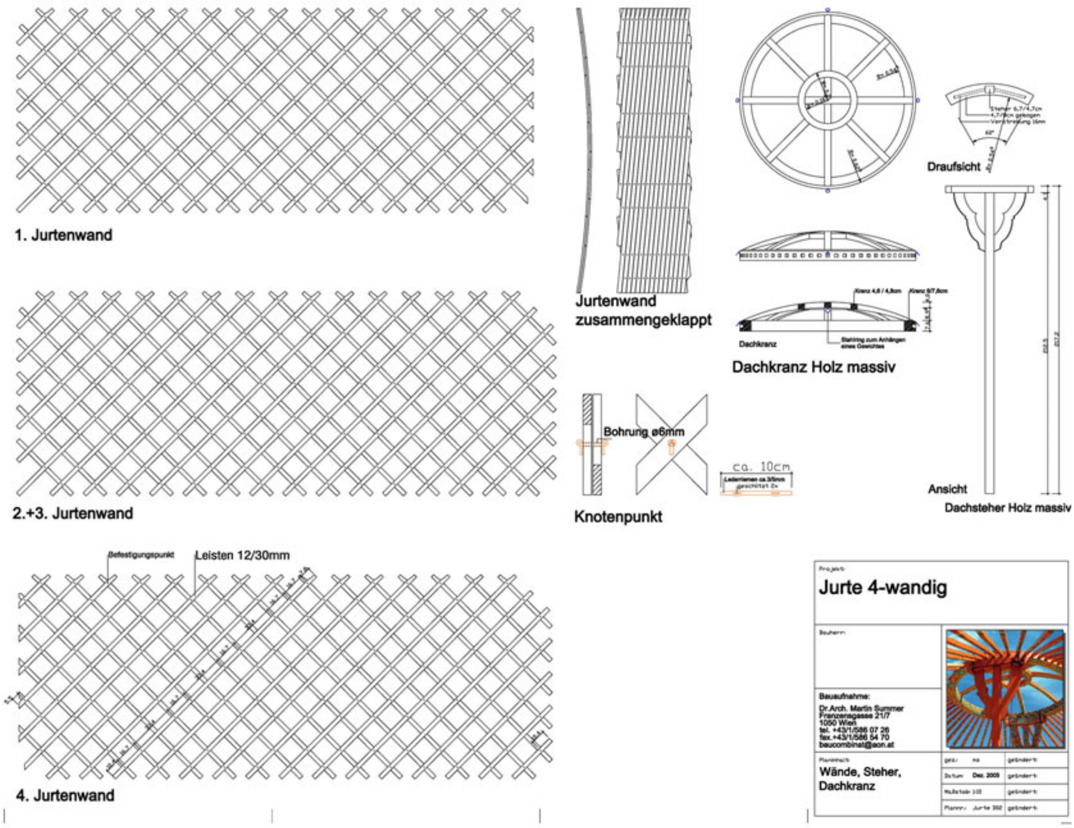
Architecture: Nomadic Architecture of Inner Asia, Fig. 24 Preparing to roll up the wool placed on the "mother felt" (Source: Birtalan et al., 2009)

Architecture: Nomadic Architecture of Inner Asia, Fig. 25 Preparing to roll up the wool placed on the "mother felt" (Source: Birtalan et al., 2009)

A



Architecture: Nomadic Architecture of Inner Asia, Fig. 26 Plans of a Mongolian ger, survey by Martin Summer



Architecture: Nomadic Architecture of Inner Asia, Fig. 27 Plans of a Mongolian ger, survey by Martin Summer

forces. If supporting middle posts are used, much of the load and thus of the outward pushing forces is taken over by them.

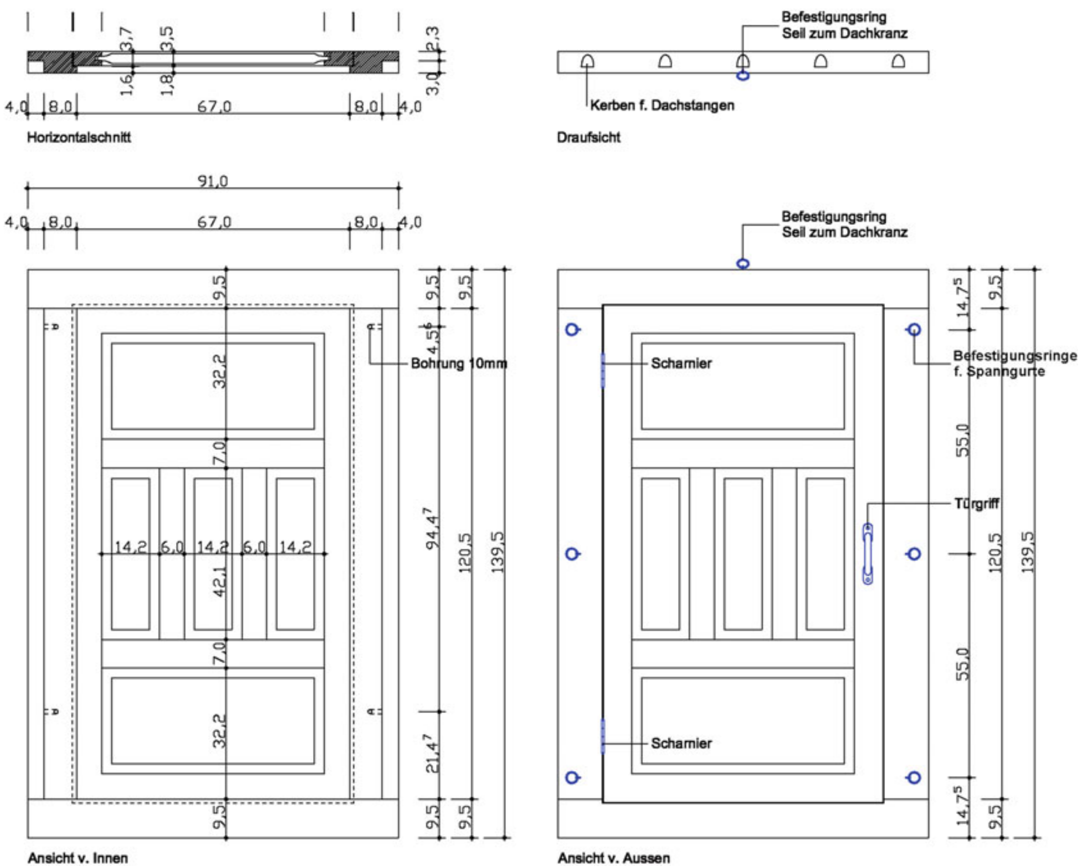
To strengthen the walls, several ropes are tied from one door jamb to the other, holding together the wall elements like a belt or a ring, adsorbing the forces pushing in the outer direction. If these ropes are cut, the walls will lean outward, and eventually the whole construction will collapse.

It is also these ropes that ensure that no fixed connections between the roof poles and the heads of the wall elements are needed (the connections are flexible ones, a loop fixed to the end of the roof poles being wound on the heads of the wall elements). The only more or less fixed connections in the structural system of the dwelling are those joints where the roof poles are sunk into cavities of the roof ring and of course those of the roof frame, which add a lot to the stability of the structure.

The form of the Mongolian yurt apparently changed at least to a slight extent from the Middle Ages on. One essential difference seems to be that as nowadays no open fire is used anymore and smoke is led by a chimney pipe outside the dwelling, the roof ring and maybe also the roof shape has become lower. When open fire is used, a high pitched roof is more favorable. This roof can also be topped by a chimney-like roof ring, thus generating even more effective upward draught transporting the smoke outside.

The reasons for change in the form of yurts through the ages have not been thoroughly examined so far, so maybe further research will provide more insight into this topic.

A



Architecture: Nomadic Architecture of Inner Asia, Fig. 28 Plans of a Mongolian ger, survey by Martin Summer

Manufacture of a Nomadic Dwelling

The wooden frame of trellis tents is usually manufactured by specialists (Fig. 22), that is, somebody of the community versed in carpentry work. The production of the felt cover is done by nonspecialists (Figs. 23, 24 and 25).

In Mongolia, larch wood is traditionally used for the trellis, the roof wheel, and the columns, while willow or birchwood is used for the roof struts. It is important to note that after felling the wood it is usually put for some time into a lake, river, or creek, as the water leaches out the nutrients and the sap inside the wood and thus makes it less prone to insects and decay. While formerly yurts where made by a carpenter with simple hand tools, nowadays there are often factories producing yurts or gers with the help of power tools and modern machinery (Figs. 30, 31, 32, 33 and 34).

The size of a ger is usually measured by the number of its trellis wall elements, the *xan*. The most common gers have 4, 5, or 6 xan, which means their diameter ranges from about 4.25 m to 5.5 m and 6.4 m respectively. There are gers which only have 3 xans, but they are only used as storage buildings and not for dwelling purposes. When Mongolians talk about gers, they not only mention the number of xans but also sometimes the number of roof struts (*uni*).

The most common gers have a ground floor area of 20–30 m^2, and if dismantled and packed for travel, a middle-sized ger weighs around 1,000 kg. The wall height is around 1.5 m; the overall height of a ger in use nowadays is around 2.3–2.5m (Figs. 26, 27, 28 and 29).

Architecture: Nomadic Architecture of Inner Asia, Fig. 29 Painted column (*bagana*) of a Mongolian ger (Source: Birtalan et al., 2009)

The felt covering is made by the whole community in late summer or autumn. First the sheep are sheared, and then the wool is beaten with sticks. This procedure loosens the wool and helps to free it from dirt. After that, the wool is laid on an already finished piece of old felt (the mother felt) and is wound around a wooden axle. It has to be taken care how the wool fibers are placed and which quality of wool is used in which place. The axle is bound to the saddle of a horse and dragged behind on a clean flat stretch of 300–350 m around 15 times. After that the felt bundle is opened, and the new piece of felt (son felt) turned, wound up again, and dragged again around (Birtalan et al., 2009) (Figs. 23, 24 and 25).

Use of Space Within the Ger

When entering a ger from the south through the entrance, the most prestigious part can be found exactly opposite the door to the north in front of the wall. Here, usually sacral objects, Buddhist icons, or butter lamps can be found; sometimes photos of family members are placed here. This part of the inner space has the highest rank, which diminishes

Architecture: Nomadic Architecture of Inner Asia, Fig. 30 Ger manufacture in Ulan Bataar

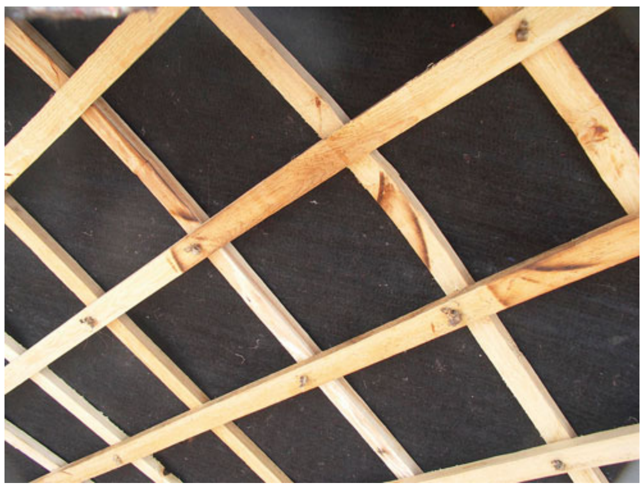
Architecture: Nomadic Architecture of Inner Asia, Fig. 31 Ger manufacture in Ulan Bataar, using modern tools

Architecture: Nomadic Architecture of Inner Asia, Fig. 32 Ger manufacture in Ulan Bataar

when moving toward the door. Guests are seated according to this plan: The most respected, the higher ranking, or maybe also the oldest are given a place more to the north, near the prestigious part, while younger or nether-ranking guests are seated nearer to the doorway (Fig. 37).

Customarily one moves inside a ger from left to right in a clockwise direction. The central part of the dwelling is avoided; the roof-supporting columns, which demarcate this space, should not be touched. Also one should not pass between them. The inner space within a ger is divided

Architecture: Nomadic Architecture of Inner Asia, Fig. 33 Ger manufacture in Ulan Bataar



Architecture: Nomadic Architecture of Inner Asia, Fig. 34 The black marks on the trellis laths of this Mongolian ger show, that they are bent over fire, and not steamed and bent into shape like the laths of Turkic yurts, which have a more elegant curve

into two halves: the mens' part (the Western half) and the womens' part (the Eastern half). Upon entering the dwelling one would first see the saddles and tools stored on the left-hand side from the entrance in the men's half. Also newly born sheep and goats are usually brought into this part of the ger if the spring weather turns very severe. Somewhat more inside there is a container for *koumiss*, the fermented mare's milk. Also further, tools or weapons (if there are any) can be found here.

From this first part one enters the living or sleeping part of the yurt; the boundary is usually signified by chests or boxes, and also beds can be found here. On the womens' side the subdivision of the space is similar: near the door there are kitchen utensils, pots, and a water container, while more inside there are chests and a bed. People sleep always with their heads pointing toward the north. Formerly people slept on felt mats, but nowadays almost everybody owns a proper bed.

Architecture: Nomadic Architecture of Inner Asia, Fig. 35 Roof wheel of an Uzbek yurt (Source: Erich Lehner)

The ger is heated by an iron stove situated in the center of the dwelling, right below the *tonoo*, the roof wheel. Nowadays a chimney pipe leads the smoke out of the dwelling; in former times there was an open fire. As usually in the steppe there is not enough firewood to be found, dried animal dung is used for fuelling the fire. The ger is lit mainly by the opening in the roof wheel (Figs. 35 and 36) and partly by the translucent walls themselves if the felt is not too thick. The lighting from above has a pleasant quality. The light coming through the tonoo produces a spot within the inner space, which changes its position according to daytime and thus functions like a sundial.

From a Nomadic Lifestyle to Modern Sedentary Forms

Mongols usually only choose a sedentary lifestyle when migrating to towns or when other reasons make staying in one place possible or necessary. Tourism can be such a reason.

In the northern forested areas a long tradition of sedentary architecture exists. These buildings are mostly log cabins of some kind. The Buriat people have evolved a traditional way of building with wood and log structures; the other timber buildings usually have a little bit makeshift and improvised appearance (Figs. 38, 39, and 40).

Architecture: Nomadic Architecture of Inner Asia, Fig. 36 Detail of a roof wheel of an Uzbek yurt (Source: Erich Lehner). The rim of such wheels is steamed and bent to a circular shape. The roof wheel of Mongolian gers is assembled from several pieces and not bent

In urban areas timber is an expensive building material; so many poor people use bricks or concrete instead. Loam is sometimes applied over a wooden latticework as plastering to walls of both

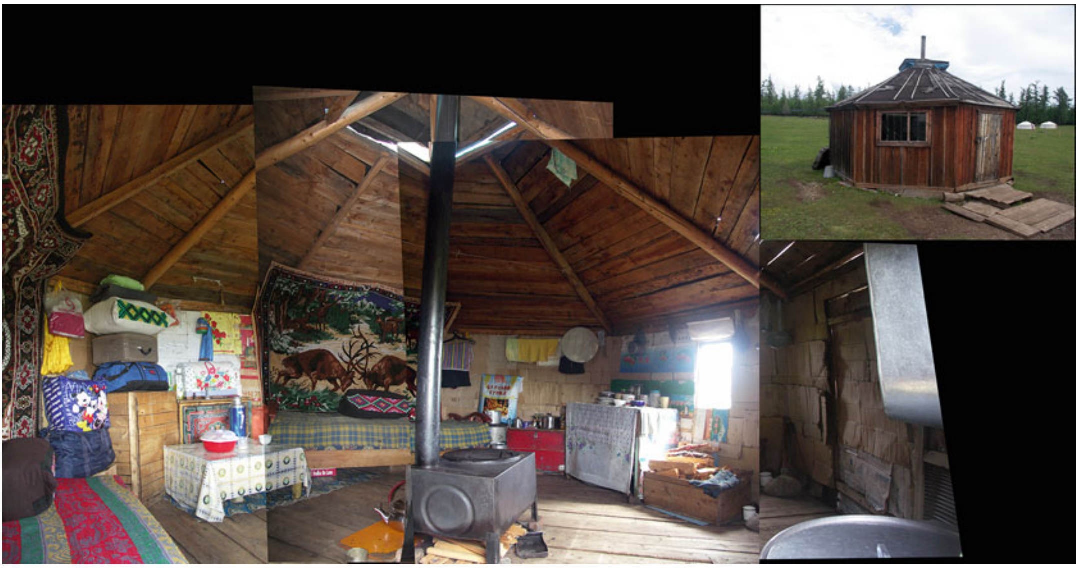
Architecture: Nomadic Architecture of Inner Asia, Fig. 37 Inside a Mongolian ger, looking northward from the entrance

Architecture: Nomadic Architecture of Inner Asia, Fig. 38 Log cabin being built, Mongolia

wooden and concrete houses. Most of the building materials are imported from China or Russia; bricks are also manufactured in Ulan Bataar in several factories.

If a sedentary or more or less sedentary lifestyle is chosen, the ger is only abandoned after a longer period of time. It is usual to see in most cases a parallel existence of the nomadic dwelling and houses made out of wood or stone. In this case the houses are mostly inhabited in winter and the yurt in summer. A reason for this is that the yurt is airier. In winter as one house dweller in Ulan Bataar said, the ger can be heated up very fast, but it gets cold again very

A

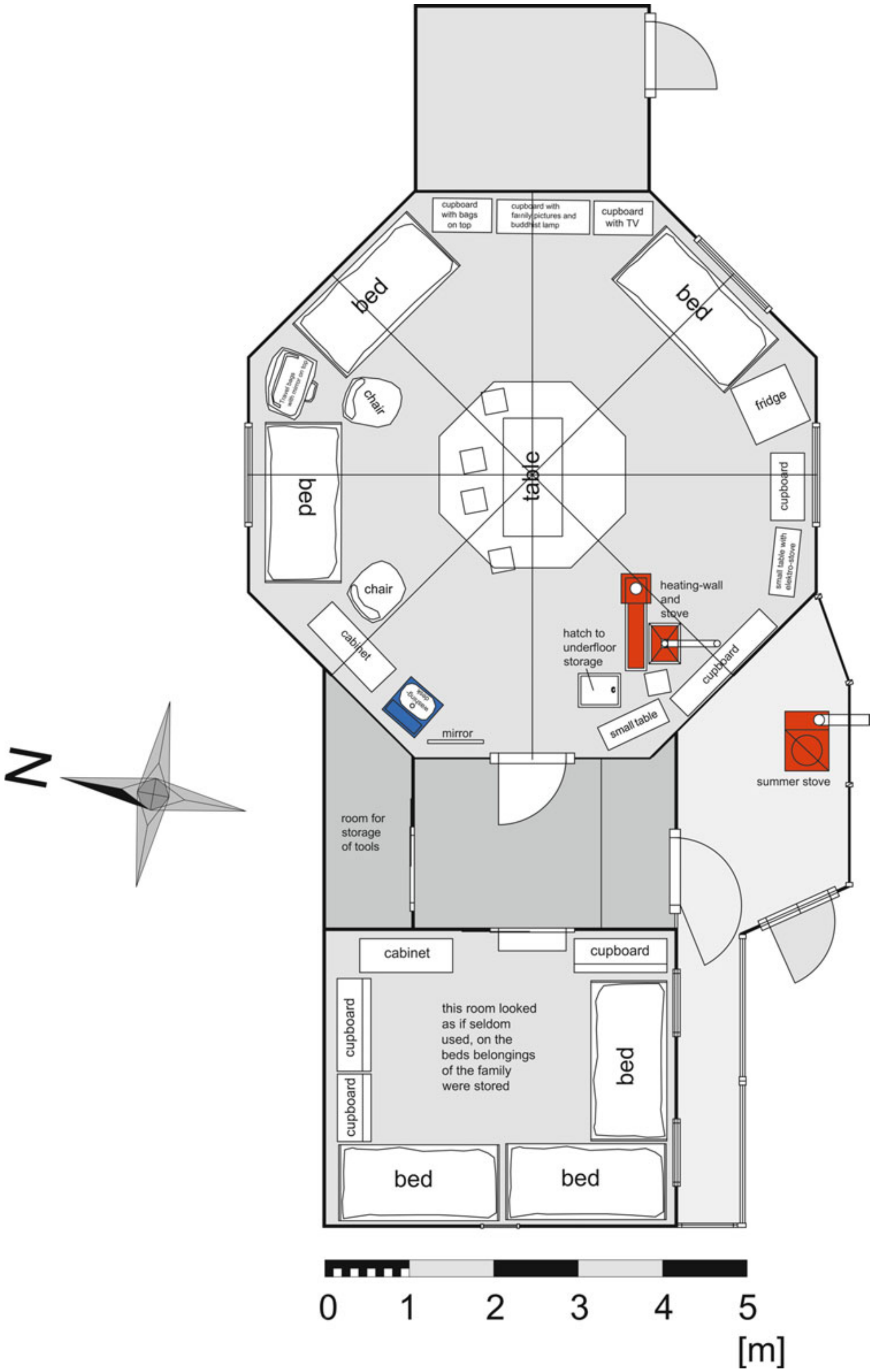


Architecture: Nomadic Architecture of Inner Asia, Fig. 39 Many wooden houses are built in a form closely related to the ger, and have also a similar inner organisation

Architecture: Nomadic Architecture of Inner Asia, Fig. 40 Log cabin in the shape of a ger

Architecture: Nomadic Architecture of Inner Asia, Fig. 41 Octagonal house in Ulan Bataar

Architecture: Nomadic Architecture of Inner Asia, Fig. 42 Stove with heating wall inside an the octagonal house. The wall ensures that heat is radiated slowly to the surrounding room in winter



Architecture: Nomadic Architecture of Inner Asia, Fig. 43 Ground plan of the octagonal house shown above

Architecture: Nomadic Architecture of Inner Asia, Fig. 44 Buriat log cabin

Architecture: Nomadic Architecture of Inner Asia, Fig. 45 Buriat log cabin with peculiar roof structure

fast as well. This is because the walls have no thermal storage capacity. The houses with their thick walls hold the heat better but are usually badly ventilated because of inferior design and material quality (especially the windows). This makes living in them during summer not really comfortable (Figs. 41, 42, and 43).

In the northern forested areas the Buriat people have developed an octagonal house, which closely resembles the yurt. Its walls are made of timber logs, the corners connected usually with a butt-and-pass method, sometimes with interlocking saddle notches. However, most log architecture in Mongolia is built with a local variant of the butt-and-pass method, where half

Architecture: Nomadic Architecture of Inner Asia, Fig. 46 Corner detail of a Buriat log cabin

of each log is left longer and protrudes over the wall plane. One fourth of the logs are sawed away on the upper and lower part of the corner joint, so an interlocking pattern of log ends in both directions emerges. This method is one of the simplest connection methods in log building and is mostly used over all of Mongolia. Some houses in the Buriat regions use or used interlocking saddle notches as corner joints, which already needs more expertise in woodworking. Gaps between logs are stuffed with moss to prevent wind blowing through the building (Figs. 44, 45, and 46).

In some Buriat houses there is a quadratic space in the center, which is lowered slightly below floor level and also contains the hearth. It is flanked by four posts, which support a frame in the ceiling, above which there is a kind of lantern with windows or at least a roof-covered smoke hole. In smaller houses the pillars are maybe not necessary; the radially running rafters are able to hold the structure up by themselves. In other houses the rafters are not radial. The roof construction is supported by beams placed diagonally over the corners and then in layers on top of each other, thus diminishing the open span each time until only the smoke hole is left free.

These buildings are traditionally covered with earth, wooden shingles, timber boards, or tree bark. In recent time tar-bitumen roof sheeting or corrugated iron sheets are also used.

In areas where log building has not much tradition or where the stationary buildings also have a more temporary character, octagonal houses are also often built out of timber boarding with a slightly stronger wooden skeleton. Here the substructure is connected with the timber boards by nailing, forming panels in much the same technique a wooden garden door is made. These makeshift panels are put together to form an octagonal shape, with a roof made with the same method. On top of the roof a lantern with windows is placed, and some of the wall panels have windows as well. All in all these are usually not very well-built houses, but they show direct structural relation and proximity to the Buriat houses and the nomadic yurts. Usually in these octagonal houses the central hearth is replaced by a table, and the oven is shifted to the kitchen area on the right side from the entrance near the wall.

There are some intermediary types of these houses, where a yurt roof ring is still used, sometimes planted on a pole (Figs. 47, 48, and 49).

In the northern regions there is also a strong tradition of rectangular house building. These houses are usually log structures and often show strong Russian influence. In cases where the house interior is still one single room, people try to adhere to the spatial organization of areas within the yurt.

In urban areas houses stand on plots surrounded by high timber board fences which prevent passing people and neighbors from looking inside. The gates of the plot are usually painted with traditional motifs. Houses are

Architecture: Nomadic Architecture of Inner Asia, Fig. 47 Wooden house resembling a ger. Mongolia, Terelj

Architecture: Nomadic Architecture of Inner Asia, Fig. 48 Wooden house resembling a ger. Mongolia, Terelj

Architecture: Nomadic Architecture of Inner Asia, Fig. 49 Inside a wooden house resembling a ger. In this house even a roof wheel has been used. Mongolia, Terelj

mostly situated on the northern part of the plot, entrances looking south. Very often there is still a yurt standing on the plot in front of the house, and in the southeast or southwest corner an outhouse and other auxiliary buildings can be found. Sometimes houses show a double organization pattern, which means that they are built symmetrically and can accommodate two families. Very typical features are the heating walls, which are walls made of bricks which lead the smoke from the iron oven with inner tubes in many bends to the chimney. As the smoke has a long way to pass through the wall its energy heats up the bricks which provide a large surface area radiating warmth into the house interior. The negative side effect is that as the smoke cools down on its lengthened path, acidic substances contained within start to condense and corrode the chimney. This can also lead to gases escaping into the living area, which can have adverse health effects.

Constant features of urban living are sheds and auxiliary buildings. Some of them are built on runners to be movable within the plot boundaries. In some cases these sheds are also used as

Architecture: Nomadic Architecture of Inner Asia, Fig. 50 Little rectangular shed, Mongolia

Architecture: Nomadic Architecture of Inner Asia, Fig. 51 Rectangular anteroom attached to a ger-like hall of Gandan Monastery, Ulaan Bataar

entrance buildings for yurts and houses as a kind of anteroom. This seems to be quite an old invention, as yurt-like halls of monasteries also frequently show these features (Figs. 50 and 51).

References

Alexander, A., De Azevedo, P., Hirako, Y., & Tsering, N. (2006). *A manual of traditional Mongolian architecture*. Ulan Bator, Mongolia: Tibet Heritage Fund (supposedly).

Ambrosch, K. (2005). *KaraHane – Schwarzzelte als temporäre mobile Behausungen für Archäologen in trockenen heißen Regionen*. Wien: Publizierte Diplomarbeit, Tu Wien, IVA-ICRA Verlag.

Andrews, P. A. (1997). *Tübinger Atlas des Vorderen Orients (TAVO), Beihefte, 74/1 nomad tent types in the middle east*. Wiesbaden, Germany: Dr ludwig Reichert Verlag.

Andrews, P. A. (1999). *Felt tents and pavilions. The nomadic tradition and its interaction with princely tentage*. Kölner Ethnologische Mitteilungen, Sonderband, Institut für Völkerkunde. Köln, Germany: Universität zu Köln.

Birtalan, Á., Rákos, A., Tartsák, A., & Zámolyi, F. (Eds.). (2009).*Traditional Mongolian culture – Part I material culture*. Budapest, Hungary/Vienna, Austria: Institut für Innerasienkunde ELTE Budapest, IVA-ICRA Wien..

Bruun, O., & Narangoa, L. (Eds.). (2006). *Mongols – From country to city – Floating boundaries, pastoralism and city life in the Mongol lands*. Copenhagen, Denmark: Nias Press – Nordic Institute of Asian Studies.

di Plano Carpini, J. (1245–1247). *Kunde von den Mongolen*, eingeleitet, übersetzt und erläutert von Felicitas Schmieder, Thorbecke, Sigmaringen

Janzen, J., Taraschewski, T., & Ganchimeg, M. (2005). *Ulaanbataar at the Beginning of the 21st century – Massive in migration, rapid growth of ger-settlements, social spatial segregation and pressing Urban problems – The example of 4th Khoroo of Songinokhairkhan Duureg* (GTZ research papers 2). Ulan Bator, Mongolia: NationalUniversity of Mongolia, CDR-Center for Development Research.

Maidar, D., & Darisüren, L. (1976).*Ger*. Ulānbātar. [The yurt – The Mongolian felt tent].

Pfeifer, K. (formerly: Ambrosch, K.) (2015). The Yörük Black Tent - Adaptation in Design in the Course of Changes in Production. Unpublished PHD Thesis, Vienna University of Technology.

Sinor Research Institute, Indiana, Bloomington. http://www.iu.edu/~srifias/about/about-the-region/ . Accessed February 28,2015.

Szalay, P. (2009). Carts and tent carts. In Á. Birtalan, A. Rákos, A. Tartsák, & F. Zámolyi (Eds.), *Traditional Mongolian culture – Part I material culture*. Budapest, Hungary/Vienna, Austria: Institut für Innerasienkunde ELTE Budapest, IVA-ICRA Wien.

Szilágyi, Z. (2009). Tents. In Á. Birtalan, A. Rákos, A. Tartsák, & F. Zámolyi (Eds.), *Traditional Mongolian culture – Part I material culture*. Budapest, Hungary/Vienna, Austria: Institut für Innerasienkunde ELTE Budapest, IVA-ICRA Wien.

Arithmetic in India: *Pāṭīgaṇita*

Takao Hayashi
Doshisha University, Kyoto City, Japan

Pāṭīgaṇita, which literally means "mathematics (*gaṇita*) by means of algorithms (*pāṭī*)," is the name of one of the two main fields of medieval Indian mathematics, the other being *bījagaṇita* or "mathematics by means of seeds." The two fields roughly correspond, respectively, to arithmetic (including mensuration) and algebra.

The compound *Pāṭīgaṇita* seems to have come into use in relatively later times. In older works, the expressions, *gaṇitapāṭī* and *gaṇitasya pāṭī* (mathematical procedure, i.e., algorithm), are common, and sometimes the word *pāṭī* occurs independently. *Pāṭīgaṇita* is also called *vyaktagaṇita* or "mathematics of visible (or known) [numbers]," while *bījagaṇita* is called *avyaktagaṇita* or "mathematics of invisible (or unknown) [numbers]." Some scholars maintain that the word *pāṭī* originated from the word *paṭṭa* or *paṭa* meaning the calculating board, but its origin seems to be still open to question.

The division of mathematics (*gaṇita*) into those two fields was not practiced in the *Āryabhaṭīya* (AD 499), which has a single chapter called *gaṇita*, but it existed in the seventh century, when Brahmagupta included two chapters on mathematics in his astronomical work, *Brāhmasphuṭasiddhānta* (AD 628). Neither the word *pāṭī* nor *bījagaṇita* occurs in the book, but chapter 12 (simply called *gaṇita*) deals with almost the same topics as later books of *pāṭī*, and chapter 18, though named *kuttaka* or the pulverizer (solution of a linear indeterminate equation), has many topics in common with later books of *bījagaṇita*. Śrīdhara (ca. AD 750) is known to have written several textbooks of *pāṭī* and at least one of *bījagaṇita*.

Extant works of *pāṭī* include Śrīdhara's *Pāṭīgaṇita* (incomplete) and *Triśatikā* (and *Gaṇitapañcaviṃśī*?), Mahāvīra's *Gaṇitasārasaṃgraha* (ca. AD 850), chapter 15 (*pāṭī*) of Āryabhaṭa's *Mahāsiddhānta* (ca. AD 950 or 1500), Śrīpati's *Gaṇitatilaka* (incomplete) and chapter 13 (*vyaktagaṇita*) of his *Siddhāntaśekhara* (ca. AD 1050), Bhāskara's *Līlāvatī* (AD 1150), Ṭhakkura Pherū's *Gaṇitasārakaumudī* (ca. AD 1315), Nārāyaṇa's *Gaṇitakaumudī* (AD 1356), Gaṇeśa's *Gaṇitamañjarī* (ca. AD 1600), and Munīśvara's (b. AD 1603) *Pāṭīsāra*.

A book (or chapter) of *pāṭī* consists of two main parts, namely, fundamental operations (*parikarmāṇi*) and "practical problems" (*vyavahārāḥ*). The former usually comprises six or eight arithmetical computations (addition, subtraction, multiplication, division, squaring, extraction of the square root, cubing, and extraction of the cube root) of integers, fractions, and zero, several types of reductions of fractions, and rules concerning proportion including the so-called rule of three (*trairāśika*). The latter originally consisted of eight chapters (or sections), i.e., those on mixture (*miśraka*), mathematical series (*śreḍhī*), plane figures (*kṣetra*), excavations (*khāta*), stacking [of bricks] (*citi*), sawing [of timbers] (*krākacika*), piling [of grain] (*rāśi*), and on the shadow (*chāyā*).

To this list of the practical problems, Śrīdhara added in his *Pāṭīgaṇita* one named "truth of zero" (*śūnyatattva*). A large portion of the work including that chapter is, however, missing in the only extant manuscript. The way the *Gaṇitasārasaṃgraha* of Mahāvīra divides its contents into chapters is unusual, but still it can be characterized as a book of *pāṭī*. It is quite rich in mathematical rules and problems.

In his *Līlāvatī*, Bhāskara separated the rules on proportion from the arithmetical computations and created with them a new chapter named *prakīrṇaka* (miscellaneous [rules]), in which he also included the *regula falsi*, the rule of inverse operations, the rule of sum and difference, etc. After the ordinary topics of practical problems, he treated *kuṭṭaka* as well as *aṅkapāśa* or the nets of numerical figures (combinatorics). Written in elegant but plain Sanskrit and organized well, the *Līlāvatī* became the most popular textbook of *pāṭī* in India.

The *Gaṇitasārakaumudī* written in Apabhraṃśa by Ṭhakkura Pherū consists of five chapters. The first three chapters treat the traditional contents of *pāṭī*, namely, the fundamental operations of integers and fractions, several kinds of reductions of fractions, and the eight types of "procedures" such as mixture, series, plane figures, etc. The remaining two chapters contain supplementary material from diverse areas of contemporary life such as mathematical riddles, conversion of dates from Vikrama era to Hijrī era, and average yield per *bīghā* of several kinds of grains and pulses. It is in this part that magic squares were treated for the first time in mathematical works in India.

In his *Gaṇitakaumudī*, Nārāyaṇa included in the practical problems not only *kuṭṭaka* and *aṅkapāśa* but also *vargaprakṛti* or the square nature (indeterminate equations of the second degree including the so-called Pell's equation), *bhāgādāna* or the acquisition of parts (factorization), *aṃśāvatāra* or manifestation of fractions (partitioning), and *bhadragaṇita* or mathematics of magic squares. These topics had already been dealt with to a certain extent by his predecessors, but he developed them considerably. He also investigated new mathematical progressions, some of which turned out to be useful when Mādhava (ca. AD 1400) and his successors obtained power series for the circumference of a circle (or π), sine, cosine, arctangent, etc.

In his *Gaṇitamañjarī*, Gaṇeśa gave many rules and examples based on the *Līlāvatī*, but he was not a blind follower of Bhāskara. Following Jñānarāja, Gaṇeśa explicitly criticized Bhāskara's assertion of the invariability of *khahara* ("zero divisor"). He also expressly pointed out that one of Bhāskara's rules for concurrence, that is, $\left(a^2 - b^2\right)/(a - b) = a + b$, is indefinite when $a = b$. He prescribed the so-called Gelosia method of multiplication under the name *kapāṭasandhi* ("door junction"); other writers used this name for the slide multiplication which was most popular in India, but Gaṇeśa does not mention it at all. He gave a chord table for a circle of diameter 3,438 and used 600/191 for pi.

Munīśvara, nephew of the Kṛṣṇa who wrote the commentary *Bījapallava* on Bhāskara's *Bījagaṇita*, composed a work on *pāṭī* called *Pāṭīsāra*, which consists of three chapters: Miscellany (*prakīrṇaka*), Mixture (*miśra*), and Geometrical Figures (*kṣetra*). One of the interesting features of this book is that not only the rules and examples but also rationales (*upapatti*) of the rules are given in verse.

See Also

► Algebra in India: Bījagaṇita
► Bakhshālī Manuscript
► Combinatorics in Indian Mathematics
► Līlāvatī
► Magic Squares in India
► Mahāvīra
► Nārāyaṇa Paṇḍita
► Śrīdhara
► Śrīpati

References

Bag, A. K. (1979). *Mathematics in ancient and medieval India*. Varanasi: Chaukhambha Orientalia.

Burnett, C. (2002). Indian numerals in the Mediterranean basin in the twelfth century, with special reference to the "eastern forms". In Y. Dold-Samplonius et al. (Eds.), *From China to Paris: 2000 years transmission of mathematical ideas* (pp. 237–288). Stuttgart: Franz Steiner.

Colebrooke, H. T. (1817). *Algebra with arithmetic and mensuration from the Sanscrit of Brahmegupta and Bháscara*. London: Murray. (Rpt. Wiesbaden: Dr Martin Söndig oHG, 1973. Rpt. with a foreword by S. R. Sarma, Delhi: Sharada Publishing House, 2005).

Datta, B., & Singh, A. N. (1935–1938). *History of Hindu mathematics* (2 Vols.). Lahore: Motilal. (Rpt. in 1 vol. Bombay: Asia Publishing House, 1962. Rpt. in 2 vols. Delhi: Bharatiya Kala Prakashan).

Hayashi, T. (1990). The words of a courtesan: A true-false problem in Indian mathematics. *Kagakusi kenkyu*, ser. II, *29*(174), 93–99.

Hayashi, T. (1991). The *Pañcaviṃśatikā* in its two recensions: A study in the reformation of a medieval Sanskrit mathematical treatise. *Indian Journal of History of Science*, *26*, 399–448.

Hayashi, T. (1993). The mathematical section of the *Nāradapurāṇa*. *Indo-Iranian Journal, 36*, 1–28.

Hayashi, T. (1995). Śrīdhara's authorship of the mathematical treatise *Gaṇitapañcaviṃśī*. *Historia Scientiarum, 4*(3), 233–250.

Hayashi, T. (2000a). The *Caturacintāmaṇi* of Giridharabhaṭṭa: A sixteenth-century Sanskrit mathematical treatise. *SCIAMVS, 1*, 133–208.

Hayashi, T. (2000b). Govindasvāmin's arithmetic rules cited in the *Kriyākramakarī* of Śaṅkara and Nārāyaṇa. *Indian Journal of History of Science, 35*(3), 189–231.
Hayashi, T. (2006). A Sanskrit mathematical anthology. *SCIAMVS, 7*, 175–211.
Hayashi, T. (2013). The Gaṇitapañcaviṃśī attributed to Śrīdhara. *Revue d'Histoire des Mathématiques, 19*, 245–332.
Hayashi, T. (Ed.) (2013). *Gaṇitamañjarī of Gaṇeśa*. New Delhi: Indian National Science Academy.
Hayashi, T. (2013). Authenticity of the verses in the printed edition of the *Gaṇitatilaka*. *Gaṇita Bhāratī, 35*, 97–116.
Heeffer, A. (2007). The tacit appropriation of Hindu algebra in renaissance practical arithmetic. *Gaṇita Bhāratī, 29*, 1–60.
Joseph, G. G. (2011). *The crest of the peacock: Non-European roots of mathematics*. Princeton/Oxford: Princeton University Press, Chapters 8–10.
Mallayya, V. (1997). Arithmetic operation of division with special reference to Bhāskara II's "Līlāvatī" and its commentaries. *Indian Journal of History of Science, 32*(4), 315–324.
Patte, F. (Ed. & Trans.) (2004). *Le Siddhāntaśiromaṇi* (2 Vols.). Genève: Droz.
Plofker, K. (2009). *Mathematics in India*. Princeton/Oxford: Princeton University Press.
Ramanujacharia, & Kaye, G. R. (Trans.) (1912–1913). The *Triśatikā* of Śrīdharācārya. *Bibliotheca Mathematica*, Ser 3 *13*, 203–17.
Raṅgācārya, M. (Ed. & Trans.) (1912). *Gaṇitasārasaṃgraha of Mahāvīra*. Madras: Government Press.
SAKHYA (Eds. & Trans.) (2009). *Gaṇitasārakaumudī by Ṭhakkura Pherū*. Delhi: Manohar.
Sarma, S. R. (1985). Mathematical literature in Telugu: An overview. *Oriental Journal* (Sri Venkateswara University) *28*, 77–90.
Sarma, S. R. (1987). Pāvulūrigaṇitamu: The first Telugu work on mathematics. *Studien zur Indologie und Iranistik, 13/14*, 163–176.
Sarma, S. R. (1997). Some medieval arithmetical tables. *Indian Journal of History of Science, 32*, 191–198.
Sarma, S. R. (2002). Rule of three and its variations in India. In Y. Dold-Samplonius et al. (Eds.), *From China to Paris: 2000 years transmission of mathematical ideas* (pp. 133–156). Stuttgart: Franz Steiner.
Sarma, S. R. (2009). On the rationale of the maxim *Aṅkānāṃ vāmato gatiḥ*. *Gaṇita Bhāratī, 31*, 1–22.
Sarma, S. R. (2011). Mathematical literature in the regional languages of India. In B. S. Yadav & Man Mohan (Eds.), *Ancient leaps into mathematics*. New York: Birkhauser, pp. 201–212.
Sarma, S. R. (2012). Kaṭapayādi system of numerical notation. *Revue d'Histoire des Mathématiques, 18*, 37–66.
Sen, S. N. (1971). Mathematics. In D. M. Bose et al. (Eds.), *A concise history of science in India* (pp. 136–212). New Delhi: Indian National Science Academy.
Shukla, K. S. (Ed. & Trans.) (1959). *Pāṭīgaṇita of Śrīdhara*. Lucknow: Lucknow University Press.
Singh, P., & Singh, B. (2005). *Pāṭīsāra* of Munīśvara: English translation with notes. *Gaṇita Bhāratī, 26*, 56–104; *27*, 64–103.
Sinha, K. N. (1982). Śrīpati's *Gaṇitatilaka*: English translation with introduction. *Gaṇita Bhāratī, 4*, 112–33.
Sinha, K. N. (1985). Śrīpati: An eleventh-century Indian mathematician. *Historia Mathematica, 12*, 25–44.
Sinha, K. N. (1988). Vyaktagaṇitādhyāya of Śrīpati's *Siddhāntaśekhara*. *Gaṇita Bhāratī, 10*, 40–50.
Srinivasiengar, C. N. (1967). *The history of ancient Indian mathematics*. Calcutta: The World Press.

Arithmetic in Islamic Mathematics

Julian A. Smith

Mathematics flourished during the golden age of Islamic science, which began around the seventh century AD and continued through to about the fourteenth century. Both arithmetic and algebra were advanced dramatically by Muslim mathematicians, who adopted Indian innovations such as decimal numbers and considerably extended them – they also developed earlier Greek concepts of geometry, trigonometry, number theory and the resolution of equations. Islamic mathematicians did far more than just copy Greek and Indian techniques – their additional researches developed and systematized several fields of mathematics. Even modern mathematical language, including terms like "algebra", "root" and "zero", owes an important debt to Arabic scientists. Algebra, for example, comes from the ninth-century Arabic Astronomer and mathematician ► al-Khwārizmī (ca. 780–ca. 850), whose book *Algebra* (*al-Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa 'l-muqābala*) described techniques of transposing quantities from one side of an equation to another (*jabr*), then simplifying them (*muqābala*).

Yet while Arabic contributions to algebra have been widely discussed by historians of science and culture, their parallel work in arithmetic has been until recently far less well known. During the early nomadic period of Arabic history, numbers were given names – and around the time of the Prophet Muḥammad (ca. 570–632), the letters of the Arabic alphabet were often used as numerals. However, it was not until the rise of Islam in the seventh and eighth centuries that a recognizably modern system of arithmetic was developed. Muslim arithmetic operations were largely based on ancient Greek definitions, but Islamic scholars pioneered new techniques, including the network or lattice method (*shabaqah*) to multiply numbers, and various techniques of long division.

Muslim mathematicians are best known for their contributions to the pivotal system of modern "Hindu-Arabic numerals" – i.e. the technique of expressing all numbers through the repeated use of a few basic symbols. Though originally invented in India, Arab scholars dramatically improved both the writing and manipulation of decimal numerals, and also developed the Hindu idea of positional notation. It is not known exactly when Indian mathematicians began using decimal numbers, but they seem to have been in place by the early sixth century AD – astronomer Āryabhaṭa I (476–ca. 550) did not use them, but they were employed in a limited way by the middle of the sixth century. Decimal numbers were quite popular and spread quickly – by the seventh century, they had reached Iraq and the Middle East, and were praised by Syrian Nestorian bishop Severus Sebokht (fl. AD 630), who considered this new Hindu arithmetic "done with nine signs" even more ingenious than the calculations of Greek mathematicians. Arabs began using Hindu decimal arithmetic around the seventh century, but it was not until the ninth century that Arabic works describing this type of reckoning appear. The earliest known Arabic treatise on decimal arithmetic, *Kitāb al-hisāb al-hindī* (Book of Addition and Subtraction According to the Hindu Calculation), was written by Al-Khwārizmī around AD 800 – the Arabic text is lost, but a twelfth century Latin translation is still extant.

Al-Khwārizmī is better known among historians of Muslim mathematics for his many contributions to algebra. Yet his investigations into arithmetic were equally important, and were so widely read in the medieval Latin West that they later gave Europeans one of their early names for arithmetic, the "algorism" or "algorithm". Al-Khwārizmī's book treated all arithmetic operations, spreading knowledge of Hindu techniques throughout the Muslim world. Another important early treatise that publicized decimal numbers was Iranian mathematician and astronomer Kūshyār ibn Labbān's (fl. 1000) *Kitāb fī uṣūl ḥisāb al-hind* (Principles of Hindu Reckoning), a leading arithmetic textbook.

Coupled to the important development of decimal numbers was the equally significant Arabic use of the *sifr* (meaning "empty"), or zero, again from Indian roots. An early symbol for zero appears in an AD 876 inscription at Gwalior, India; in the Arab world, Kūshyār introduces the zero in the tenth century as a sign to be placed "where there is no number".

Though scholars concede that much of Arabic arithmetic has its ultimate origins in India, Muslim mathematicians were the first to integrate the various discoveries of Hindu mathematicians into a coherent whole. Historian J. L. Berggren, for example, concludes that while the Hindus were the first to use a "cipherized, decimal positional system", the Arabs pioneered in extending this system to "represent parts of the unit by decimal fractions". In Europe, meanwhile, the zero and decimal system were not widely used until the late twelfth century.

Following ► al-Khwārīzmī, many Arabic mathematicians developed Indian techniques of arithmetic over the next few centuries. The astronomer, translator, and editor ► al-Kindī (801–ca. 873), for example, wrote several important treatises on arithmetic, including manuscripts on the use of Indian numbers, on lines and multiplication with numbers, on measuring proportions and times, on numerical procedures and cancellation, and many more.

Two centuries later, ► al-Karajī of Baghdad (fl. 1020) wrote mathematical works that led to his being called "the most scholarly and original writer of arithmetic" by historian Al-Daffa. Al-Karajī's works included a manuscript on the rules of computation entitled *Al-Kafī fī al-ḥisāb* (Essentials of Arithmetic), and *al-Fakhrī fī'ljabr wa'l-muqābala*, which was named after his longtime friend, the Baghdad grand vizier.

The depth of early Islamic knowledge of arithmetic is often quite unexpected. Arabic mathematicians were well aware of the existence of irrational numbers, and sometimes developed complex theories to explain their properties. Persian poet and philosopher ʻUmar al-Khayyām, or Omar Khayyam (ca. 1048–ca. 1122) and Persian astronomer ► Naṣīr al-Dīn al-Ṭūsī (1201–1274) both argued that every ratio of two magnitudes can be considered a number, whether that ratio be commensurable (rational) or incommensurable (irrational). Islamic arithmetic used many of the same Hindu techniques for operating with irrationals as it did with rationals. Also from Indian sources came various operations with numbers, including transformations such as $\sqrt{x^2y} = x\sqrt{y}$ and $\sqrt{xy} = \sqrt{x}\sqrt{y}$.

Islamic arithmeticians did not accept everything offered them by Hindu scholars. For example, negative numbers, long a staple in Indian arithmetic, were transmitted to the Arab world but rejected by it – Arabic mathematicians instead held that negative numbers did not exist.

Modern notation for fractions is also based in part on Muslim arithmetic. Celebrated Hindu mathematicians such as ► Bhāskara II (1114–ca. 1185) wrote common fractions by just writing a numerator above a denominator, but the idea of a line of separation between the numerator and denominator was an early Islamic development. Decimal fractions, meanwhile, appear in seminal tenth century Arabic texts, such as the *Kitāb al-fuṣūl fī'l* ḥ*isāb al-hindī* (Book of Chapters on Hindu Arithmetic), written by Damascus mathematician ► al-Uqlīdisī (fl. 952). In the late twelfth century, al-Samaw'al (fl. 1172) used decimal fractions for division, root extraction and approximation. By the fifteenth century, decimal fractions had been formally named and systematically developed, but they were not widely used in Europe until the Dutch physicist and engineer Simon Stevin (1548–1620) published *La Thiende* (The Tenth) in 1585, and Scottish mathematician John Napier (1550–1617) reintroduced his decimal point in the early seventeenth century.

While Arabic mathematicians pioneered in decimal arithmetic, they also made considerable contributions to the ancient sexagesimal (base 60) system of arithmetic, which had been developed by the Babylonians in Mesopotamia around 2000 BCE. This system was widely used for astronomical calculation throughout the ancient world, particularly in Alexandrian astronomer and geographer Claudius Ptolemy's (ca. AD 100–170) cosmological treatise, *Almagest*, which was later adopted by Islamic scholars as the theoretical base of their astronomy. Sexagesimal addition, subtraction, multiplication and division became so commonplace among Islamic astronomers it was renamed "the astronomer's arithmetic". Arabic astronomers and mathematicians such as Kūshyār and Samarqand's al-Kāshī (fl. 1406–1429) used sexagesimal numbers to determine approximate roots, extract square roots and even find the fifth roots of certain numbers.

Islamic arithmetic was often influenced by the needs of astrology, talismans and sorcery, as in the casting of horoscopes and magic spells. Muslim mathematicians such as Syrian scholar Thābit ibn Qurra (ca. 836–901) and Tunisian historian Ibn Khaldūn (1332–1406) studied amicable numbers, or number pairs where the sum of the factors of each number is equal to the other number. Two hundred and twenty and 284 are amicable numbers, because the sum of the factors of 284 (1 + 2 + 4 + 71 + 142) equals 220, and vice versa.

Muslim mathematics was also affected by practical considerations such as problems of inheritance and finance, and the need to calculate events in the lunar-based Islamic calendar. For example, ► al-Khwārizmī devoted the second half of his treatise on algebra to the question of *ʻilm al-farā'iḍ*, or the calculation of shares of an estate given to various heirs. These problems employed the arithmetic of fractions, and were heavily influenced by religious law and custom. A typical example treated by al-Khwārizmī was to calculate the shares of a dead woman's estate that would accrue to her husband, her son, and her three daughters. As the law required that the husband receive a fourth and each son get twice what a daughter would receive, al-Khwārizmī simply divides the estate into 20 parts, giving five to the husband, six to the son, and three to each daughter. Similar problems involved the topic of *zakāt*, which was the calculation of the share of private wealth that various persons would pay to the community each year.

Islamic arithmetic was often ingenious. Arabic scholars gave us much of the modern system of arithmetic, and while many of its foundations were borrowed from Indian and Greek sources, it is clear that Islamic mathematicians united the various strands of arithmetic into a form recognizable to us today.

See Also

- ▶ al-Karajī
- ▶ Al-Kāshī
- ▶ al-Khwārizmī
- ▶ al-Kindī
- ▶ *Almagest*: Its Reception and Transmission in the Islamic World
- ▶ al-Uqlīdisī
- ▶ Ibn Khaldūn
- ▶ Mathematics
- ▶ Naṣīr al-Dīn al-Ṭūsī
- ▶ Number Theory in Islamic Mathematics
- ▶ Sexagesimal System
- ▶ Thābit ibn Qurra
- ▶ Trigonometry in Islamic Mathematics

References

Al-Daffa, A. A. (1977). *The Muslim contribution to mathematics*. London: Croon Helm.

Berggren, J. L. (1986). *Episodes in the mathematics of medieval Islam*. New York: Springer.

Høyrup, J. (1984). Formative conditions for the development of mathematics in medieval Islam. In W. Callebaut et al. (Eds.), *George Sarton centennial*. Ghent, Belgium: Communications & Cognition.

Rashed, R. (1994). *The development of Arabic mathematics*. Dordrecht, The Netherlands: Kluwer.

Saidan, A. S. (1996). Numeration and arithmetic. In R. Rashed (Ed.), *Encyclopedia of the history of Arabic science* (pp. 331–348). London: Routledge.

Youschkevitch, A. P. (1976). *Les Mathématiques Arabes (VIIIe–XVe siècles)*. Paris: Vrin.

Armillary Spheres in China

Jiang Xiaoyuan

The equatorial armillary sphere was a traditional Chinese astronomical instrument used to observe celestial bodies in an equatorial coordinate system. Its origin is still not very clear. Astronomer ▶ Luoxia Hong (ca. 100 BCE) of the Western Han Dynasty was probably the first maker of this instrument which possessed a very basic form.

The early equatorial armilla was composed of two layers: the outside layer included a meridian circle, equatorial circle, and vertical circle – all three of these were fixed. The inside layer included a polar axis, right ascension circle, and sighting tube. The right ascension circle could rotate around the polar axis, and the sighting tube could rotate in the right ascension circle freely so it could point to everywhere in the sky.

In the Tang Dynasty (AD 618–907), a third layer was added to the equatorial armillary which included an ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) circle and a circle of the moon's path. Astronomers could then measure three coordinate systems with one instrument, but the three-layer armilla was too complex to observe, so from the Northern Song Dynasty (AD 960–1126) a course of simplification was begun. The third layer was canceled, and the so-called "abridged armilla" (*Jian Yi*) appeared. It is in fact two different instruments (one equatorial armilla and one altazimuth) on the same pedestal.

The equatorial armilla was one of the most important astronomical instruments in ancient China. It was the result of the equatorial tradition of Chinese astronomy which lasted more than 2,000 years. In ancient China, armilla (and almost all astronomical instruments) were only made by the imperial government, so their size was always very large.

See Also

▶ Astronomy in China
▶ Luoxia Hong

References

Study Group for the History of Chinese Astronomy. (1981). *Zhong Guo Tian Wen Xue Shi (The history of Chinese astronomy)*. Beijing, China: Science Press.
Zheng, W., & Defen, L. (1973). *Sui Shu (The history of Sui Dynasty)* (Vol. 19). Beijing, China: Zhonghua Press.

Armillary Spheres in India

Manu V. Devadevan
Archive India Institute, Bhubaneswar, Odisha, India

The armillary sphere was an important instrument used by Indian astronomers for demonstrational and observational purposes. In an age when satellite-aided observatories or even the telescope did not exist, the study of planetary positions was possible only with the aid of working models, which in turn depended on the little that naked eyes could observe of planetary and sidereal positions. The armillary sphere was one such model. It was known in India as *golayantra* (globe machine) or *golabandha* (globe band).

The *Sūryasiddhānta* gives a description of the construction of an armillary sphere. Āryabhaṭa describes it briefly in his *Āryabhaṭīya*. Its construction is treated at different lengths in Varāhamihira's *Pañcasiddhāntikā*, Brahmagupta's *Brahmasphuṭasiddhānta*, Lalla's *Śiṣyadhīvṛddhida*, Śrīpati's *Siddhāntaśekhara*, Bhāskara II's *Siddhāntaśiromaṇi*, and Vaṭaśśeri Parameśvaran's *Goladīpikā*.

We do not know when the armillary sphere was introduced in India, nor are we in a position to say whether it was developed by the Indian astronomers or borrowed from the Greco-Romans who were perhaps familiar with it in the days of Aristotle. Aristotle's contemporary Eratosthenes (ca. 276–196 BCE) is likely to have used it for studying eclipses. This might have been a simple instrument, as were the three spheres mentioned a few centuries later by Ptolemy in his *Almagest*.

The *Āryabhaṭīya* (476 CE) is by far the oldest text in India that speaks of the armillary sphere. It is not forthcoming enough in its description of the sphere, though. All we gather from it is that the sphere must be completely spherical, shaped in wood with uniform density throughout, and made to rotate with the help of mercury, oil, water, and the application of one's mind! Several writers tell us how the models are constructed, but many shy away from describing how the spheres rotate. The *Sūryasiddhānta* urges that the technique of (rotating the sphere by) using mercury must remain a secret learned from a teacher, never to be described (in writing).

Sūryadeva proposes the following method. The sphere to be rotated is mounted on two vertical posts fixed on the ground, one in the north and the other in the south. These are connected with an iron string, which functions as the axis to which the sphere is fastened. The holes at the north and south of the sphere are lubricated with oil to ensure a smooth rotation. A cylindrical water container with a hole at the bottom is placed in a pit to the west of the sphere. The hole is fashioned in such a way that the water drains away completely in 60 *ghaṭi*s (24 h). A nail is fixed close to it, and a string is tied to the nail and bound on the sphere across the line represents its equator. The other end of the string is tied to a hollow gourd containing enough mercury to keep it afloat. The gourd is placed in the water container. Once set in motion, the gourd reaches the bottom of the container in 60 *ghati*s in course of which time the sphere connected to it with the string completes one rotation.

The method described by Sūryadeva is too simple to be a secret. It does not warrant the use of mercury either. Besides, a major limitation of this model is that the outflow of water from the container is greater when the container is full and slows down as pressure decreases with the decrease in water level. The rotation of the sphere is never uniform.

The real purpose of using mercury seems to have been different, which is described in the *Brahmasphuṭasiddhānta*. This description is striking in its theoretical simplicity, although difficult to practice under premodern conditions. A wheel is mounted on two supporting posts with the help of a horizontal axis passing through its center. Several small tubes are filled with mercury to the desired quantity and fixed like spokes between the center and the circumference of the wheel. The to-and-fro motion of mercury within the hollow spokes makes the wheel rotate at a uniform speed. The speed of the wheel is determined by the quantity of mercury present in the hollow spokes.

Simple models involving one or two globes do not seem to have been used in observations, as it could at best serve demonstrational and pedagogic needs. Armillary spheres of greater complexity are required for determining the latitudes and longitudes of the planets. Brahmagupta tells us how to construct an armillary sphere in which 51 globes are simultaneously in motion. Bhāskara II describes a model that is exceptional for its intricate constructions. There are three parts to this model: the *bhagola*, a sidereal sphere of fixed stars; the *khagola*, a sphere beyond the *bhagola* to represent the firmament; and the *dṛggola*, a sphere beyond the *khagola* where the two other spheres are brought together.

The model described by Parameśvaran consists only of the inner *bhagola* and the outer *khagola*. It operates around a central axis, which both spheres share. The *bhagola* is constantly in motion while the *khagola* remains fixed. At the center of the axis is a globe that represents the earth, its position being the figuration at zero latitude.

The components of this model are made of bamboo, iron, and strings. The earth, the moon, and the planets are made of wood or clay. Śripati prescribes hard woods like *śrīparṇi* (*Gmelina arborea*) for making them. A thin bamboo strip fashioned into a band runs in the north–south direction of the model as the solstitial colure (*dakṣinottara*). It is divided into 360 parts of equal size. Another strip in the east–west direction indicates the celestial equator (*ghaṭikā-maṇḍala*) and is divided into 60 equal parts. More bands are placed at appropriate positions: one made of 360 equal parts to indicate the equinoctial colure (*unmaṇḍala*), another inclined at 24° north and south of the zenith and the nadir to record the ecliptic (*apamavṛtta*), and several others to represent the diurnal circles (*ahorātra-vṛtta*s). Outside the *bhagola* and the *khagola*, three other bands are introduced: a horizontal band to represent the horizon (*kṣitija*), a band in the east–west direction to indicate the prime vertical (*samamaṇḍala*), and a third band in the north–south direction to mark the meridian (*dakṣinottara*). The movement of the moon and other planets is then projected on to this by introducing movable globes. The orbits are so orchestrated as to enable the planets cross the ecliptic at their respective nodes and reach their maximum latitudes at 90° from the nodes.

The model described by Parameśvaran is also found in Brahmagupta. It appears that Brahmagupta's armillary sphere was massive in size. In his model, the globe representing the earth is placed at the center of the three outer circles, viz., the prime vertical, the meridian (which he calls *yāmyottara*), and the horizon. What is intriguing is that the observer is made to stand on the globe, an indication of its enormous size.

Lalla's model also has the *bhagola* and the *khagola*. Here, a pin is introduced to correspond appropriately to the equator and the ecliptic, and the *bhagola* rotated in such a way that the pin's shadow passed through the center of the sphere. The arc of the equator intervened by the pin and the horizon indicates the time elapsed since sunrise, and the one on the ecliptic, the degrees risen since sunrise. This is Lalla's method of determining time and the orient ecliptic point (*lagna*).

The armillary sphere was invaluable, and perhaps indispensible, in the preparation of almanacs. A direct testimony to this effect is found in Lalla's text where the "globe machine" is said to have been deployed to determine time and the *lagna*.

See Also

► Astronomical Instruments in India

References

Ohashi, Y. (1994). Astronomical instruments in classical siddhāntas. *Indian Journal of History of Science, 29*(2), 155–313.

Rai, R. N. (1985). Astronomical instruments. *Indian Journal of History of Science, 20*(1–4), 308–336.

Armor in Japan and Korea

Joseph Ryan[1] and Gina Barnes[2]

[1]Department of Archaeology, Osaka University, Osaka, Japan

[2]SOAS, University of London, London, UK

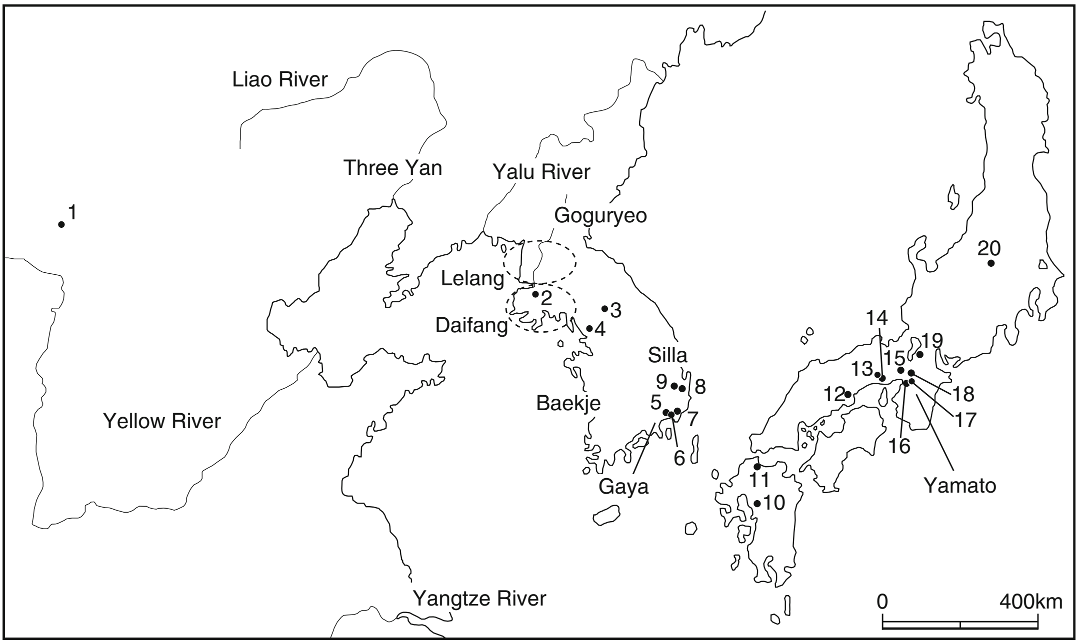
The Roman Empire (27 BCE–476 CE) and the Han Dynasty (206 BCE–220 CE) overlapped in time as the great empires of Eurasia. Both had to deal with mounted, often pastoralist, and frequently aggressive steppe peoples on their northern borders. Horse-riding equipment and iron armor styles were transmitted among these northerners from west to east all the way into the Korean Peninsula and Japanese Islands (Fig. 1). These latter areas will be collectively referred to below as the Pen/Insulae (following Barnes, 1999). The time period under discussion is between the second half of the first millennium BCE and the fifth century CE, within the Samhan or Proto-Three Kingdoms (300 BCE–300 CE) and Three Kingdoms (300–668 CE) periods on the Peninsula (Barnes, 2001) and the Yayoi (800 BCE–250 CE) and Kofun (250–710 CE) periods in the Japanese archipelago (Barnes, 2007).

During the Late Han Dynasty (29–220 CE), horsemen of the Manchurian Basin Puyo and Goguryeo (Koguryŏ) peoples were used by the Han as cavalry in protecting against the steppe Xiongnu and Xianbei warriors. The Goguryeo turned on the Han, raiding the commanderies established in the lower Manchurian Basin and northern Korean Peninsula. The Lelang commandery near modern Pyongyang was a particular target but also influenced armor development in the Pen/Insulae. Goguryeo, as a rising state after the demise of the Han, took over the commandery areas in the early fourth century and began pushing into the southern Korean Peninsula. Polities existing on the southern coast, which had begun as iron producers during the commandery era, turned their skills to making armor and weapons to combat this aggression.

Sporadic finds of flexible lamellar armor from Han are found in Pen/Insular sites, but local manufacture began with fixed-plate iron cuirasses which replaced organic cuirasses that had been used in the Pen/Insular regions until then. Within the East Asian context, "plate armor" refers to a cuirass composed of wide sheets laced or riveted together. As plate armor was made to wrap around the torso, the shape and curvature of each plate is greatly determined by its unique place within the cuirass. In contrast, lamellar armor is composed of a great number of small, narrow tabs that are often rounded at one end. While dedicated lamellae do exist for the waist and hem, the remaining majority are of the same all-purpose size and shape (Furuya, 1996). Additionally, not only do plates and lamellae display significantly different styles of lacing and placement of their lacing holes, but riveting was used solely in plate armor.

Plate-armor manufacture was initiated in the southeastern Peninsula in the early fourth century and was developed further in the Japanese Islands (see Barnes, 2000). The Mongolian helmet, made of vertical strips of iron, was transferred in from the steppes. Used as it was on the Korean Peninsula, it was transformed into two different types in the Japanese Islands: a visored helmet still consisting of vertical strips and a keeled helmet, with the iron strips running horizontally to meet in a keel at the forehead. In the fifth century, lamellar armor suits replaced cuirasses on the Peninsula and were introduced to the Japanese Islands in response to Goguryeo's fielding of troops down to the southern Peninsular coast in 400 CE.

While a comprehensive treatment of protective armor requires consideration of helmets and



1 Ershijiazi	6 Daeseong-dong Tomb Group	11 Inadō Tomb Group	16 Shimoda
2 Anak Tomb No. 3	7 Bokcheon-dong Tomb Group	12 Minamikata	17 Shiroyama No. 2
3 Daeseong-ri	8 Kujeong-dong Tomb Group	13 Ono-ōzuka	18 Tsubai-ōtsukayama
4 Mongchon-toseong	9 Sara-ri Tomb Group	14 Toshinokami	19 Azuchi-hyōtanyama
5 Yangdong-ri Tomb Group	10 Marozuka	15 Shikinzan	20 Kanai-higashiura

Armor in Japan and Korea, Fig. 1 Map of sites mentioned in the text and figures

other auxiliary wear such as guards for the shoulder, shin, and neck, this entry will focus mainly on body armor and only through the fifth century CE.

Organic Armor

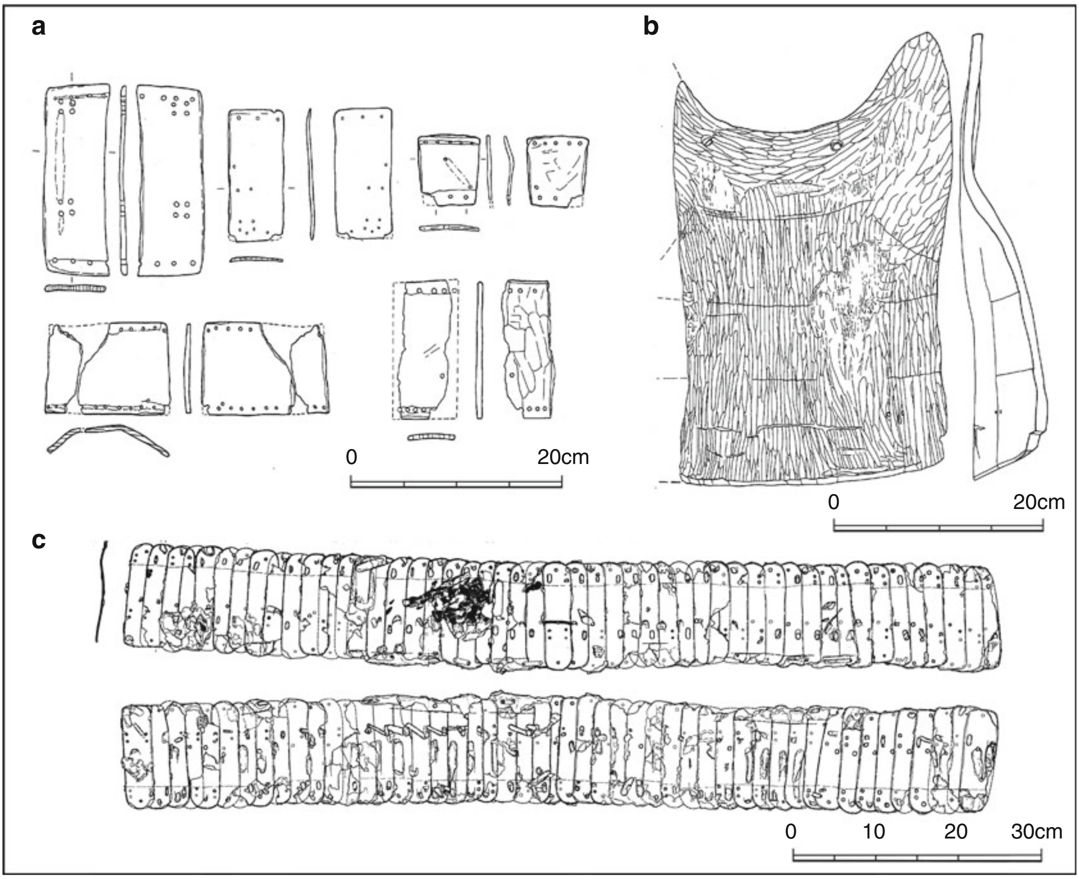
Before Pen/Insular domestic production of iron armor began in the fourth century CE, the need for bodily protection was satisfied with imports of iron armor from China and locally made organic armor. Unfortunately, organic material does not fare well in the Pen/Insular acidic soil, leaving archaeologists with only a fragmentary record.

Korean Peninsula, Organic Armor

The earliest example of organic armor is a set of lacquered leather lamellae uncovered in Pyongyang dating to the first century BCE (Song, 2004; Yi, 2008). Accompanying artifacts suggest Han influence through the Lelang commandery. Subsequent scattered finds of wooden and lacquered leather lamellae are found through the third century. Additionally, bone lamellae have been found from several sites, most notably the late fifth-century Mongchon-toseong (Mongch'on T'osŏng) site in Baekje (Paekche). The discovery of only iron neck guards, lamellae that circle the waist in a long lamellar suit, or helmets at several tombs in the Daeseong-dong (Taesŏng-dong), Bokcheon-dong (Pokch'ŏn-dong), and Yangdong-ri (Yangdong-ni) tomb groups suggests the existence of organic armor or composite armor combining organic and iron materials, even after local production of iron armor began in the fourth century (Fig. 2c).

Japanese Archipelago, Organic Armor

Wooden armor from the Japanese archipelago can be categorized into two types: plate armor made by binding numerous wooden tabs together



Armor in Japan and Korea, Fig. 2 Examples of organic armor. (**a**) Wooden plate armor from the Minamikata site, Okayama, Japan (After Okayama City Board of Education, 2005, Fig. 53). (**b**) Wooden fitted cuirass from the Shimoda site, Osaka, Japan (After Osaka Center for Cultural Heritage, 1998, Fig. 198). (**c**) Iron waist lamellae from a composite iron/organic suit excavated from Bokcheon-dong Tomb No. 21, Busan, South Korea (From Busan University Museum, 1990, Fig. 34)

(Fig. 2a) and "fitted" cuirasses made by hollowing out a log and comprising a single rear and two front sections (Fig. 2b) (Hashimoto, 1996; Kamiya, 2010). The former are confined to the second half of the first millennium BCE and may represent continental influence. The latter are believed to be a domestic development and stretch from the second half of the first millennium BCE to the late fourth century CE.

In addition to wooden armor, lacquer-coated leather cuirasses, fiber cuirasses, leather tasses, and leather-keeled helmets are also known. Moreover, the discovery in late 2012 of dozens of bone lamellae at the early sixth-century Kanai-higashiura site in Gunma Prefecture attests to the diverse nature of materials used. The existence of composite armor using both organic and iron materials has also been inferred from the discovery of iron "placket" plates excavated from fourth-century tombs. While organic body armor is replaced by iron armor in the fourth century, the above finds testify that organic materials nevertheless continued to be used to some extent.

Iron Plate Armor

Approximately 60 examples of iron plate armor have been discovered from the Korean Peninsula and approximately 530 examples from the Japanese Archipelago. Significant differences existed between Peninsular and Insular manufacture, dependent primarily on the shape and orientation of the plates. Peninsular cuirasses are composed of long rectangular plates oriented vertically, while Insular examples utilize shorter rectangular, square, or triangular plates fixed in horizontal bands – until long rectangular plates were utilized horizontally in the latest style (Fig. 6c).

Vertical-Plate Armor, Korean Peninsula

To date, no vertical-plate cuirasses have been found in Goguryeo or Baekje territory. The production of vertical-plate armor began in the early fourth century solely in Gaya (Kaya) and Silla in the southeastern Peninsula (Kim, 2009; Song, 2004, 2008; Yi, 2008). The fourth century can be divided roughly into three stages based on technological development (Figs. 3, 4).

Stage-1 (early fourth century) examples emerged already equipped with base plates running along the bottom edge of the cuirass and extended shoulder plates that project out to the side (Fig. 3), which may suggest their evolution from an organic predecessor. Almost all were fixed with iron rivets; the only known leather-thonged example is from Bokcheon-dong Tomb No. 38, which is morphologically considered one of the oldest examples of vertical-plate armor. It is believed that iron riveting replaced lacing almost immediately. Neck guards comprise long, narrow plates that curve outward from the cuirass neck and wrap around the side of the head (Fig. 3).

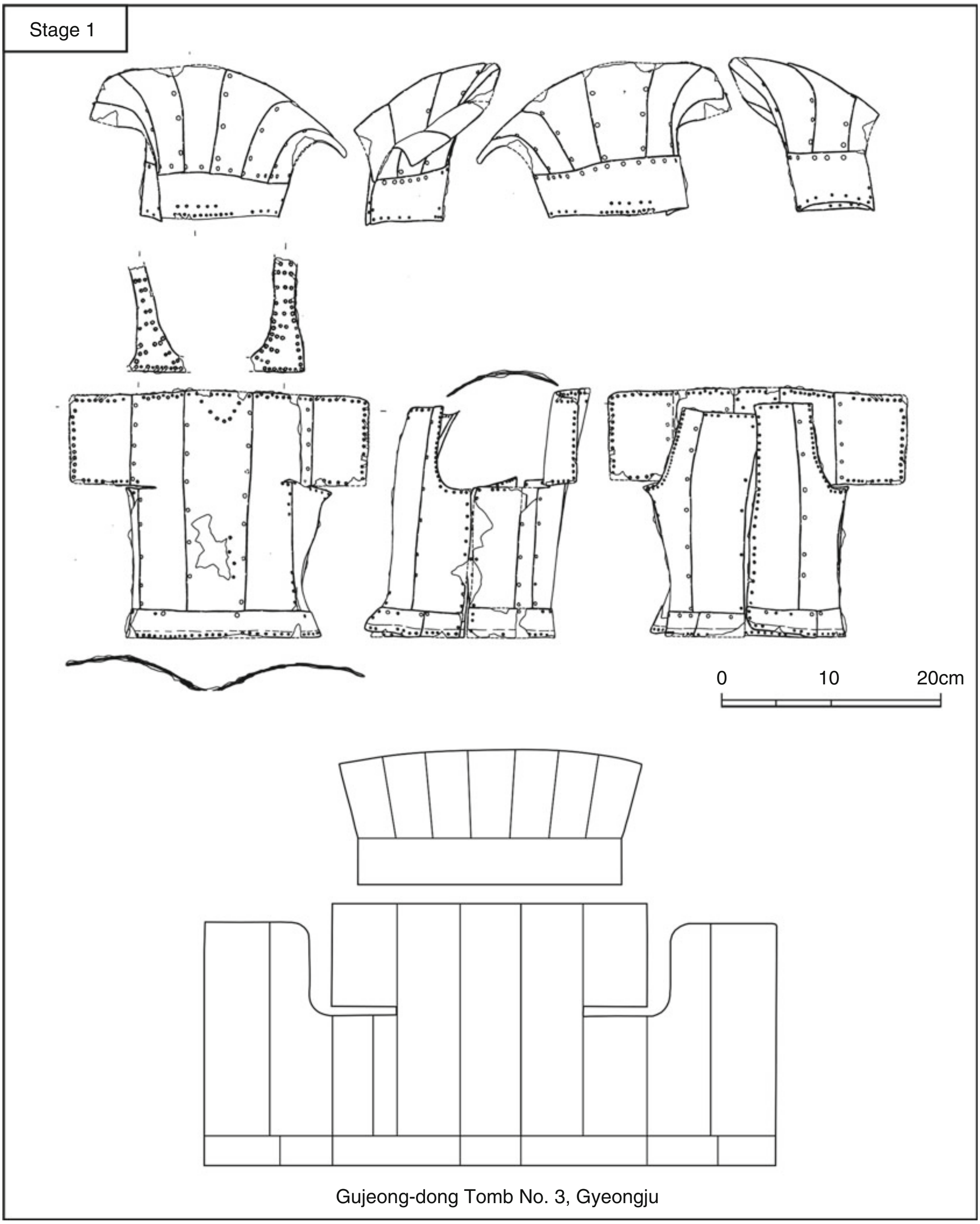
While cuirasses from Stage 2 (mid-fourth century) retain the base plates, the extended shoulder plates and outward-curving neck guards all but disappear. A new type of rear neck guard appears that extends vertically and is composed of fewer, wider plates and is almost always accompanied by two crescent-shaped side protectors that extend along the sides of the neck from the shoulder (Fig. 4a). Stage 2 is characterized by standardization of a horizontal shoulder plate (which a majority of Stage-1 cuirasses did not have), in addition to the appearance of an outer frame that wraps across the chest and under the arms. This frame offered increased stability. While not present in all Stage-2 cuirasses, it is considered a major technological development and it becomes fairly standard in the following stage. Stage-2 frames, however, are composed of two plates fastened together, perhaps representing the technological difficulty of forming a curved piece that wraps from the chest to the underarm.

In Stage 3 (late fourth century), the curved border frame of many examples is now made from one plate that wraps from the chest, down through the underarm, where it is riveted to the rear border frame. Further developments include a marked increase in ornamentation (Fig. 4b) and a general increase in the number of vertical plates. This increase in narrow plates is accompanied by greater plate curvature (long the armpit) and an enhanced fit to the torso, separating Stage-3 cuirasses from the previous boxlike suits. They are believed to represent improved wearability. While a very small number of vertical-plate cuirasses remain into the fifth century on the Peninsula, they are generally replaced by lamellar armor.

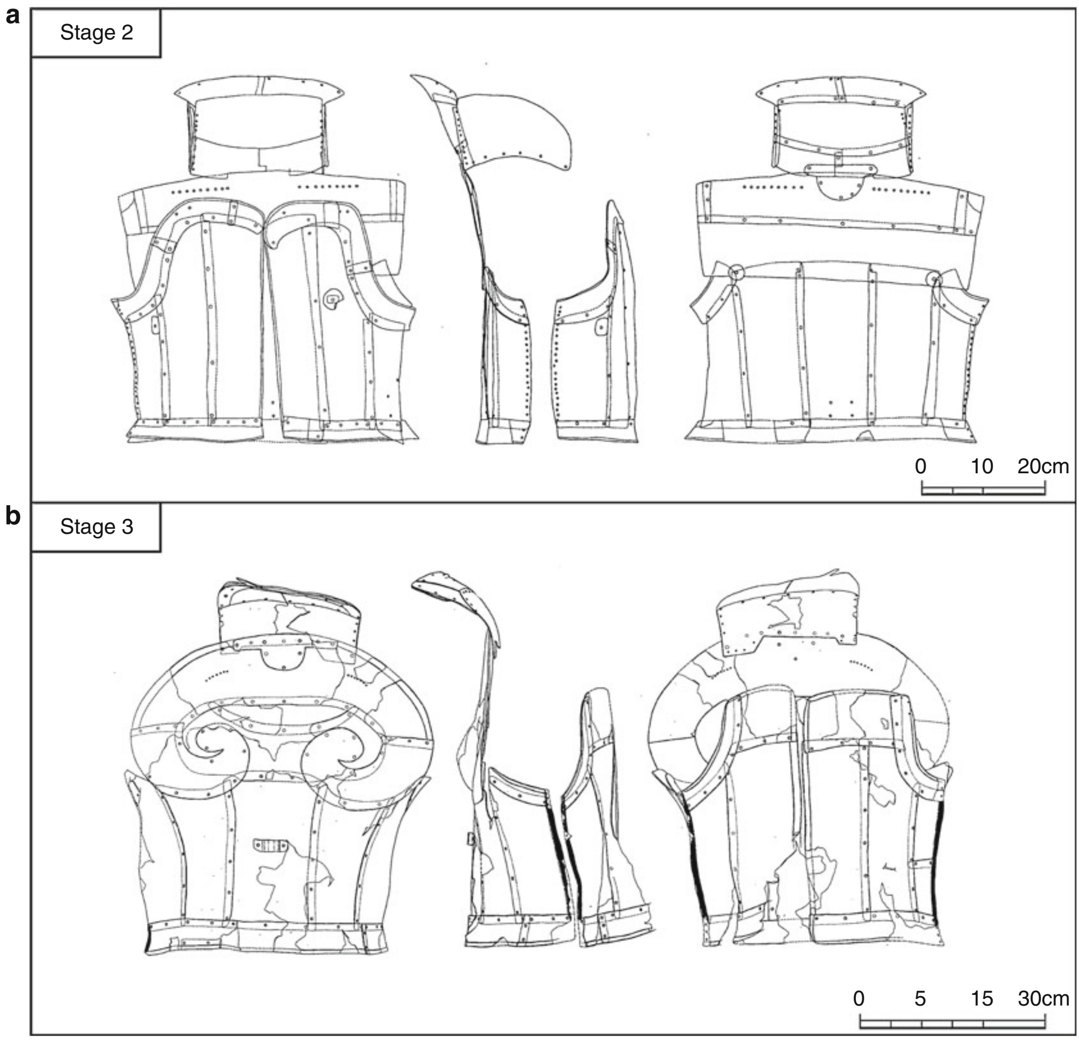
In addition to vertical-plate cuirasses, almost 30 cuirasses with plates arranged in horizontal rows have been found in the southern half of the Peninsula, making up almost half the total number of iron plate armor uncovered. Typological considerations, however, strongly suggest that these are imports from the Japanese archipelago (Hashimoto, 2013; Kim, 2011).

Horizontal Plate Armor, Japanese Archipelago

Vertical-plate cuirasses appear in the first half of the fourth century (Fig. 5a) (Hashimoto, 2013; Sakaguchi, 2010). The three known examples share the same vertical-plate alignment as those of the Peninsula, leading many to view them as imports. Significant differences do exist, however. All Insular examples are laced, rather than riveted, and lack the base plates, neck guards, extended shoulder plates, and decoration customary in Peninsular examples. It thus seems appropriate to consider them as having been domestically produced under Peninsular influence.



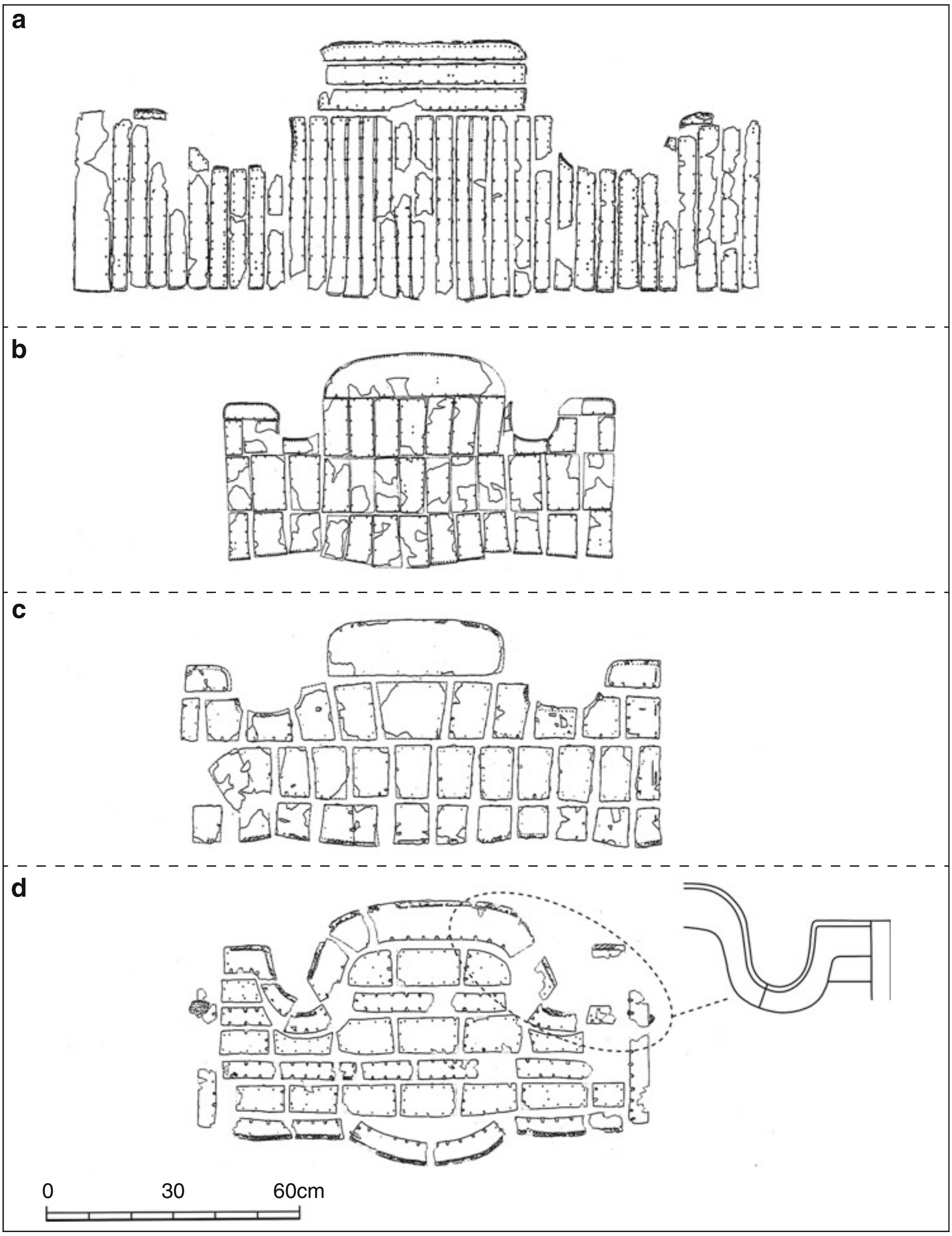
Armor in Japan and Korea, Fig. 3 Expanded view (*bottom*) of an iron cuirass (*top*). Iron cuirasses are often represented in expanded form, viewed from the rear, so their structure can be readily understood (*Top*: After Gyeongju National Museum, 2006, Fig. 21. *Bottom*: After Song, 2008, Fig. 10)



Armor in Japan and Korea, Fig. 4 Typological development of Peninsular vertical-plate armor. (**a**) Sara-ri Tomb No. 55, Gyeongju, South Korea. (**b**) Bokcheon-dong Tomb No. 10, Busan, South Korea (**a**: After Yeongnam Institute of Cultural Properties, 2007, Figs. 96, 97. **b**: After Busan University Museum, 1983, Fig. 4)

These early cuirasses are soon replaced by those consisting of short rectangular or square plates laced into horizontal rows (Fig. 5b), 16 examples of which have been excavated from fourth-century tombs. This shift to a horizontal alignment represents a significant technological break from the preceding vertical-plate tradition and has been interpreted as a functional development to accommodate the curvature of the torso more effectively. While these cuirasses utilize a horizontal alignment, the long side of each plate is situated longitudinally, attesting to their evolution from their vertical-plate predecessors. These cuirasses are also not riveted and lack the base plates, decorative elements, neck guards, and underarm-wrapping frame seen in contemporaneous vertical-plate armor from the Peninsula – thus, they seem likely to be domestic products.

A



Armor in Japan and Korea, Fig. 5 Evolution of the earliest iron cuirasses in the Japanese archipelago (After Sakaguchi, 2010, Fig. 2). (**a**) Vertical-plate cuirass– Shikinzan Tomb, Osaka, Japan. (**b**) Horizontally organized plate cuirass (longitudinal alignment of plate edges)– Azuchi-hyōtanyama Tomb, Shiga, Japan. (**c**) Horizontally organized plate cuirass (longitudinal alignment weakens)– Inadō Tomb No. 15, Fukuoka, Japan. (**d**) Horizontally organized plate cuirass in a frame (latitudinal alignment of plate edges)– Ono-ōzuka Tomb, Hyogo, Japan

The existence of horizontally organized examples with weakened longitudinal alignment is worthy of attention (Fig. 5c). This shift to a horizontal alignment of independently laced rows and a weakening of the longitudinal alignment set the stage for a major epoch in Insular iron armor production: the development of the Insular-style frame. All subsequent plate armor is equipped with this frame.

The late fourth-century framed armor (Fig. 5d) consists of rectangular plates positioned with their long sides horizontally aligned. An extensive frame provides enhanced strength and stability; in addition to the underarm-wrapping frame and the base plates, two ranks of narrow metal bands, one between each row of plates, act as supporting ribs. While the first two elements appear in Silla and Gaya examples from the early to mid-fourth century (Fig. 4), the iron bands across the chest and abdomen are an Insular development. Nevertheless, all three elements appear almost simultaneously in the Japanese archipelago at the end of the fourth century.

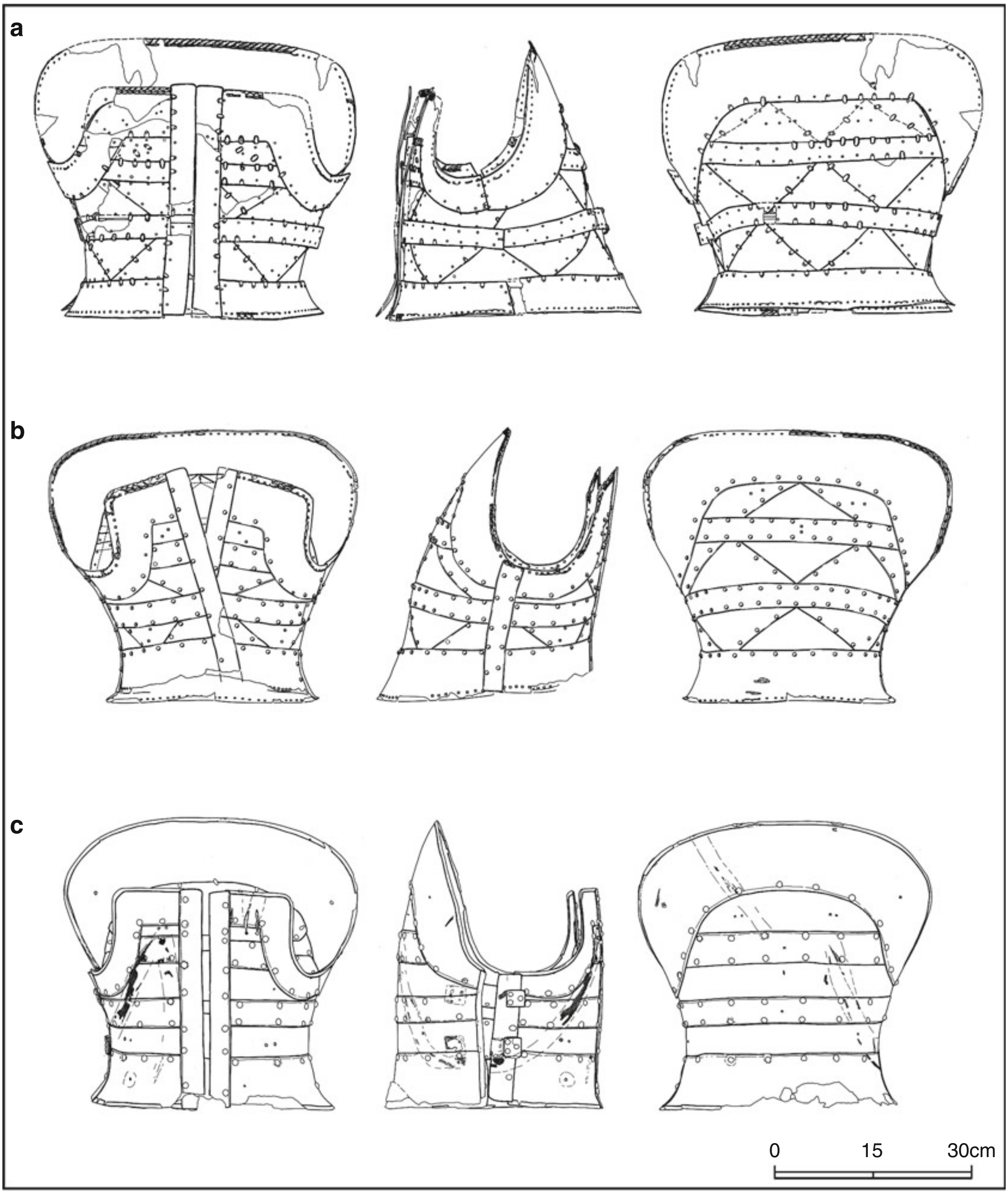
Shortly after framed cuirass production began, yet still within the late fourth century, cuirasses utilizing triangular plates appeared (Fig. 6a). Early examples utilize equilateral plates. The number of plates per row quickly decreases with a switch to wider obtuse-angle plates. Concerning the production of triangular-plate armor concurrent with rectangular-plate cuirasses, it was long assumed that a curved cuirass would be easier to construct using triangular plates. However, the plates across the underarm, which require the greatest curvature, are mostly rectangular in shape – there are almost no examples of triangular plates used across this area. Sharing the repeating triangle design with numerous ritual artifacts, the sustained use of triangular plates would seem to be the adoption of a magico-symbolic design, rather than a functional consideration (Sakaguchi, 1998). Construction of laced cuirasses continues through the first half of the fifth century.

Riveted cuirasses (Fig. 6b, c) appear in the archipelago during the early second quarter of the fifth century, approximately a century after Peninsular examples. While riveting technology was certainly introduced from the southeastern Peninsula, there are two factors worthy of consideration. Plate-armor production on the Peninsula had all but ended by this time in favor of lamellar armor, and the type of rivets used differed. In contrast to the flat-headed rivets used in Peninsular cuirasses, insular rivets display rounded or conical heads. Similarity with the rivets used in contemporary auxiliary neck protectors and horse trappings offers a clue as to the route of introduction (Sakaguchi, 2008; Tsukamoto, 1993). Rivets did not immediately put an end to leather lacing, however, which is attested by overlap between both types during the mid-fifth century.

The earliest riveted cuirasses had triangular plates (Fig. 6b), suggesting that the new riveting technology was incorporated into the existing armor tradition. In quick succession, however, riveted rectangular-plate cuirasses (Fig. 6c) also appear, most likely developing from the previous laced cuirasses with latitudinally organized rectangular plates (Fig. 5d; Takizawa, 1990). Both styles of riveted cuirasses, however, follow a similar labor-saving trajectory: during the latter half of the fifth century, the number of rivets decreases, the diameter of each rivet head increases, the characteristic horizontal bands become wider, and the use of hinges on the right side of the cuirass becomes standardized (Yoshimura, 1988). Moreover, riveted rectangular-plate cuirasses are found in the greatest number and from the widest spread of tombs, both geographically and sociopolitically; these riveted rectangular-plate cuirasses display striking similarities between cuirasses (Takizawa, 2008), and recent analysis via 3D laser scanning even suggests the possibility of common "blueprints" among the riveted rectangular-plate cuirasses (Yoshimura, 2014). Armor production of the late fifth century is thus considered to have entered a period of mass production. Nevertheless, however, the production of all plate armor is considered to have ended with the close of the fifth century.

Iron Lamellar Armor

Approximately 100 lamellar suits have been unearthed in the Korean Peninsula. Kofun-period



Armor in Japan and Korea, Fig. 6 Iron plate armor from the Japanese archipelago. (**a**) Triangular-plate-laced cuirass (Toshinokami Tomb, Hyogo, Japan) (After Hyogo Prefectural Board of Education, 2002, Figs. 10, 11). (**b**) Triangular-plate-riveted cuirass (Ono-ōzuka Tomb, Hyogo, Japan) (After Ono City Board of Education, 2006, Fig. 31). (**c**) Rectangular-plate-riveted cuirass (Marozuka Tomb, Kumamoto, Japan) (After National Museum of Japanese History, 2012, Figs. 44, 46, 47)

Armor in Japan and Korea, Table 1 Lamellar armor traditions of East Asia

			Imbrication	Waist			Alignment		Hem		
				1	2	3	A	B	1	2	3
Continent											
	Han		Inward	—	—	—	●	—	—	—	—
	Three Yan/ Goguryeo		Outward	●	●	—	●	—	—	—	—
	Baekje		Outward	●	?	○	●	—	—	—	○
	Gaya/Silla	4c	Outward	●	—	—	●	—	—	—	—
		Late 4c-5c	Outward	○	●	○	●	○	●	—	○
	Peninsular standard:		Outward		●		●		●		
Insulae											
	Early 5c		Outward	○	○	—	○	—	○	—	—
	Late 5c		Outward	—	○	●	○	●	●	—	●
	Insular standard:		Outward			●		●			●

—: Not present in the armor tradition ○ : Not dominant ● : Dominant

While various types existed within each region, only the characteristic or dominant types are represented above. A certain type's exclusion from the chart does not signify its nonexistence, but simply that it was not the most well attested.

"Alignment" here refers to waist lamellae; in the case that waist lamellae are not present in the armor tradition, it refers to the majority of body lamellae.

"?" indicates that the type has not yet been found, but its discovery may be expected.

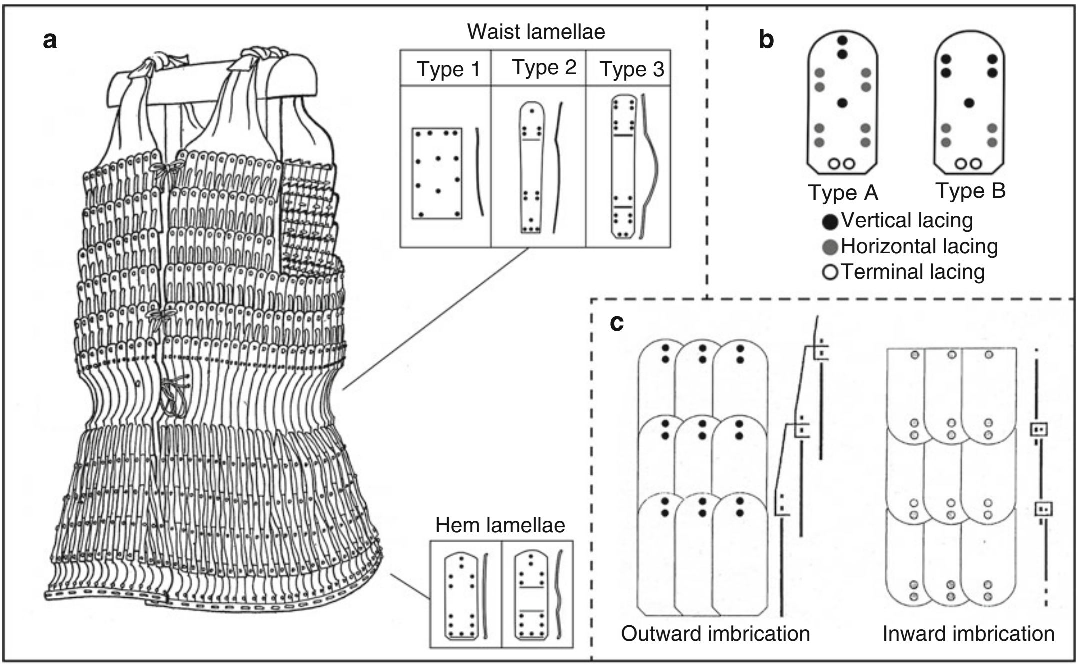
lamellar suits unearthed from the Japanese Islands number approximately 200 (although the majority of these date to the sixth century) (Table 1).

Outward-imbricating lamellae (Fig. 7c) are normally laced only through the head, progressively moving away from the wearer's body. There are examples of outward-imbricating lamellae laced at both ends in the Chinese tradition. These appear to have comprised auxiliary protectors, which required much more flexibility than body armor. As this entry focuses on body armor, outward imbrication will here refer to lamellae laced solely through the head. In contrast, inward-imbricating lamellae are laced at both ends and progressively move toward the body. This difference has a significant effect on wearability, with the former being much more flexible than the latter.

Lamellae situated around the waist tend to be of a different size and construction (Fig. 7a, inset). Based on their cross section, they can be roughly divided into straight or slightly outward curving (Type 1), S shaped (Type 2), and Ω shaped (Type 3). Additionally, lamellae are laced together horizontally utilizing pairs of holes located along the lamellae edges; the holes used for lacing vertical columns of lamellae are located at the head (Fig. 7b). While older lamellae have only one row of hole(s) for this purpose located in the center of the head (Type A), newer lamellae may have two rows located on either side of the head (Type B).

Lamellar Armor, Korean Peninsula

Dating to around the turn of the Common Era, the earliest finds of iron lamellae concentrate in the central Peninsula (Fig. 8a) and are accompanied by artifacts betraying strong Han influence through the Lelang commandery (Shimizu, 1996; Morikawa, 2008; Yi, 2014). Subsequent finds through the second century also display similarities in lamella shape and hole placement (including Type A placement) to Han examples.



Armor in Japan and Korea, Fig. 7 Lamellar armor. (**a**) Major types of waist and hem lamellae (After Suenaga, 1944, Fig. 8). (**b**, **c**) Examples of lacing holes and styles (After Shimizu, 1996, Figs. 1, 3)

Discoveries of actual Goguryeo armor are sparse and most treatments rely on tomb murals. Several scattered finds dating back to the late third century, however, hint at when lamellar armor first appeared in the region. While there is a dearth of Goguryeo materials until Type 2 waist lamellae dated to the mid-fifth century appear, the neighboring lower Manchurian Basin has proven useful in filling in this gap. This area was occupied by three successive states of the Murong Xianbei, often referred to as the Three Yan, during the Sixteen Kingdoms period (304–439). Type 2 waist lamellae with Type A hole placement appear in the first half of the fourth century in Former Yan tombs. Type 1 waist lamellae have been uncovered from contemporaneous tombs, suggesting that Type 2 waist lamellae did not completely replace Type 1 examples. Judging by the mid-fourth-century mural discovered inside Tomb No. 3 at Anak and subsequent fifth-century excavated materials, outward-imbricating suits became standard in the equestrian cultures of both Goguryeo and the Three Yan. Similarities in the lamellae morphology of both also suggest a common armor tradition.

Examples of iron armor from Baekje territory are also limited. Type 1 waist lamellae with Type A hole placement dating to the late fourth century are the oldest confirmed find and display technological influence from the Three Yan (and presumably Goguryeo). Subsequent finds from the fifth and sixth centuries continue to display similarities with northern examples. In the first half of the sixth century, however, lamellar suits incorporating design elements from the Japanese archipelago (Type 3 waist lamellae with Type 3 hem lamellae) appear accompanied by Kyushu-style stone chambers, revealing the diverse nature of Baekje foreign relations.

In contrast, the Silla and Gaya regions offer a relatively large amount of material for analysis. Local production of iron lamellar and plate armor began in the early fourth century; one of the earliest examples of both has been found at

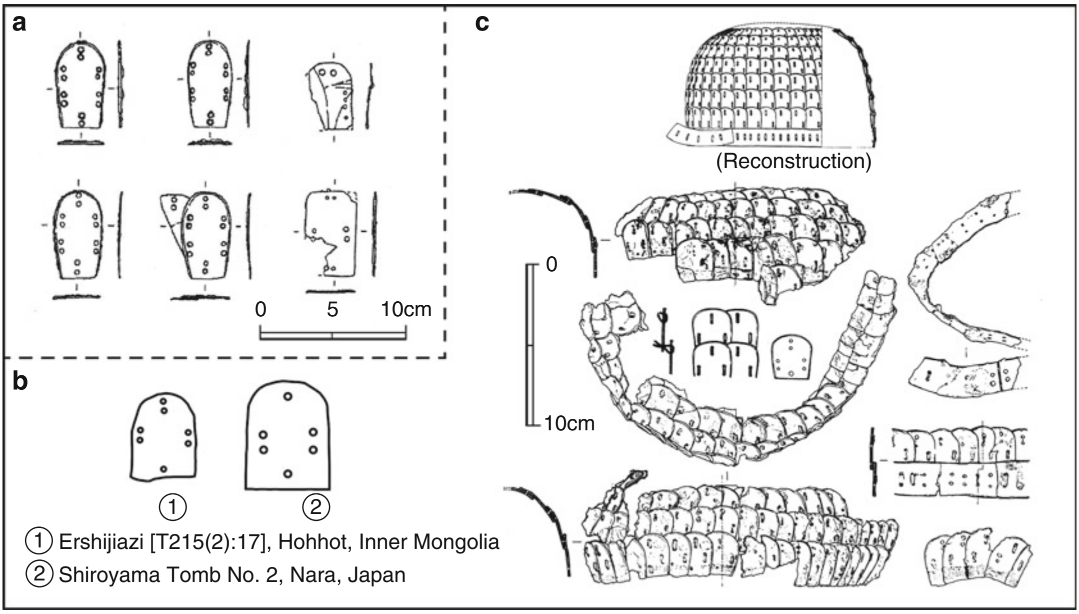
Bokcheon-dong Tomb No. 38. The lamellae are Type 1 waist lamellae with Type A alignment. Throughout the fourth century and into the early fifth century, Type 1 waist lamellae are dominant. From the late fourth century through the late fifth century, Type 2 are found throughout these regions. While few in number, Type B hole placement is seen from the early fifth century. Its advent is believed to represent increased flexibility. Type 3 waist lamellae appear in the latter fifth century and are often paired with Type B holes. The evolution of Type 3 waist lamellae from Type 2 is believed to represent a significant functional development. Not only did it bring the suit snug against the waist, decreasing unnecessary movement (Hatsumura, 2011), it also served to decrease friction against the inner lacing of the lower lamellae (Shimizu & Takahashi, 1998). While the handful of known examples of Type 3 present strong ties to the Japanese archipelago, early transitional examples may eventually be found in the southeastern Peninsula.

To summarize, the fourth-century appearance in Three Yan and Goguryeo territory of outward-imbricating suits with Type 2 waist lamellae represents a major technological break from the previous sporadic finds of Han-style lamellae, which were traditionally laced at both ends and used inward imbrication. The horse-riding culture of this region is believed to have necessitated this development. Type 2 waist lamellae subsequently appear in the southern Korean Peninsula from the late fourth century, more or less replacing Type 1 waist lamellae. Furthermore, Type 3 waist lamellae date from the latter fifth century and are often paired with Type B hole placement. Nevertheless, Type 2 waist lamellae with Type A hole placement and Type 1 hem lamellae remain the standard combination throughout the fifth century. Additionally, lamellae comprising one suit decrease in size and greatly increase in number in the fifth century. After the late fifth century, however, the burial of armor and weapons all but disappears from Goguryeo, Baekje, and Silla, attending changes in mortuary ritual. However, the burial of armor continued for a time in the Yeongsan River Basin of the southwestern Peninsula and in Gaya territory.

Lamellar Armor, Japanese Archipelago

Lamellar armor in the Han tradition first appeared in the archipelago in the late third and fourth centuries (Fig. 8c). There are 14 lamellar helmets and 2 lamellar suits (Hatsumura, 2011; Uchiyama, 2008). While lamella shape and hole placement are almost identical to late Western Han examples (Yang, 1985, 2000, Fig. 8b), the significant temporal gap and lack of viable contemporaneous examples from China warrant caution. Nevertheless, these early lamellar examples from the archipelago can no doubt be placed within the Chinese tradition and were most likely introduced after Queen Himiko sent a diplomatic mission in 239 CE to the successor of the Han, the Wei Dynasty (220–265 CE), and the Japanese archipelago was subsequently incorporated into the Wei geopolitical investiture system. Lamellar armor makes its next appearance in the second quarter of the fifth century. Following the limited appearance of Type 1 and Type 2 waist lamellae (which are similar to those of the southeastern Peninsula), domestic production is believed to have come into full swing in the late fifth century. The majority of suits have Type 3 waist lamellae with Type B hole placement and Type 3 hem lamellae – in stark contrast to the standard Peninsular combination of Type 2 waist lamellae with Type A hole placement and Type 1 hem lamellae. The suits of the Japanese Islands display a high level of standardization.

The introduction of lamellar armor has traditionally been interpreted as signaling the spread of horse-riding culture and the establishment of an equestrian elite. An analysis of the earliest lamellar armor and horse trappings in the archipelago, however, reveals they are not discovered together; approximately half a century passes before they appear together with any frequency. Moreover, the common assumption that lamellar armor was for equestrian and plate armor was for foot soldiers has also been called into question. Of fifth-century tombs, horse trappings are found paired with lamellar armor in 31 tombs and plate armor in 83 tombs (Hashimoto, 2010).



Armor in Japan and Korea, Fig. 8 Earliest examples of Pen/Insular iron lamellae. (**a**) Lamellae from the Daeseong-ri site in Gapyeong, South Korea (After Bokcheon Museum, 2010, Figs. I-1∼4). (**b**) Comparison between Han-style and Insular lamella (Redrawn from Yang, 1985, Fig. 12). (**c**) Lamellar helmet from Tsubai-ō tsukayama Tomb, Kyoto, Japan, with reconstruction (After Umehara, 1964, Figs. 15, 16)

Conclusion

A symbol of the elite, Pen/Insular iron armor was imbued with sociopolitical importance and characterized by strong regional variation. As with weapons and horse trappings, iron armor is highly instructive of international relations in ancient East Asia. The meticulous typological and technological research conducted by Japanese and Korean archaeologists has enabled reconstructions of these relations on an unprecedented level.

References

Barnes, G. L. (1999). *The rise of civilization in East Asia: The archaeology of China, Korea and Japan*. London: Thames & Hudson (New edition due in 2015 from Oxbow Books, Oxford entitled "Archaeology of East Asia").

Barnes, G. L. (Guest ed.). (2000). *Clashes of iron: Armor, weaponry, and warfare in early East Asian states. Journal of East Asian Archaeology*, *2*(3/4). Leiden: Brill.

Barnes, G. L. (2001). *State formation in Korea: Historical and archaeological perspectives*. London/Richmond: Routledge/Curzon.

Barnes, G. L. (2007). *State formation in Japan: The emergence of a 4th-century elite*. London: Routledge.

Busan University Museum. (1983). *Dongnae Bokcheon-dong gobun-gun 1* [Bokcheon-dong tomb group, Dongnae 1]. Busan National University Museum Site Reports, no. 5. Busan: Busan University Museum (in Korean).

Busan University Museum. (1990). *Dongnae Bokcheon-dong gobun-gun 2* [Bokcheon-dong tomb group, Dongnae 2]. Busan National University Museum Site Reports, no. 14. Busan: Busan University Museum (in Korean).

Bokcheon Museum. (2010). *Hanguk-e kodae gapju* [Ancient Korean armor]. Bokcheon Museum Academic Research Series, no. 31. Busan: Bokcheon Museum (in Korean).

Furuya, T. (1996). Kofun jidai katchū kenkyū no hōhō to kadai [Methods and issues in research on Kofun-period armor]. *Kōkogaku Zasshi, 81*(4), 58–85 (in Japanese).

Gyeongju National Museum. (2006). *Gyeongju Gujeong-dong gobun* [Gujeong-dong tomb group, Gyeongju]. Report of Archaeological Research of the Gyeongju National Museum (Vol. 18). Gyeongju: Gyeongju National Museum (in Korean).

Hashimoto, T. (1996). Kofun jidai zenki katchū no gijutsu to keifu [Technology and development of Early

Kofun-period armor]. In Yukinoyama Kofun Hakkutsu Chōsadan (Ed.), *Yukinoyama Kofun no kenkyū, kōsatsuhen* [Research on Yukinoyama Tomb: Essays] (pp. 255–292). Osaka: Osaka University Department of Archaeology (in Japanese).

Hashimoto, T. (2010). Kofun jidai chūki katchū no shūen to sono hyōka: chūki to kōki wo wakatsu mono [The end of Middle Kofun-period armor: On the division between the Middle and Late Kofun period]. In Osaka University Department of Archaeology (Ed.). *Machikaneyama kōkogaku ronshū 2: Ōsaka daigaku kōkogaku kenkyūshitsu 20-shūnen kinen ronshū* (pp. 481–501), Osaka: Osaka University Department of Archaeology (in Japanese).

Hashimoto, T. (2013). Kofun/Sangoku jidai no ita-yoroi no keifu [Development of plate armor in the Kofun and Three Kingdoms periods]. In O. Mitsuzane (Ed.), *Gijutsu to kōryū no kōkogaku* (pp. 336–347). Tokyo: Dōseisha (in Japanese).

Hatsumura, T. (2011). Kofun jidai chūki ni okeru kozane-yoroi no hensen [Development of lamellar armor during the Middle Kofun period]. *Kodaigaku Kenkyū, 192*, 1–19 (in Japanese).

Hyogo Prefectural Board of Education. (2002). *Toshinokami kofun-gun* [Toshinokami tomb group]. Hyogo Prefecture Site Reports, no. 234. Hyogo: Hyogo Prefectural Board of Education (in Japanese).

Kamiya, M. (2010). Nihon shutsudo no mokusei tankō/kumiawase mokkō/uchikake mokkō nitsuite [Wooden fitted armor, plate armor, and poncho-style armor excavated from the Japanese archipelago]. *Kobunka Dansō, 65*(2), 51–98 (in Japanese).

Kim, H.-J. (2009). Yeongnam jibang chulto jongjang pangap-eui bunpo-wa uimi [Distribution and significance of vertical-plate armor from the Yeongnam region]. *Yeongnam Archaeological Review, 49*, 5–51 (in Korean).

Kim, H. -J. (2011). Yeonsan-dong 8-hobun chulto daegeum-gye gapju-eui gujo-wa seonggyeok [Structure and significance of the framed cuirass excavated from the Yeonsan-dong Tomb No. 8]. In Publication Committee for the collection of essays in celebration of the 30th anniversary of the Kyungpook National University Department of Archaeology and Anthropology (Ed.). *Collection of essays in celebration of the 30th anniversary of the Kyungpook National University Department of Archaeology and Anthropology* (pp. 719–751). Daegu: Kyungpook National University Press (in Korean).

Morikawa, Y. (2008). Tōhoku Ajia ni okeru kozanekō no yōsō: sangoku jidai wo chūshin ni [Lamellar armor of Northeast Asia: With a focus on the Three Kingdoms period]. *Chōsen Kodai Kenkyū, 9*, 65–83 (in Japanese).

National Museum of Japanese History (Ed.). (2012). *Marozuka Kofun shutsudohin wo chūshin ni shita Kofun jidai chūki buki bugu no kenkyū* [Arms and armor of the Middle Kofun period: A study of the artifacts excavated from Marozuka Tomb]. Bulletin of the National Museum of Japanese History, no. 173. Chiba: Foundation for Museums of Japanese History (in Japanese).

Okayama City Board of Education. (2005). *Minamikata (Saiseikai)-iseki: mokki-hen* [Minamikata (Saiseikai) site: Wooden implements]. Okayama: Okayama City Board of Education (in Japanese).

Ono City Board of Education. (2006). *Ono-ōzuka Kofun: shutsudo ibutsu hozon shori hōkokusho* [Report on the conservation of artifacts unearthed from Ono-ōzuka Tomb]. Ono City Site Reports, no. 27. Hyogo: Ono City Board of Education (in Japanese).

Osaka Center for Cultural Heritage. (1998). *Shimoda iseki [Shimoda site]*. Osaka: Osaka Center for Cultural Heritage (in Japanese).

Sakaguchi, H. (1998). Chōhōban kawatoji tankō to sankakuban kawatoji tankō: hensen to sono tokushitsu [Rectangular-plate and triangular-plate laced cuirasses: Development and significance]. *Shirin, 81*(5), 607–645 (in Japanese).

Sakaguchi, H. (2008). Iwayuru "byōdome gihō dōnyūki" no hyōka [A reevaluation of the introduction of riveting technology]. *Kodai Buki Kenkyū, 9*, 39–51 (in Japanese).

Sakaguchi, H. (2010). Obigane-shiki katchū no seiritsu [Development of framed armor]. In Enko Tōhan Publication Committee (Ed.), *Enko tōhan: a gedenkschrift for Tōyama Akito* (pp. 305–320). Kyoto: Shinyōsha (in Japanese).

Shimizu, K. (1996). Higashi Ajia no kozane-kō no tenkai [Development of lamellar armor in East Asia]. *Kodai Bunka, 48*(4), 197–214 (in Japanese).

Shimizu, K., & Takahashi, T. (1998). Kofun jidai no gairaikei katchū shiryō ni tsuite: Fukuoka-ken Tsukandō Kofun to Kumamoto-ken Narasakiyama go-gōfun shutsudo katchū [Imported armor and foreign influence on Kofun-period armor: a study of armor excavated from Tsukandō Tomb in Fukuoka prefecture and Narasakiyama Tomb No. 5 in Kumamoto prefecture]. *Ōsaka-shi bunkazai kyōkai kenkyū kiyō, 1*, 33–49 (in Japanese).

Song, G. -H. (2004). Gaya gobun-eui gapju byeonhwa-gwa han-il gwangye [Changes in armor from Gaya tombs and Korean-Japanese relations]. In National Museum of Japanese History (Ed.). *Bulletin of the National Museum of Japanese History* (No. 110, pp. 187–224). Chiba: Foundation for Museums of Japanese History (in Korean and Japanese).

Song, J.-S. (2008). Jongjangpangap-eui jejak gongjeong-gwa gisul byeonhwa yeongu [The manufacturing process and technological change of vertical-plate armor]. *Journal of the Korean Archaeological Society, 69*, 4–43 (in Korean).

Suenaga, M. (1944). *Nihon jōdai no katchū* [Ancient Japanese armor]. Osaka: Sōgensha (in Japanese).

Takizawa, M. (1990). Byōdome tankō no hennen [Chronology of riveted iron cuirasses]. *Kōkogaku Zasshi, 76*(3), 16–51 (in Japanese).

Takizawa, Makoto. (2008). *Kofun jidai chūki ni okeru tankō no dōkōhin ni kansuru kisoteki kenkyū* [Research on identical cuirasses of the Middle Kofun period]. JSPS KAKENHI Grants-in-Aid for Scientific Research (C) (No. 17520517), 2005–2007 (in Japanese).

Tsukamoto, T. (1993). Byōdome tankō no gijutsu [Technology of riveted cuirasses]. *Gekkan Kōkogaku Journal, 366*, 22–26 (in Japanese).

Uchiyama, T. (2008). Kozane-yoroi no hensen to kōryū: Kofun jidai chū/kōki no odoshiana 2 retsu to Ω-ji-gata koshizane [Change and exchange in lamellar armor: Middle and Late Kofun-period Type-B lamellae and Ω-shaped waist lamellae]. In S. Fuminori (Ed.), *Ōken to buki to shinkō* (pp. 708–717). Tokyo: Dōseisha (in Japanese).

Umehara, S. (1964). *Tsubai-ōtsukayama Kofun* [Tsubai-ōtsukayama Tomb]. Kyoto Prefectural Report on Cultural Properties, no. 24. Kyoto: Kyoto Prefectural Board of Education (in Japanese).

Yang, H. (1985). Riben Gufen shidai jiazhou ji qi he Zhongguo jiazhou de guanxi [Japanese armor of the Kofun period and its connection with Chinese armor]. *Kaogu, 1985*(1), 61–77 (in Chinese).

Yang, H. (2000). Lamellar armor and horse bardings in Yamato and Goguryeo and their connections with China. *Journal of East Asian Archaeology, 2*(3–4), 123–137.

Yeongnam Institute of Cultural Properties. (2007). *Gyeongju Sara-ri yujeok 3* [Sara-ri site, Gyeongju 3]. Yeongnam Institute of Cultural Properties Research Report of Antiquities Vol. 130. Gyeongju: Yeongnam Institute of Cultural Properties (in Korean).

Yi, H. -J. (2008). Samguk sidae-eui gapju [Armor of the Three Kingdoms period]. In K. Takamitsu (Ed.). *Nikkan no bugu* (pp. 56–90). Miyazaki: Saitobaru Archaeological Museum of Miyazaki Prefecture (in Korean and Japanese).

Yi, H. -J. (2014). Hanguk gapju yeongu-eui hyeonhwang-gwa gwaje: chalgap jejak gisul-eui suyong-gwa jeongae [Issues in Korean armor research: The spread and development of lamellar armor production technology]. In Society of Ancient Arms and the Yamaguchi University Department of Archaeology (Ed.). *Dai-jukkai kodai buki kenkyūkai: happyō shiryōshū* (pp. 41–68). Yamaguchi: Society of Ancient Arms and the Yamaguchi University Department of Archaeology (in Korean and Japanese).

Yoshimura, K. (1988). Tankō keifu shiron [Essay on the development of plate armor]. *Kashihara Kōkogaku Kenkyū Kiyō: Kōkogaku Ronkō, 13*, 23–39 (in Japanese).

Yoshimura, K. (2014). *Sanjigen rēzā keisoku wo riyō shita Kofun jidai katchū seisaku no fukugenteki kenkyū* [Analysis of Kofun-period armor production through 3D laser scanning]. JSPS KAKENHI Grants-in-Aid for Scientific Research (C) (No. 23520945), 2011–2014 (in Japanese)

Yukinoyama Kofun Hakkutsu Chōsadan (Ed.). (1996). *Yukinoyama Kofun no kenkyū, kōsatsuhen* [Research on Yukinoyama tomb: Essays]. Osaka: Osaka University Department of Archaeology (in Japanese).

Āryabhaṭa

R. C. Gupta

Āryabhaṭa (b. AD 476) was a celebrated astronomer and mathematician of the classical period of the Gupta dynasty (AD 320 to ca. 600). This era is called the Golden Age in the history of India, during which Indian intellect reached its high water mark in most branches of art, science, and literature, and Indian culture and civilization reached a unique stage of development which left its deep impression upon succeeding ages. Āryabhaṭa played an important role in shaping scientific astronomy in India. He is designated as Āryabhaṭa I to differentiate him from Āryabhaṭa II, who flourished much later (ca. AD 950–1100) and who wrote the *Mahāsiddhānta*.

Āryabhaṭa I was born in AD 476. This conclusion is reached from his own statement in the *Āryabhaṭīya*: "When sixty times sixty years and three quarters of the *yuga* (now *Mahā*) had elapsed, twenty three years had then passed since my birth" (III, 10).

Since the present *Kaliyuga* (the last quarter of the *Mahāyuga*) started in 3102 BCE, Āryabhaṭa was 23 years old in 3600 minus 3101, that is in AD 499. The exact date of birth comes out to be March 21st, when the Mean Sun entered the zodiac sign of Aries in AD 476. The significance of mentioning AD 499 is that the precession of equinoxes was zero at the time, so that the given planetary mean positions did not require any correction. According to some commentators, AD 499 was also the year of composition of the *Āryabhaṭīya*.

We have no knowledge about his parents or teachers, or even about his native place. Āryabhaṭa composed the *Āryahhaṭīya* while living at Kusumapura, which has been identified as Pāṭaliputra (modern Patna in Bihar State), the imperial capital of the Gupta empire. It is possible that Āryabhaṭa headed an astronomical school there.

The association of Patna, where Āryabhaṭa taught and wrote on mathematics and astronomy, with his professional career, does not settle the question of his birthplace, but it may have been a place where he was educated.

Āryabhaṭa's fame rests mainly on his *Āryabhaṭīya*, but from the writings of ▶ Varāhamihira (sixth century AD), ▶ Bhāskara I, and ▶ Brahmagupta (seventh century), it is clear that earlier he composed an *Āryabhaṭa Siddhānta*. Although voluminous, the *Āryabhaṭa Siddhānta* is not extant. It is also called *Ārdharātrika Tantra*, because in it the civil days were reckoned from one midnight to the next. Its basic parameters are preserved by Bhāskara I in his *Mahābhāskarīya* (Chap. VII). Rāmakṛṣṇa Ārādhya (AD 1472) has quoted 34 verses on astronomical instruments from the *Āryabhaṭa Siddhānta*, of which some were devised by Āryabhaṭa himself.

The *Āryabhaṭīya* is an improved work and the product of a mature intellect. Considering the genius of Āryabhaṭa, it is easy to agree with the view that he composed it at the age of 23. The date is also in fair agreement with the recent research and analysis by Roger Billard. Unlike the *Āryabhaṭa Siddhānta*, the civil days in the *Āryabhaṭīya* are reckoned from one sunrise to the next – a practice which is still prevalent among the followers of the Hindu calendar. The *Āryabhaṭīya* consists of four sections or *pādas* (fourth parts):

1. *Daśagītikā* (10 + 3 couplets in Gīti meter)
2. *Gaṇitapāda* (33 verses on mathematics)
3. *Kāla-kriyāpāda* (25 verses on time-reckoning)
4. *Golapāda* (50 verses on spherical astronomy)

That the *Āryabhaṭīya* was quite popular is shown by the large number of commentaries written on it, from Prabhākara (ca. AD 525) through ▶ Nīlakaṇṭha Somayāji (ca. 1502) to Kodanḍarāma (ca. 1850).

An Arabic translation of the *Āryabhaṭīya* entitled ▶ *Zīj al-Ārjabhar* was made in about 800, possibly by al-Ahwāzī. In spite of the *Āryabhaṭīya's* popularity, H. T. Colebrooke failed to trace any work of Āryabhaṭa anywhere in India.

The use of modern scientific methodology, as described by Roger Billard in his *L'astronomie indienne*, along with new ephemerides, clearly shows that both of Āryabhaṭa's major works were based on accurate planetary observations. In fact, the use of better planetary parameters, the innovations in astronomical methods, and the concise style of exposition rendered the *Āryabhaṭīya* an excellent textbook in astronomy. In opposition to the earlier geostationary theory, Āryabhaṭa held the view that the earth rotates on its axis. His estimate of the period of the sidereal rotation of earth was 23 h, 56 min, and 4.1 s, which is quite close to the actual value.

Āryabhaṭa has been also considered the father of Indian epicyclic astronomy. The resulting new planetary theory enabled Indians to determine more accurately the true positions and distances of the planets (including the sun and the moon). He was the first Indian to provide a method of finding celestial latitudes. He also propounded the true scientific cause of eclipses (instead of crediting the mythological demon Rāhu). In fact his new ideas gave rise to the formation of a new school of Indian astronomy: the Āryabhaṭa School or *Āryapakṣa*, for which the basic text was the *Āryabhaṭīya*.

Exposition and computation based on the new astronomical theories were made easy by Āryabhaṭa, because of the development of some mathematical tools. One of them was his own peculiar system of alphabetic numerals. The 33 consonants of the Sanskrit alphabet (Nāgarī script) denoted various numbers in conjunction with vowels which themselves stood for no numerical value. For example, the expression *khyughṛ* (=*khu* + *yu* + *ghṛ*) denoted

$$2 \times 100^2 + 30 \times 100^2 + 4 \times 10^3 = 4,300,000,$$

which is the number of revolutions of the sun in a Yuga.

The development of Indian trigonometry (based on sine instead of chord, as the Greeks had done) was another of Āryabhaṭa's achievements which was necessary for astronomical calculations.

Because of his own concise notation, he could express the full sine table in just one couplet, which students could easily remember. For preparing the table of sines, he gave two methods, one of which was based on the property that the second order sine differences were proportional to sines themselves.

Āryabhaṭa seems to have been the first to give a general method for solving indetermininate equations of the first degree. He dealt with the subject in connection with the problem of finding an integral number N which will give a remainder r when divided by an integer a, and s when divided by b. This amounts to solving the equations

$$N = ax + r = by + s.$$

Although at present the topic of indeterminate analysis comes under pure mathematics, in ancient times it arose and was used for practical and astronomical problems. In fact, Āryabhaṭa successfully used his theory of indeterminate analysis to determine a mean conjunction of all planets at the zero mean longitude at the start of the *Kaliyuga* (3102 BCE). Recently it has been shown that his algorithm solves more general problems than the Chinese remainder theorem, and works irrespective of the sign of numbers.

The solution of a general quadratic equation and the summation of certain series were some other algebraic topics dealt with by Āryabhaṭa. The methods of adding an arithmetical progression were known in all ancient cultures, but he was perhaps the first to supply a general rule for finding the number of terms (n) when the first term (a), the common difference (d) and the sum (s) were given. His solution is a root of the quadratic equation

$$dn^2 + (2a - d)n = 2s,$$

which comes from the usual formula for the sum of an arithmetical progression.

In geometry, his greatest achievement was an accurate value of π. His rule amounts to the statement

$$dn^2 + (2a - d)n = 2s.$$

This implies the approximation 3.1416 which is correct to its last decimal place. How he arrived at this is not known.

From what we know about Āryabhaṭa, it is clear that he was an outstanding astronomer and mathematician. His scientific attitude, rational approach, and mathematical methodology ushered in a new era in the history of the exact sciences in India. It was quite befitting that the first Indian satellite launched on the 19th April 1975 was named Āryabhaṭa.

See Also

▶ Astronomy: Indian Astronomy in China
▶ Mathematics in India
▶ Trigonometry in Indian Mathematics

References

Achar, B. N. N. (2002). Aryabhata and the table of RSines. *Indian Journal of History of Science, 37*, 95–99.

Ayyangar, A. A. K (1925–1926). The mathematics of Āryabhaṭa. *Quarterly Journal of the Mythic Society, 16*, 158–179.

Billard, R. (1977). Āryabhaṭa and Indian astronomy: An outline of an unexpected insight. *Indian Journal of History of Science, 12*(2), 207–224.

Elfering, K. (1975). *Die Mathematik des Āryabhaṭa I.* Munich, Germany: Wilhelm Fink Verlag.

Hari, K. C. (2002). Genesis and antecedents of Aryabhatiya. *Indian Journal of History of Science, 37*(2), 101–113.

Hayashi, T. (1997). Aryabhata's rule and table for sine-differences. *Historia Mathematica, 24*, 396–406.

Jha, P. (1988). *Āryabhaṭa I and his contribution to mathematics*. Patna, India: Bihar Research Society.

Kak, S. (1986). Computation aspects of the Āryabhaṭa algorithm. *Indian Journal of History of Science, 21*(1), 62–71.

Sarma, K. V. A. (2001). His name, time and provenance. *Indian Journal of History of Science, 36*(3–4), 105–115.

Sen, S. N. (1963). Āryabhaṭa's mathematics. *Bulletin of the National Institute of Sciences of India, 21*, 27–319.

Sengupta, P. C. (1929). Āryabhata the father of Indian epicyclic astronomy. *Journal of the Department of Letters Calcutta University, 18*, 1–56.

Shukla, K. S. (1976a). *Āryabhaṭa Indian mathematician and astronomer*. New Delhi, India: Indian National Science Academy.
Shukla, K. S. (Ed.). (1976b). *Āryabhaṭīya, with the commentary of Bhāskara I and Someśvara*. New Delhi, India: Indian National Science Academy.
Shukla, K. S., & Sarma, K. V. (Eds. & Trans.) (1976). *Āryahhaṭiya of Āryabhaṭa*. New Delhi, India: Indian National Science Academy.

Asada Goryu

Nakayama Shigeru

Asada Goryu (1734–1799) was a Japanese astronomer who was instrumental in turning Japanese astronomy and calendrical science away from the traditional Chinese style and toward Western models.

In adopting the traditional idea of secular diminution of tropical year length, astronomers at the time were required only to account for the ancient records and modern data of Chinese solstitial observations by a single formula. Classical Western data, such as those listed in the *Almagest* of Ptolemy, became available to Asada through the Jesuit treatises. He endeavored to synthesize Western and Chinese astronomy and to give a numerical explanation, by means of a single principle, of all the observational data available to him – old and new, Eastern and Western.

Copernicus appears in the Sino-Jesuit treatises, not as an advocate of heliocentricism but as an observational astronomer and the inventor of the eighth sphere of trepidation. He is said to have believed that the ancient tropical year was longer than that of the Middle Ages, which in turn was shorter than the contemporary constant. Asada, perhaps struck by this passage, formulated a modified conception in which the length of the ancient tropical year tended to decrease until it reached a minimum in the Middle Ages and to grow longer afterward, varying in a precession cycle of 25,400 years.

It is apparent that what Asada really intended to do was account for the newly acquired Western data. His basic goal, that of "saving the ancient records" by numerical manipulation, differs not at all from that of the traditional approach. His consideration of the precession cycle was theoretical decoration.

References

Asada, G. *Shocho ho*. Manuscript Preserved in Tohoku University Library.
Nakayama, S. (1969). *A history of Japanese astronomy*. Cambridge, MA: Harvard University Press.

Astrolabe

Julian A. Smith

The astrolabe is a portable wooden or metal astronomical instrument which is used to measure the positions and altitudes of celestial bodies, to find the observer's time or latitude, or to solve other mathematical problems. In its complete form, it consists of a main body, or flat plate ("mater" or "mother") to which is attached a series of smaller plates (called climates) engraved with various coordinate lines, according to various latitudes. An alidade, a rotatable straight rule with sights used to find altitudes, is fastened to the back. Attached to the front, above the climates, is a smaller fretted circular plate called the rete – this is a moveable map of the heavers, with pointers indicating various stars. The whole rotating assembly is fastened together by a pin through the center of the mater and climates, and it is secured at the top by a wedge-shaped piece of metal called the horse, after its fanciful resemblance to a horse's head.

To use the astrolabe, an observer would typically rotate the alidade until a star became visible through the sights, and then read its altitude in degrees from a scale on the back of the instrument. Then one would turn the rete until that star corresponded to the almucantar (curves representing parallels to the horizon) for the right altitude. The time could then be determined from the place of the "sun" on the instrument. Astrolabes could measure solar time, sidereal time, and time in unequal hours, depending on how the hour lines were marked.

Although the astrolabe is usually considered an Arabic invention, its true roots go back to the mathematical astronomers of ancient Greece – the word itself comes from the Greek terms for a "star-taking" instrument. Engraving great circles and hour lines demanded considerable skill – in essence, the instrument-maker had to collapse a three-dimensional celestial sphere into the flat, circular plane of the astrolabe. Some historians attribute this discovery to Appolonius of Perga (ca. 262-ca. 190 BCE), but according to Otto Neugebauer, the planispheric or stereographic projection of the heavens upon a flat surface was first accomplished by Greek astronomer Hipparchus of Nicea/Rhodes (ca. 190-ca. 120 BCE). In addition, Hipparchus may have built simple astrolabes, consisting of solid sky maps covered with open networks of lines. Finally, he is credited with developing the projection for an anaphoric clock, an ancestor of the astrolabe. This is an axle with a large circular star map, laid out in a stereographic projection – attached to it is a smaller stationary grill showing the projection of the horizon, and a visible hemisphere for a given latitude. The dial is powered by a clepsydra, and as it rotates, a model of the sun traces out the hours of the day. The anaphoric clock was described by Roman engineer Vitruvius (ca. 25 BCE), and may have been built in the famous Athenian "Tower of the Winds" around 50 BCE.

The first clear descriptions of the construction of the astrolabe occur in the *Planisphere* of Alexandrian astronomer Claudius Ptolemy (ca. 150 AD). By this time, the complexity of various lines had made the astrolabe's covering bulky, a problem Ptolemy solved by switching the lines to the mater and the star map to the rete. The astrolabe was further developed in the works of Greek mathematician Theon (fl. AD 360–380), now lost, and John Philoponus (fl. 520), both of Alexandria. Syrian Severus Sebokht (fl. 630) also wrote an early treatise on the astrolabe.

Medieval Islamic scientists took the basic planispheric astrolabe of Hellenistic astronomers and improved it dramatically between AD 700–1500, applying it to questions of astronomy, surveying, mathematics, geography, and much more. In AD 843, Baghdad mathematician ▶ al-Khwārizmī (fl. AD 810–850) claimed his astrolabe could solve 43 problems – a century later, Persian astronomer al-ṣūfi (AD 903–986) said that it could answer a thousand astronomical questions. David King divides Arabic astrolabe innovations into five basic categories: the making of tables, nonstandard retes, qiblas, multiple climates, and the development of three new forms of the instrument.

Astronomers like ▶ al-Farghānī of Baghdad (ca. 830-ca. 861) compiled numerical tables of radii and center distances of both azimuth and almucantar circles for every degree of latitude and azimuth, for every terrestrial latitude. These tables, which exceeded 13,000 entries, were used extensively by Arabic astronomers alongside geometric projections to construct astrolabes for different latitudes. Islamic astronomers also constructed nonstandard retes, which would symmetrically represent the otherwise dissimilar northern and southern halves of the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course). The Oxford myrtle astrolabe is an example.

Arabic astrolabists inscribed specific markings on their instruments, corresponding to Islamic prayer times and directions. By the thirteenth century, they engraved lists of cities with latitudes, longitudes, and Mecca directions, known as qiblas – this would help observers orient themselves for prayers. Arabic astrolabes also developed multiple plates or climates, giving astronomical tables usually found in handbooks or textbooks. An early example is referred to by ▶ Abū Jaʿfar al-Khāzin (d. 961/971).

Finally, Islamic scientists developed at least three new types of instrument: the linear, universal and geared astrolabes. The linear astrolabe consists of a series of scales on a stick which represents the meridian for a given latitude, to which are attached a series of threads through which one can perform all the standard operations of an astrolabe. This was invented by Iranian mathematician ► Sharaf al-Dīn al-Ṭūsī (d. ca. 1213), and was known as "al-Ṭūsī's cane." The universal astrolabe was developed by Ḥabash of Baghdad (d. ca. 864–874), and Alī ibn-Khalaf (al-Shakkāz) in Toledo in the eleventh century, who devised a special shakkaziya plate for it. Though powerful, it was not widely known, and was reinvented in early fourteenth century Syria. This astrolabe could determine the risings, culminations, and settings of celestial bodies at all latitudes using a single plate. Astronomer al-Zarqāllu (Azarquiel) of Toledo (ca. 1029–1087/1100) simplified this by replacing the rete with an alidade having a movable cursor, and by putting the ecliptic and star pointers on the shakkaziya plate. Geared astrolabes contained complex mechanisms to reproduce the motion of the sun and moon mechanically – their date of invention is unknown, but they were described by Persian astronomer ► al-Bīrūnī (ca. 973–1048).

The astrolabe was reintroduced into Europe from the Arabs by the tenth century. Gerbert of Aurillac, Pope Sylvester II (ca. 945–1003), imported much astronomical knowledge into the medieval Latin west from Islamic sources, and may have used the astrolabe as a teaching tool. Meanwhile, Hermannus Contractus (1013–1054) transmitted many Arabic concepts in his two influential Latin treatises on the astrolabe: *De Mensura Astrolabii* and *De Utilitatibus Astrolabii*. Ptolemy's *Planisphere* was translated by Hermann the Dalmatian in the twelfth century, and in 1276, an influential Arabic astrolabe treatise by the Egyptian Jew Māshā'allāh (fl. 762-ca. 815) was translated into Latin, where it formed the basis for the first English book on the astrolabe, by poet Geoffrey Chaucer (ca. 1340-ca. 1400) in 1391.

Though the astrolabe was widely developed in Arab countries, it was virtually ignored in the East. Joseph Needham says that Chinese astronomers made no astrolabes of their own, though they did develop the anaphoric clock independently. The reasons are twofold: Chinese scientists instead developed sophisticated ► globes and armillary spheres quite early, and they lacked the analytical techniques in their mathematical astronomy which led to the stereographic projection in the West. Needham suggests the astrolabe was imported to China from Persia in 1267 by the Maraghan Observatory astronomer Jamāl al-Dīn ibn Muḥammed al-Najārri, but the mathematical projections remained obscure until the arrival of the Jesuits in the sixteenth century.

Indian scientists also borrowed the astrolabe from Islamic sources. Astronomer ► Bhāskara II (1114-ca. 1184) used spherical astronomy to construct a wheel-like instrument, called the *phalaka yantra*, which essentially served the same purpose as a primitive astrolabe. However, the true planispheric astrolabe, the *ustaralava*, was first imported by Muslims in the thirteenth century – a Damascus astrolabe of 1204 is still preserved in the Rampur State Library. The astrolabe was described in detail in the *Yantrarāja* of ► Mahendra Sūri in 1370 – this work is based on Islamic sources. Lahore later became a center for its construction, under families of instrument makers like those of Shaikh Allāh-Dad (fl. 1570–1660). Indian astronomers also developed some of the largest astrolabes in the world. The great brass astrolabe at the Jaipur observatory of Sawai Jai Singh (1686/1688–1743) is 3 m tall, 2.12 m across, and weighs over 400 kg. Jai Singh's *Yantrarājaracanā* also gives instructions for astrolabe construction based on stereographic projections.

The astrolabe was popular as an astronomical instrument until long after the introduction of the telescope in the early seventeenth century. It survived another century, until it was replaced in the 1730s by English astronomer

John Hadley's (1682–1744) reflecting quadrant, a precursor to the sextant.

See Also

- ▶ Abū Jaʿfar al-Khāzin
- ▶ al-Farghānī
- ▶ al-Khwārizmī
- ▶ Al-Bīrūnī
- ▶ Al-Ṣūfī
- ▶ Astronomical Instruments in the Islamic World
- ▶ Bhāskara I
- ▶ Ibn Al-Zarqāllu
- ▶ Jai Singh
- ▶ Mahendra Sūri
- ▶ Māshāʾallāh
- ▶ *Qibla* and Islamic Prayer Times
- ▶ Sharaf al-Dīn al-Ṭūsī

References

Abdi, W. H., et al. (1990). *Interaction between Indian and central Asian science and technology in medieval times*. New Delhi, India: Indian National Science Academy.

Bose, D. M., et al. (1971). *A concise history of science in India*. New Delhi, India: Indian National Science Academy.

Burnett, C. (2000). Addendum to King Ptolemy and Alchandreus the philosopher: The earliest texts on the astrolabe and Arabic astrology at Micy Fleury, and Chartres. *Annals of Science, 57*(2), 187.

Drachman, A. G. (1954). The plane astrolabe and the anaphoric clock. *Centaurus, 3*, 183–189.

Gunther, R. T. (1976). *Astrolabes of the world*. London: Holland Press.

Jaggi, O. P. (1977–1986). *History of science, technology and medicine in India, esp*. (Vols. 6–7). Delhi, India: Atma Ram.

Kennedy, E. S., Kunitzsch, P., & Lorch, R. P. (1999). *Abu Ja'far Ahmad ibn 'Abd Allah. The melon-shaped astrolabe in Arabic astronomy*. Stuttgart, Germany: F. Steiner.

King, D. (1987). *Islamic astronomical instruments*. London: Variorum.

Kuppuram, G., & Kumudami, K. (1990). *History of science and technology in India* (Vol. 1–12). Delhi, India: Sundeep Prakashan.

Michel, H. (1947). *Traité de l'Astrolabe*. Paris: Gauthier-Villars.

Needham, J. (1954). *Science and civilisation in China*. Cambridge: Cambridge University Press.

Needham, J. (1960). *Heavenly clockwork*. Cambridge: Cambridge University Press.

Neugebauer, O. (1949). The early history of the astrolabe. *Isis, 40*, 240–256. Studies in Ancient Astronomy IX, Reprint.

North, J. D. (1974). The astrolabe. *Scientific American, 230*, 96–106.

Saunders, H. N. (1984). *All the astrolabes*. Oxford, UK: Senecio.

Astrology in Babylonia

Nicholas Campion
Trinity Saint David, University of Wales, Ceredigion, UK

Astrology remains a feature of popular culture in the modern west. Most histories of the subject, from Thorndike (1923–1958) to Tester (1987), assume a fundamental conceptual and technical break between Babylonian and Greek astrology in the last centuries BCE and that western astrology also effectively came to an end in the late seventeenth century, when it lost its intellectual respectability. The Encyclopaedia of Religion (Culianu, 1987, p. 472) states categorically that "astrology, a product of Hellenistic civilisation, appeared at the end of the third century BCE," completely denying any Mesopotamian connection. Chambers' Encyclopaedia is more circumspect, considering that "It was in Greece, about the fourth century BCE that astrology underwent a great development and was regarded as regulating all things in the universe, including the fates of men (1970, p. 724)." However, while it is clear that astrology, like any other belief system, experiences periods of reinvention as it passes between different cultures and periods, it is possible to identify a fundamental continuity from the earliest Babylonian astrology to the present day. Contemporary popular astrology may therefore be seen as a remarkable revival of the practical applications of an ancient non-western astronomy: that of Mesopotamia of 4,000 years ago (Campion, 2012). Recent scholarship includes Rochberg's work on horoscopes (1998), the collection of papers by Steele and Imhausen (2002), Steele's work on calendars (2007), general histories by Brown (2000a) and Rochberg-Halton (2004), and the discussion in Campion (2009, pp. 35–86).

Mesopotamian Astrology

The civilizations of Mesopotamia flourished between 2,000 and 5,000 years ago. Like many societies, they adhered to the belief that the terrestrial, physical, and human worlds were so intimately connected to the celestial, intangible, and divine realms as to effectively constitute a single entity. The natural environment, it was believed, provided the principal means of communication between humanity and the pantheon of invisible gods and goddesses. From this sense that the entire world was alive, there developed various means of reading divine intentions; for example, the practice of omen (from the Latin meaning "sign") divination relied on the assumption that any visible natural phenomenon, whether predictable or not, might represent an attempt by a god or goddess to communicate their intentions or instructions to humanity.

Divination took on many forms, from the rolling of dice to the royal reliance on extispicy, or divination from the livers. Gradually, over the second millennium BCE, astrology (the divinatory use of celestial phenomena) appears to have grown in importance. As it did so, it encouraged the increasing observation of planetary and stellar patterns and ultimately, by the seventh to eighth centuries BCE, their extrapolation into the future. Thus, by the time that the Greek astronomers first began to speculate on the nature of the heavens, the Mesopotamian astrologers had made the crucial transition from a purely observational astronomy to one which was both mathematical and predictive.

There are a number of very good reasons for studying the history of Mesopotamian astrology. Firstly, it offers a point of entry into understanding Mesopotamian culture. Then there is the question of the astronomical records, which were not only used by the ancient Greeks but are of relevance for modern science. The use of eclipse records to demonstrate that the slowing in the Earth's rotation is much greater than previously thought is ample demonstration of the value of such ancient observations (Stephenson, 1998). But there is also the vexed question of the connections between the endeavors of Babylonian astronomers and astrologers and their counterparts in the Greek world and the extent to which classical culture borrowed from the Mesopotamians. Such issues run to the heart of European respect for the Greeks as inventors of the western rational and scientific tradition and raise deep questions concerning European self-identity and ambivalent relationship between the Occident and Orient. At the broadest level then, we are not just examining the history of culture or science but also touching on issues which are as alive today as they ever were.

Babylonian astrology can be described as practical theology, its express function being to enhance dialogue with the gods. Bartel van der Waerden set out a seductively neat scheme in which the development of the first millennium BCE astronomy and astrology is related to a steady drift towards monotheism. He identified three main phases in which religion, astronomy, and astrology progressed together from the simple observational astronomy, stellar polytheism, and omen astrology of the beginning of the first millennium to the monotheistic religion, mathematical astronomy, and natal astrology of its end (1974, vol. II, pp. 127–128, 178). This is a point of view challenged by many historians of religion, and as applied to Mesopotamia, the supposed connections between astronomy and religion are roundly rejected by some scholars. At the very least, van der Waerden's generalizations provide a worthwhile interdisciplinary model for approaching developments in the history of astronomy.

Questions of Definition

The interlocking relationship between Mesopotamian astrology and astronomy has a particular relevance to contemporary debates on the nature of science and perceptions of its relationship with "superstition" or "rational" and "magical" thought. Indeed, no study of Mesopotamian astrology can begin until we have at least acknowledged such questions of definition (Bottéro, 1992, pp. 125–137). Modern comparisons may counter a natural tendency to see ancient cultures as being so inherently different to our own that they can never be approached. All we can do is remember that our descriptions of Mesopotamian thought can never entirely recapture its true nature.

Whereas modern definitions generally categorize astronomy, the observable measurement of the heavens, as scientific, and astrology, the interpretation of those measurements, as superstitious, the Mesopotamian experience suggests that those definitions are fluid and might even be reversed. For the sake of simplicity, I shall stick to modern usage, and I shall use astronomy when talking specifically about measurement of the heavens and astrology when discussing the interpretation of those measurements.

The final problem of definition concerns the alternative use of the terms Mesopotamian and the more common Babylonian. Mesopotamia is a geographical designation for much of the area is covered by modern Iraq. Between the mid-third millennium and the end of the first millennium BCE, the region passed through a series of political eras from the period of the city states of Sumer and Akkad through the Babylonian and Assyrian empires, a second Babylonian Empire, and finally the Persian and Greek Seleucid periods. Given that Babylon appears to have retained a special cultural status from around 1800 BCE onwards, the terms Babylonian and Mesopotamian are often used interchangeably to describe the astrology of the entire region (Koch-Westenholz, 1995).

Translation Issues

There are substantial source difficulties in this field, largely due to the sheer volume of primary source material which has either only recently become available or is yet to be translated. The difficulties involved in working out what the Mesopotamians actually thought, though, are genuinely problematic. Even slightly differing nuances between different translations can suggest entirely different conclusions. For example, one version of the moon's function in the creation epic – the Enuma Elish (V.13), "When Above" – is "to make known the days" (Heidel, 1942, pp. 44–45), while another is "to measure time" (Jacobsen et al., 1946, p. 181). The latter expands the use of the moon to announce the name or nature of the day to the notion that in the second millennium BCE, the Mesopotamians had a concept of time as a continuous entity which can be understood mathematically. Similarly, when Sachs (1952) translated the first known horoscopes for the birth of infants, dating back to 410 BCE, he converted Babylonian constellation names into Greek zodiac signs, creating the impression that the Greek zodiac was in use. All translations are therefore to be treated as provisional.

Divination and Science

In what sense was Babylonian astrology scientific? There is a clear argument that it was not, given that it did not fulfill one of the criteria of modern science, namely, verification of predictions through large samples in controlled conditions. The astrologers' success was measured in terms of one-off forecasts, a satisfactory means of measuring success at the time, if not for modern scientists. When the astrologers were wrong, it was seen as a result of human error, not a sign of the fallibility of the essential hypothesis that the stars were conveying messages from the gods. The statement that divination equals science may seem a strange one by modern standards, but not if the definition focuses on the logical procedures of prediction and ignores the surrounding belief system.

The fundamental process involved in all divination was one of circumstantial associations. In other words, if event *y* correlates with sign *x*, then when x next appears, y will happen. If we again remove the gods from the equation, then there is no direct link between *x* and *y*. That is, the "signs indicated events in a variety of ways, mostly by means of schematic symmetries, associations and analogy. The relationship between the sign (ittu) and its prediction (parassu) had no component of causation, nor necessity of any particular temporal relation, be it synchronistic or sequential" (Rochberg-Halton, 1998, p. 52). Although the gods caused both the omen and the succeeding event, there was no cause and effect relationship between the two. Thus, if Babylonian astrology was scientific, it was because it relied on a deductive methodology and logical inferences made on the basis of empirical observation, and emphatically not because it posited a set of physical relationships between stars and society.

Larsen argues that if the development of modern science has seen the replacing of "imaginary representations of "intentional" causes by the representation of unintentional and inevitable relationships" (1987, p. 208), then by removing the intentions of the gods from the equation, we are left with the inevitable relationship between the present omen and future event, between astronomical observation and political action. A relationship which is inevitable rather than intentional, so this argument runs, is scientific.

Babylonian astrology's scientific qualities are also said to be evident in its foundation in empirical observation, its mathematical rigor, and the value-free objective procedures which meant that there was no bias in the forecasts, which might imply criticism of the king's conduct as much as praise. Just as scientific method can be seen as a mode of inquiry, so astrology might be seen as language, yet one with a code which was written into the fabric of the universe. To this end, the Babylonians compiled lists of lexigraphical correspondences between stars, gods, mundane objects, terrestrial events, and geographical regions which are themselves identified as characteristic of astrology's scientific nature (Larsen, 1987).

The Origins of Astrology

In 1997, Carlos Jaschek (135–145) set out a standardized, speculative pattern for the development of astronomy, moving from the measurement of solar and lunar risings and settings to the identification of first individual stars and then planets, the creation of calendars (to facilitate political order), and the recognition that celestial movements are periodic, allowing the crucial transmission from an observational to theoretical astronomy. In this process, astrology occupies a crucial place between these last two stages, its requirement for correct forecasts eventually making it essential to predict future planetary positions.

However, we really have little idea of how complex divinatory practices evolved in Mesopotamia, although a number of explanations have been proposed. They may, for example, have "developed from a simple folk practice, capable of giving yes-no answers to specific questions, to a systematized science, covering nearly all observable phenomena and permitting detailed predictions of unanticipated events, as well as giving detailed answers to queries" (Koch-Westenholz, 1995, p. 14).

All accounts of astrology's origins are speculative and limited as they have by serious source problems and the tendency to apply modern theories in what might be an inappropriate manner. Could the development of astrology be the direct consequence of what we might call an "environmental theology"? From the title of Jacobsen's description of the Mesopotamian cosmos, "The Cosmos as a State" (1946), I have derived the term cosmic state (2009) to describe societies in which the earthly system is thought to be inseparable from the celestial. The Mesopotamian system was obviously autocratic in the sense that once a royal order had been given, only the astrologers could amend it. Actually, even though the king had the power to dismiss or punish astrologers who gave him poor advice, it is a debatable point as to who was the master: the astrologer who interpreted the divine will or the king who implemented it.

The reasons that one culture should develop a system of complex astrology and another should not may be found partly in environmental factors. One argument refers to distinctions between Egyptian culture, which developed a highly codified astral theology, and Mesopotamian, which made the leap from the use of the stars as religious objects to their application to forecasting and the precise management of the state. It is true that both cultures believed that the stars offered a means of communication between the divine and humanity and that they applied this knowledge to political management, but astrology is essentially an extrapolation from astral religion, distinguished by its interpretative complexity. According to (Jacobsen et al., 1946, pp. 126–127), the most obvious natural difference between the two cultures is found in Mesopotamia's existential insecurity: Mesopotamia had no natural boundaries and was surrounded by hostile enemies and the flooding of the rivers on which its agriculture depended was erratic. By contrast, according to Jacobsen, Egypt was well protected by desert, had few neighbors, and could rely totally on the Nile's annual flood. Such environmental factors fed directly into political cosmology and conduct. However, the proposition that the development of astrology was a direct response to collective insecurity has been challenged firstly on the general grounds that it represents the inappropriate projection of modern concerns onto an ancient society and, secondly, by the specific argument that the omen literature indicates a society which, far from being insecure, was very certain of its beliefs (Koch-Westenholz, 1995, pp. 17–18).

If the environment produces political forms, then politics, in turn, requires divination. Jacobsen found evidence in the idea of the divine assembly and in mythical claims that the divine pantheon took its decisions democratically, at least in part. In the Enuma Elish (VI.17-18), Marduk assembles the divine council and gives it its orders, yet his supremacy was not unqualified: destiny itself was determined by seven other gods (VI.81). This is a persuasive argument which gives us further insights into the motives behind divination. Not only was the city or temple assembly obliged to ascertain its divine counterpart's views before it could reach satisfactory solutions to the many mundane problems it had to consider, such as drainage and irrigation or disputes over field boundaries, but it also seems that decisions were reached by consensus. We can imagine situations in which extispicy or the casting of lots might have been the only way to break an impasse. Oppenheim (1977, p. 208) supports Jacobsen's view that divination emerged as a possible solution to the difficulties involved in political decision-making, pointing out that it might have had social functions. For example, he drew attention to the casting of lots to determine the division of an estate amongst the sons. A further development was the emergence of sacred kingship, an institution which took on different forms in each culture, whether in Egypt or Mesopotamia (Engnell, 1943; Frankfort, 1948). In Mesopotamia, the monarch was but a human servant of the gods, whereas the Egyptian pharaoh was himself divine. Babylon was built as the gods' sanctuary on earth and the city's heart was the Esagila, Marduk's temple and the residence of Ea and Enlil. The physical hierarchy of earth and heaven was therefore reflected in a political order in which the king was subordinate to the divine council, headed by Enlil, or to Marduk.

The king's greatest attribute, perhaps even more than military prowess, was the wisdom necessary to navigate his way through a world of omens, dreams, and oracles, to understand and heed the advice of the astrologers and to perform the correct action at the appropriate moment. Kingship was a sacred office (Engnell, 1943), and divination was no mere optional accessory; it was a central part of the political machinery.

Others have proposed religious reasons for the development of astrology. Leo Oppenheim has argued that third millennium BCE Sumerian religion was underpinned by an earlier near-eastern formulation which reveals the existence of "an age-old pre-deistic deterministic concept of life" (1964, pp. 203–204) which was conducive to astrology's development. This proposition is supported by astrologers' letters from the Assyrian period, in which there are frequent references to auspicious times to undertake rituals. The Mesopotamians' purpose was to describe the world. Having done that, divination allowed them to participate in its management through divination and, increasingly, astrology.

The Development of Astrology

The earliest examples of astrological practices have been traced to the third millennium, but the evidence is now challenged. In 1939, Jacobsen found evidence of the use of an eclipse in 2403 BCE (1939, pp. 203–204), but his account relies too heavily on the reconstruction of missing words in broken tablets and is now dismissed. There are a number of examples of astrological omens dated to the reigns (for which dates are uncertain) of Sargon of Akkad (ca. 2334–2279 BCE), Ibi-Sin (ca. 2028–2004 BCE), and Shulgi of Ur (ca. 2094–2047 BCE) (Weidner, 1928–1929, pp. 231, 236; Walker, 1982, p. 22). Although some scholars, such as David Pingree (1998, p. 125), regard these tablets as genuinely Sumerian, there is some skepticism about their precise origin, and it is thought that they may represent later accounts written as if they were omens from earlier times (Rochberg-Halton, 1988b, p. 7, n 32; Koch-Westenholz, 1995, p. 35). This is a fairly standard practice in prophetic literature, occurring notably and almost two millennia later in the Book of Daniel, which was written perhaps 300 years after the time in which it is supposedly set. A similar practice is found in extispicy, and there are references to liver omens relating to rebellion against Ibi-Sin apparently written 50 years after the event (Bottéro, 1987, p. 131). There is also the problem that some of the eclipses mentioned could not have occurred as claimed (Koch-Westenholz, 1995, p. 35). The skeptical argument holds that as the most substantial sources date from the Assyrian period, the eighth and seventh centuries, the evidence for astrology's importance in earlier periods is unconvincing.

We do know, however, that the Sumerians watched the sky, naming some of the constellations and planets, and that these played a role in their religion. For example, the goddess Nisaba, who may have been an antecedent of the god Nabu, who himself was associated with Mercury, was said to measure heaven and earth, to know the secrets of calculation and, together with Suen, the lunar deity, to "count the days." Her temple in the city of Eresh was called the e-mul-mul, the "House of Stars," and she was the owner of a lapis lazuli tablet which is known variously as the dub mul-an or dub mul-an ku, "the tablet with the stars of the heavens" or "the tablet with the stars of the pure heavens." Her associated functions as goddess of grain and as the expert on accounting and the fair management of resources hint at both the practical uses of astronomy and the benefits of a well-regulated calendar in maintaining social order.

A sophisticated astrology had developed by the reign of the Babylonian emperor Ammisaduqa, Hammurabi's great-great grandson, from the survival of the so-called Venus Tablet (Reiner and Pingree, 1975; Van der Waerden, 1974, vol. II, pp. 50–58). The tablet contains 59 omens based on the first and last visibilities of the Venus, each of which will occur twice in one of the planet's 584-day synodic cycles. The omens are grouped into 8-year cycles and have attracted attention partly on account of their use in the dating of Ammisaduqa's reign and hence the chronology of the old Babylonian Empire. Nothing could illustrate better the source problems afflicting Mesopotamian studies, at least before the first millennium: even when we have historical chronicles and astronomical records, it is still impossible to agree on a definitive date. The tablet tells us that by the middle of the second millennium BCE, consistent astronomical observations were being made for the express purpose of producing astrological omens, anticipating divine intentions, predicting the weather (and hence agricultural productivity), and preparing for possible political crises. The first omen, which is typical in the information it gives, set the tone:

> In month XI, 15th day, Venus in the west disappeared, 3 days in the sky it stayed away, and in month XI, 18th day, Venus in the east became visible: springs will open, Adad his rain, Ea his floods will bring, king to king messages of reconciliation will send. (Pingree and Reiner, 1975, p. 29)

This observation was made in late winter, following the full moon (the 15th) in the 11th month. The 3-day period represents the shortest possible time that Venus might be invisible, following its last appearance in the west as morning star and its reappearance in the east as evening star. The omen reveals information about Babylonian astronomy, astrology, and politics. Regarding astronomy, it was understood that Venus as morning and evening star was the same body. Second, although their records were based on continual observation, not on extrapolation into the future, it is clear that they did recognize the concept of planetary periods (Pingree, 1998, p. 126) – an understanding of regular planetary orbital periods – and hence that they either could not or did not feel the need to calculate future planetary positions. Moreover, given that the purpose of the omens was to correlate astronomical patterns with terrestrial events, the tablets have a historical function. The Venus Tablet provides a deeply practical rationale for astrology's apparent popularity: used exclusively by the kings, it provided the government with "the hope of stealing a march on fate and forestalling catastrophe by a timely recognition of divine intentions" (Frankfort, 1978, p. 255).

There are a number of other astrological tablets from the Old Babylonian period, including some eclipse omens, but following the Venus Tablet, the two most substantial sources are the Enuma Anu Enlil ("when the gods Anu and Enlil…"), a comprehensive compendium of astrological lore which includes material dating back to the Venus Tablet and the Mul Apin, the first great star catalogue, both of which are known from Assyrian tablets of the early first millennium BCE. However, there are suggestions that both may have been compiled in the second millennium, afar from controversial idea in view of the Enuma Anu Enlil's inclusion of the Venus Tablet. Thus, while the first three centuries of the first millennium offer us virtually no sources whatsoever, suggesting that either astrology and astronomy were ignored or that the records were destroyed or, if they survived, have yet to be discovered, there is circumstantial evidence of intense astrological and astronomical activity over the same period.

The full text of the Enuma Anu Enlil was excavated in the ruins of Ashurbanipal's library at the Assyrian capital, Nineveh. It consisted of around 6,500–7,000 omina grouped into some 70 tablets, of which 13 are now available in translation or transliteration (Reiner and Pingree, 1975, 1981; Rochberg-Halton, 1988b; Van Soldt, 1955; see also Baigent, 1994, pp. 67–75; Koch-Westonholtz, 1995, pp. 74–82). An indication of the prevailing astronomical priorities is revealed in a breakdown of the topics covered. Twenty-two tablets cover the moon, while a further 18 concern the sun. Of the remainder, five relate to Venus, perhaps four to Mars, two to Jupiter, three to thunder and lightning, and one to the Pleiades. The absence of specialized tablets for Mercury and Saturn indicates the lack of attention paid to the planets as opposed to solar and lunar phenomena. The small proportion of material on, or attention paid to, Jupiter is most mysterious in view of the fact that Marduk, the planet's god, was Babylon's presiding deity.

The Mul Apin is usually described as an astronomical compendium, but it clearly served an astrological function (Hunger & Pingree, 1989). The extant tablets date from the eighth century, although may either have been compiled by 1000 BCE or be based on observations as far as back as 1350 BCE. The date of its compilation, though, is less important than the fact that, with the Enuma Anu Enlil, it indicates that scholars of the Assyrian Empire were deeply concerned with the mapping and naming of the heavens. This may be why they began to keep comprehensive records of lunar eclipses, beginning on February 6, 747 BCE, in the reign of Nabonassar.

The dramatic reassertion of Assyrian power under Tiglath-Pileser III (745–728 BCE) marks astrology's reappearance on the public stage. The evidence for this lies in the remarkable increase in extant astrological texts, but the reasons are far from clear. Sargon II (721–705 BCE) was perhaps the first of the new line of Assyrian monarchs to take an astrologer on his military campaigns, and an inscription from a tablet in the Louvre recording his attack on Musasir suggests that the timing of his invasion may have been arranged by reference to astronomical factors (Koch-Westenholz, 1995, p. 153).

Astrology was essentially a means of communication, similar to prayer in that it was conducted with a divine partner, yet in that it utilized the technology of planetary observation and measurement, its function might be comparable to that of modern information technology. Certainly its perceived advantages were similar, and the observation of Jupiter's movements prior to Sargon's campaign offered intelligence of a similar character to that provided by modern satellites in preparing for military action: modern technology reveals the disposition of enemy forces, while the location of the stars also indicated the strength of Sargon's opponents.

Sargon's lessons were not lost on his successors, Sennacherib (704–681), Esarhaddon (680–669), and Ashurbanipal (668–627). These kings maintained astrologers across the empire that effectively formed a civil service, sending reports and letters to the emperor and offering the best possible advice on the basis of their observations (Oppenheim, 1969). These paint a portrait of a society in which the scribes maintained their personal relationships with each other and with the king, offering sometimes contradictory advice on astronomical observations and astrological predictions, finding excuses for their mistakes, and claiming due credit for their successes (Baigent, 1994, pp. 50–57).

The astrologers' communications reveal an astronomy which was still based on daily records, with the result that no stellar observations could be made or omens taken in inclement weather – except for meteorological ones. It was precisely those elements in astronomy which were unpredictable which preoccupied the Babylonians, for if the cycles of the sun, the moon, and the seasons represented the endlessly repeating rhythms of fate, rich variety in natural and celestial phenomena offered a chance to negotiate with fate by opening a dialogue with the gods. Thus, astronomy was directed to goals which were theological and political rather than scientific in the modern sense of examining celestial phenomena for their own sake.

Great emphasis was placed on other meteorologically induced phenomena, such as the presence of haloes around the stars and planets, as well as their color or brightness, all of which were unpredictable. Neither was astrology absolutely distinct from other forms of divination, as Sargon II's inscription makes clear. The sun's main role was as representative of the oracle god, Shamash.

Having made their observations, the astrologers' first task was to communicate their findings to the king and offer whatever advice they felt necessary. This might be no more than to stay in the palace (SAA: 320). The king was also required to pray, offer sacrifices, and perform rituals, each of which might have its own auspicious time. When there was no other solution to a threatening omen, a substitute king was appointed (Bottéro, 1992, pp. 138–155). A letter from the astrologer Mar Istar suggested that a substitute be allowed to sit on the throne for 100 days before meeting his fate, a euphemism for death (LAS: 292).

The astrological reports are couched in more formal terms than the letters and tend to concentrate on prediction rather than advice. The information they contain makes no explicit distinction between planets, stars, and other celestial matters, "If the Pleiades enter the moon and come out to the north: Akkad will become happy; the king of Akkad will become strong and have no rival" (SAA: 443), "If Adad (the storm god) thunders in Tishri (month 7); there will be hostility in the land" (SAA: 444), and "If Jupiter passes to the right of Venus: a strong one will conquer the land of the Guti in battle" (SAA: 448).

Political demands heightened the need for accuracy of forecasting and observation and resulted in a renewed attempt to perfect astrology's predictive powers. A further innovation was taken in the mid-seventh century with the production of the so-called Astronomical Diaries, compiled almost continuously for over 600 years, beginning in 652–647 BCE (Sachs & Hunger, 1998–1999). The Diaries are records of astronomical, meteorological, and political events, presumably as a means of establishing common patterns. They represent a fresh determination in the ongoing attempt to create an empirically based astrology, in which both planetary phenomena and their relationship to political and economic matters might be properly understood.

It may be that it was the success of the Assyrian regime which encouraged the Diaries' compilation, in an attempt to further improve the state's evidently beneficial relationship with celestial matters. It may equally be the case that the empire's collapse in 626 BCE, shortly after their collation began, concentrated the astrologers' minds on the maintenance of stability and the need to perfect astrology's ability to predict and avert political crises: the relationship between intellectual endeavor and political change is a complex one. The bulk of extant astrological reports cease about 30 years before the fall of Assyria, and while there might be later examples, we lack the ability to date them with any certainty. Most importantly, the period from the eighth to fifth centuries witnessed a scientific revolution: first the creation of mathematical models for the calculation of planetary positions in advance and, secondly, the development of horoscopic astrology, consisting of planetary omens based on the date of birth and the invention of astrological techniques which did not require direct observation.

That cultural revolution occurred under the Assyrian Neo-Babylonian and Persian monarchies is not questioned. But what is not fully understood is its nature, partly because it involved dramatic changes in both astronomy and astrology, paralleled by profound religious developments in the form of the introduction of Zoroastrianism.

The Ritual Calendar

Astronomy possessed one great function, the improvement and eventual perfection of astrology's role in managing the state. An essential component of political management was the regulation of the calendar. Tablet VI of the Enuma Elish describes how Marduk ordered the moon to mark out its synodic period, with a hint (the tablets are broken) that its crucial phases signified the moments when he (Marduk) communicated destiny to the watching astrologers and that these were thus important moments for divination.

Each month began with the rising of the crescent moon, the new moon's first appearance after the spring equinox marked the beginning of the first month, Nisan. The problem, though, was the need to keep the lunar months in some sort of relationship with the solar year, and this necessitated the insertion of intercalary months. The "Diviners Manual," dating from the early first millennium (Oppenheim, 1974), gave the rules for intercalation, although the sheer variety of calendars used in the third millennium and the fact that in the Old Babylonian period 2 or 3 years in a row might contain intercalary months, suggest that there was no single set of recognized systems. It must be possible that divination (perhaps including extispicy) played as much a role in the selection of years for intercalation as did astronomy, and the purpose may have been to shift the average beginning of the year. In addition, kings in the Old Babylonian period often added intercalary months at the beginning of their reigns.

The fear that astronomical phenomena might occur on the wrong day is demonstrated vividly in the astrological reports. The Assyrian astrologer Balasœ advised the king that if the new moon occurs on the first or the full moon is seen on the 14th, then "the land will become happy," but if the full moon took place on the 12th, then "business will diminish. . .a strong enemy will oppress the land," and even though "the king of Akkad (i.e., Assyria) will bring about the downfall of his enemy," the prognosis is "bad for Akkad. . .good for Elam and the Westland (Amurru)," in other words, favorable for Babylon's hostile neighbors (SAA: 87–89).

We also have examples of Marduk's own planet, Jupiter, breaching its order by remaining visible for 5 days longer than expected. The astrologer Mar-Ishtar reported that it appeared on the sixth Simanu (month 3), close to Orion and in the way of Anu and that each of these three factors carried its own warning in the Enuma Anu Enlil. However, the planet then remained visible for another 4 days, an omen so bad that no ritual could appease divine wrath, and all communication with heavens was broken off.

The Planets

Even though the Mesopotamians identified dozens of different deities, and acknowledged the existence of hundreds of others who were not even given names, one god was not necessarily entirely separate to another. Thus, Enlil, the originator of earthly kingship, played a role which tended to merge with that of Marduk, the supreme king, who was himself venerated as the "Enlil of the gods" (Parpola, 1997, p. LXXIV) or described in terms usually reserved for solar deities.

There is evidence that the planets themselves were seen as divine (Koch-Westenholz, 1995, pp. 120–121), but the consensus amongst Assyriologists is generally that the planets were not themselves divine but were objects manipulated by the gods as agents or expressions of their divinity. There was not necessarily a one-to-one correlation between individual deities and planets. Ninurta was normally the god associated with Saturn, but in the Mul Apin (II.i,5) we read about "Mercury whose name is Ninurta." This blurring of identities is of considerable significance for astrology, in which the relationship between gods and planets was similarly flexible.

The astrology of the Enuma Anu Enlil and the Mul Apin tends to make little distinction in terms of astrological significance between the planets and the brightest stars, such as Sirius, or the most prominent constellations, such as Orion or Ursa Major. However, the planets were obviously distinguished by their erratic movements and were known in Sumerian as the udu.idim.mes or wild sheep (Akkadian bibbu). Time and space were interdependent in the Babylonian cosmos, and the crucial considerations in a planetary observation were its position, which indicated the terrestrial region at which the omen was directed and the nature of the predicted event (e.g., being in Scorpio could mean an attack by scorpions), and time (either of night or month), which might indicate the location of the event. In addition, there was the question of whether the phenomena were on time (favorable) or early or late (unfavorable).

Attention was paid to a planet's color and brightness, and careful observations were made of acronychal rising (the last visible rising in the evening after sunset), heliacal rising (first visible appearance on the eastern horizon before sunrise) and heliacal setting (the last visible setting after sunset). The birth charts began to include lunar and planetary latitude as well as zodiacal position.

In the Mul Apin (II.i,1-6), the sun and the five planets are classed as the six gods who travel in the path of the moon. Each planet possessed a range of associations with deities, colors, and times of year and with each other. They indicate the presence in Babylonian astrology of one of the central features of classical and medieval astrology: a web of relationships between planets and zodiac signs without which it would often have been impossible to reach a firm conclusion or offer definite advice.

The Sun

The sun was known in Sumerian as Utu and in Akkadian as Shamash; its bit nisirti (treasure) was the Hired Man (Aries) and in the Mul Apin its corresponding calendric event was the spring equinox. Utu and Shamash are also the names of the solar deities, but the two words could mean either the visible body or the hidden power within it, i.e., the god. Shamshu was also used for the solar body.

Nineteen of the tablets in the Enuma Anu Enlil were devoted wholly or partially to the sun, mainly to its rising or eclipses, but its invisibility at night imposed a clear restriction on its astrological use, for, however, many omens were devoted to its color or relationship with clouds, as soon as it appeared the stars vanished. However, as a god of justice Shamash became the god to whom oracles were addressed, presiding over the art and science of divination from entrails.

The Moon

The Sumerian moon god was known as Nanna or Suen, a name later contracted to Sin, by which the moon is generally known in the cuneiform texts. Nanna, it is thought, may refer specifically to the full moon and Suen to the crescent moon, while there also appears to be a third name, Asimbabbar, the new light. Nanna was the presiding god of the third dynasty Ur, and when the moon was invisible Nanna was believed to have gone to the netherworld to judge the dead, along with Utu, and special offerings were made. Fourteen tablets in the Enuma Anu Enlil were devoted to the moon's appearance and a further eight to lunar eclipses, which were thought to represent a demonic attack on Nanna. Nanna travelled the heavens in a boat and had associations with bulls and cowherds. His bit nisirti was Mul Mul, "the Stars," or Pleiades. Aside from the Enuma Anu Enlil, about half of the astrological reports deal with lunar phenomena. The reasons are obvious; for the moon is the second brightest celestial object after the sun, it possesses the fastest and most dramatic cycle, moving rapidly from one phase to another and, unlike the sun, can be tracked at night and hence form relationships with the stars, visibly passing through constellations.

Saturn

The planet Saturn is sometimes referred to as Ninurta in the texts, but also as udu.idim.sag.us (Akkadian kajamanu) meaning "the steady" or "the stable planet." Saturn has no single tablet dedicated to it in the Enuma Anu Enlil, and only 25 mentions in the reports published by Hunger, in spite of the fact that Ninurta was the son of Enlil and god of the thunderstorm, the spring flood, and the plow. Indeed the name may mean "Lord Plough." The god had an earlier form as Imdugud (the hailstone) and was also commonly known as Ningirsu (perhaps indicating the flood waters). He also had a military role as the "thunder" of the war chariot. The planet was also known as Mul Utu, the star of the Sun, a connection which may derive from a shared concern with justice and may be evident in the fact that Saturn's bit nisirti was in Zibanitu (Greek Libra), opposite the Sun's in Aries.

Jupiter

It might be thought that Jupiter, as the planet sacred to Marduk, would have more omens devoted to it than any other planet, and the fact that it does not tell us that astrology was not simply a direct projection of theology on to the stars. It was not thought necessary to devote a large number of omens to the chief god, who merited less attention in the literature than the moon or Venus. The planet Jupiter was given various names. It was known as sagmegar ("the bearer of signs to the inhabited world") when it was in the eastern sky, sulpaea ("lord of the bright rising") at its heliacal rising, nibiru ("crossing") when culminating at the meridian, muludaltar ("the heroic one"), mul.babbar ("the white star"), Bel ("Lord"), or just simply Marduk. Jupiter might signify the moon in what might have been an imitation of Saturn's relationship with the sun, and although its proximity to the moon was in general a bad omen, its presence during a lunar eclipse cancelled the evil omen. Together with Shamash, Jupiter was "Lord of the secrets of Akkad," and its brightness was therefore good for the king and the state. It was associated with the summer solstice in the Mul Apin and its bit nisirti was the crab.

Mars

Mars invariably sent evil omens, being associated with Nergal, a god of the underworld, forest fires, fever, plague, and war. When the planet was not known directly as Nergal, it was called sanumma (different, i.e., hostile), nakru (enemy), sarru (liar), lemnu (evil), ahu (strange), or sa (red). In the Mul Apin, it is referred to as Salbatanu, a name which may mean "the incalculable star" or "constantly portending pestilence." Mars' malefic tendencies were heightened when it was bright and diminished when it was faint, and when it was at its reddest, it might signify prosperity but also an epidemic of plague. Its bit nisirti was the goatfish, and in the Mul Apin it was linked to the winter solstice.

Venus

Venus was the subject of one of the first extant body of omens, and its goddess, the Sumerian Inanna (Akkadian Ishtar), was the most important single female deity, on a par with Sin and Shamash, with whom she forms a trinity, and even with Ea and Enlil. Her worship extended throughout the near east, and in Syria she was known as Astarte (Heimpel, 1982). In the texts the planet is usually known as Dilbat or Delebat, "the brightest star," or Ishtar. Although Venus was invariably female, there was a Semitic male version of Ishtar, and sometimes the morning star was considered to be male (and malefic). In other traditions, it was the evening star that was male. However, this bisexuality does not appear in the extant omen literature, and Venus' mere appearance was often considered to be benefic. Venus' bit nisirti was Anunitu (Pisces), and the planet was seen as the precursor of spring.

Mercury

Mercury was known as gu.ud (Akkadian sihtu), "the jumping one," and in the Mul Apin is consistently linked with Ninurta, the god normally connected with Saturn. Mercury is more usually identified as the planet of Nabu, the son of Mercury, and is therefore connected to the crown prince. Thus, if Mercury approaches Regulus (mul-lugal, the "king-star"), this warns of an attempt by the heir to seize the throne (SAA: 245). While Mercury's appearance warned of rain and flood, Nabu himself was the scribe of the gods. In this role, he wrote the destinies, announcing divine intentions to the diviners and astrologers, and thus joined Ea and Marduk as a god of wisdom. Mercury's bit nisirti was Ab.sin (Virgo), and in the Mul Apin the planet was regarded as the precursor of autumn.

The Development of the Zodiac

The mathematical methods used by the Mesopotamian astronomers are well documented (Neugebauer, 1975, vol. II; Van der Waerden, 1974). The three principal priorities of the second millennium astronomy were fairly straightforward: to record the rising and setting of stars and planets and to quantify and calculate such phenomena as the length of lunar visibility in the beginning, middle, and end of the month and the length of day through the year. It is the development of the zodiac, though, without which classical and medieval astrology would never have existed in any recognizable form, which is of most immediate interest for the history of astrology. Mesopotamian astronomy's enduring contribution to late astrology is undoubtedly the creation of the 12 signs of the zodiac, the equal-sized divisions of the ecliptic which are the most familiar feature of modern popular astrology. The first step to their formation was the creation of the constellations.

All theories concerning the reasons for the creation of constellations are essentially speculative. The creation of calendars for agricultural purposes or the use of the heavens for navigation requires only the recognition of single bright stars, not the fabrication of unlikely images such as the Aquarian water pourer. The creatures identified in the sky are, perhaps, more likely to be the consequence of mythical and religious projections, and we may assume that the constellations' creation was initiated at whatever time human beings began observing the heavens, worshipping the stars, keeping a rough calendar, creating art, or all four. Gurshtein (1993, 1998) controversially gives a date of around 14000 BCE for the beginning of this process and argues that the naming of important constellations was related to precession of the equinoxes and the sun's shift in relation to the stars. Owen Gingerich (1984, pp. 219–220) lent his authority to the possibility that some of the constellations, notably the Great Bear, may date from the last Ice Age. Rogers (1998) speculates that in the Mesopotamian period, one set of constellations had religious origins, another agricultural applications. Such speculation aside, serious questions have been raised concerning the antiquity of the Greek and therefore the Babylonian zodiac, by Zhitomirsky (1999), who dates it to c. 2000 BCE =/−300 years.

Individual fixed stars offer a natural frame of reference for locating planetary position, and it appears that by the Old Babylonian period, a system had been established which grouped stars according to the calendar. Three groups of 12 stars were arranged in three "paths" (translated as "bands" below) across the sky, related to the three creator gods, Anu, Ea, and Enlil (Mul Apin: Gap A 1–7, Hunger & Pingree, 1989, pp. 88–89; Koch-Westenholz, 1995, pp. 24–25). The lists of the 36 stars which are divided between the three ways are preserved in three copies known to Assyriologists as "astrolabes" but to the ancient scribes themselves as the "three stars each" (Van der Waerden, 1949).

The evolution of the 36 stars was accompanied by a parallel development, the differentiation of the 18 constellations "which stood in the path of the moon," the first known attempt to relate a sequence of constellations to a planet. The full list of these is given in the Mul Apin (I.iv, pp. 33–39, Hunger & Pingree, 1989, pp. 68–69):

- Mul.Mul The Stars (i.e., the Pleiades)
- Mul GALENA The Bull of heaven (Taurus)
- Mul SIPA.ZI.AN.NA The True Shepherd of Anu (Orion)
- Mul SU.GI The Old Man (Perseus)
- Mul GAM The Crook (Auriga)
- Mul MAS.TAB.BAGAL.GAL The Great Twins (Gemini)
- Mul AL.LUL The Crab (Cancer)
- Mul UR.GU.LA The Lion (Leo)
- Mul AB.SIN The Furrow (Virgo)
- Mul Zi-ba-ni-tu The Scales (Libra)
- Mul GIR.TAB The Scorpion (Scorpio)
- Mul Pa-bil-sag The god Pabilsag (Sagittarius)
- Mul SUHUR.MAS The Goat-Fish (Capricorn)
- Mul GU-LA The Great One (Aquarius)
- Mul KUN mes The Tails (Pisces)
- Mul SIM.MAH The Swallow (SW Pisces)
- Mul A-nu-ni-tu The goddess Anunitu Mul HUN-GA The Hired Man (Aries)

This list seems to be a clear attempt to formulate a lunar zodiac based on visible constellations. However, it clearly represents a stage towards the formulation of a solar zodiac, and most of the future zodiac signs are identified.

The process by which the establishment of a constellational lunar zodiac and the attribution of astrological meaning to stars or groups of stars led to the creation of the 12-sign zodiac is not clear. Clearly planetary meanings depended partly on their position in relation to the stars, and the Enuma Anu Enlil contains omens such as "If Mars approaches the Scorpion: there will be a breach in the palace of the prince" (50.111.8a, Reiner & Pingree, 1981, p. 41). However, we cannot be sure whether the crucial factor here was Mars' position in the sky or whether the constellation Scorpio was thought to contain meaning. The astrological letters and reports contain similar observations, referring to stars as well as constellations, suggesting that in the eighth century, there was still no neat and all-encompassing division of the sky into distinct regions.

Our earliest evidence for the existence of the zodiac occurs on a lunar tablet dated to 475 BCE, and a tablet of 419 BCE gives the positions of planets in the signs, almost certainly as an aid to drawing up birth charts (Van der Waerden, 1952–1953; Koch Westonholtz, 1994, p. 174). The development of the zodiac required the production of another form of astronomical document, the Almanacs, which survive for the years between 262 BCE and 75 CE (Sachs, 1948, pp. 279–280; Rochberg, 1993, p. 41).

Van der Waerden speculates that the formulation of 12 signs of 30° each was a projection onto the sky of the 12 months and 360 days of the year. In the Enuma Elish (II, 27–32), Tiamat creates 11 creatures to fight with her, including a few who share identities with constellations, including "the great lion, the mad dog, and the Scorpion-man."

The equal-sized signs of the Mesopotamian zodiac were defined by relation to the stars, and lunar tables in the fourth to second centuries BCE indicate that the vernal equinox took place at 8° or 10° Aries, as measured from the vernal point. The zodiac signs evolved as a system of measurement, but were also assigned astrological meanings. Indeed they have been described as "mighty powers" (Van der Waerden, 1952–1953, p. 224). An additional advantage, though, was to be the ability to tabulate planetary positions in terms of zodiac degrees. The 12 signs did not replace the three ways or constellations but could be used alongside them. Thus, a tablet of 164 BCE records that Halley's comet had been "seen in the east in the path of Anu in the area of Pleiades and Taurus, to the west…and passed along in the path of Ea" (Stephenson & Walker, 1985, p. 24).

The attention paid to the variable timing of new and full moons gives us an insight into the mind of the Assyrian astronomers. They knew that there was an inevitability about both the moon's synodic cycle, for without it they would not have had the month, and the sun's annual rhythm, for without that there would have been no years. Yet they clearly believed that it was possible for the gods to manipulate the moon's synodic period within certain limits. This might suggest that there was an awareness that the universe operated within mathematical limits and that the gods and goddesses themselves were subject to the same destinies as was humanity.

A study of planetary measurements in horoscopes (Rochberg-Halton, 1998) suggests the possibility of continuing theological motivation, for planetary synodic periods were recorded only when the planet occupied the same sign as the sun. This might have been because such information told the astrologer whether the planet was visible or not, but there might also be a trace here of the sun's growing religious significance. However, even if religious considerations did remain high, increasing levels of observational accuracy were required to provide for astrology's increasing demands in the Persian period, such as the dedekatemoria (see below), divisions of the zodiac signs by 12.

The Development of Birth Charts

According to Jacobsen (1976, p. 108), it was believed in the second millennium BCE that the "time of the shaping of the child in its mother's womb is one during which it is susceptible to both good and bad influences and so is the moment of birth; an incautious word then may saddle the child with any manner of unpropitious fate." Given that astrology relied on signs rather than influences, one would still have thought that the diviners present at birth would have been listening keenly to the gods' and goddesses' words expressed through the stars. However, the use of astrological indications based on the date of birth is a relatively late development, and the earliest known examples date to 410 BCE.

It may be that the birth chart was less an entirely new form of astrology than a variant form of divination, one created from the combination of the celestial omens of the Enuma Anu Enlil and the large corpus of birth omina (Rochberg-Halton, 1989, p. 110). Such omens, normally taken from abnormal or "monstrous" births, mainly of animals, can be dated back to the second millennium BCE and were collected in the Summa Izbu (Jastrow, 1914; Leichty, 1970). Some birth omina might include references to the date of birth and probable destiny. There was also, within the near east, a tradition of birth rituals.

The first cuneiform birth chart was discovered in the late nineteenth century and published in 1888. When Sachs published his collection in 1952, there were just six known cuneiform birth charts. By 1989, the total had risen to just 32. This must represent a fraction of the charts cast in the Persian and Seleucid eras. The development of birth charts placed fresh requirements on the astronomers, for while astrology had always been based on the observation of nocturnal messages from the gods and had ignored phenomena which could not be seen, children had a habit of being born during daylight hours. Sachs (1952, p. 52) speculates that there may therefore have been a halfway stage in which prediction of individual destiny was based on various combinations of visible and invisible planets at birth.

We do know, though, that the earliest surviving birth chart to include an interpretation was cast for a nameless child, apparently born on April 29, 410 BCE (Sachs, 1952, pp. 54–57). The text gives the date; the names of the child's father and grandfather, Shuma-usur and Shumma-iddina; the relevant astronomical details; and just one surviving line of astrological interpretation which Sachs reconstructs as "(Things?) will(?) be good before you." The rest of the tablet is missing apart from two lines which read "Month Du'uz, year 12. . .[ye]ar(?) 8. . .," suggesting that forecasts for specific dates might have been included.

We can draw various conclusions from this chart, concerning both the history of astrology and the broader cultural context. It is instructive, for example, that Mercury was not given a zodiac sign position, for its proximity to the sun rendered it invisible, suggesting that it was not taken into consideration. The development of the birth chart opened the door to the full development of Greek horoscopic astrology and the belief that accurate astrological investigation must be based on exact timing. The path was set for the development of the highly detailed technical procedures which have survived largely intact in Indian astrology, were adhered to strictly by medieval astrologers, and still form the basis of modern western astrology. If astronomy's increasing accuracy had provoked a seventh-century crisis in astrology, then it is clear that in the fifth century, it had been restored and reformed (Van der Waerden, 1974, p. 128). The new astronomy, which calculated planetary positions for decades ahead, may have been both motivated by the new developments in astrology and made them possible. As to which came first, we cannot say. But new studies suggest that the priests, the astronomers, and the astrologers were usually the same people (Rochberg, 1993; Parpola, 1993), implying that the intimate relationship between theology, divination, and science was as strong as ever. Here we have a picture of theology encouraging the development of scientific astronomy rather than inhibiting it.

The development of the birth chart represented a move away from an astrology which was structured by direct astronomical observation to one directed by worldly mundane concerns. That is, rather than waiting for a celestial omen to interpret, and having nothing to say if it did not appear, the astrologers were now obliged to construct omens for terrestrial events over which they had no control. Simple observation was no longer enough. The logic of the new astrology required that planetary positions should be plotted whether they were visible or not.

Decline and Transmission

Following Alexander's conquest of Babylon 311 BCE, the work of the astrological scribes in the temples continued, but by the second century, astrology's creative hub had moved to Egypt where the fusion of Egyptian religion, Greek philosophy, and Babylonian astrology and astronomy gave rise to the complex technical astrology of the classical world. However, there is evidence that a visual astrology based on the observation of celestial deities survived to the late classical world (Campion, 2005), while certain features of Babylonian astrology are still evident in modern western astrology (Campion, 2012).

References

Aaboe, A. (1980). Observation and theory in Babylonian astronomy. *Centaurus, 24*(1), 14–35.

Albrektson, B. (1967). *History and the gods: An essay on the idea of historical events as divine manifestations in the ancient near east and in Israel*. Lund: C.W.K. Gleerup.

Baigent, M. (1994). *From the omens of Babylon: Astrology and ancient Mesopotamia*. London: Penguin.

Beckman, G. (1978). *Hittite birth rituals*. Malibu: Undena Publications.

Black, J., & Green, A. (1992). *Gods, demons and symbols of ancient Mesopotamia: An illustrated dictionary*. London: British Museum Press.

Bottéro, J. (1992). *Mesopotamia: Writing, reasoning and the gods*. Chicago: University of Chicago Press.

Britton, J. P. (1993). Scientific astronomy in pre-seleucid Babylon. In H. D. Galter (Ed.), *Die Rolle der Astronomie in den Kulturen Mesopotamiens, Grazer*

Morganländische Studien (3rd ed., pp. 61–76). Graz: RM-Druck- and Verlagsgesellchaft m.b.H.
Brown, D. (2000a). *Mesopotamian planetary astronomy-astrology*. Groningen: Styx Publications.
Brown, D. (2000b). The cuneiform conception of celestial space and time. *Cambridge Archaeological Journal, 10*, 103–121.
Campbell, J. (1962). *The masks of God: Oriental mythology*. New York: Viking.
Campion, N. (2005). The possible survival of Babylonian astrology in the fifth century CE: A discussion of historical sources. In G. Oestmann, H. K. von Stuckrad, & D. Rutkin (Eds.), *Horoscopes and public spheres: Essays on the history of astrology* (pp. 69–92). Berlin/New York: Walter de Gruyter.
Campion, N. (2009). *A history of western astrology* (Vol. 1). London: Continuum.
Campion, N. (2012). More on the transmission of the Babylonian zodiac to Greece. *ARAM Periodical, 24*(2), 193–201.
Chadwick, R. (1989). Comets and meteors in the last Assyrian empire. In A. F. Aveni (Ed.), *World archaeoastronomy* (pp. 186–194). Cambridge: Cambridge University Press.
Dalley, S. (Ed.). (1998). *The legacy of Mesopotamia*. Oxford: Clarendon.
Engnell, I. (1943). *Studies in divine kingship in the ancient near east*. Uppsala: Almquist and Wiksells Boktryckeri.
Finkelstein, J. (1981). *The Ox that gored* (Vol. 71, part 2). Philadelphia: Transactions of the American Philosophical Society.
Frankfort, H. (1939). *Cylinder seals: A documentary essay on the art and religion of the ancient near east*. London: Macmillan.
Frankfort, H. (1978). *Kingship and the Gods: A study of near eastern religion as the integration of society and nature*. Chicago: University of Chicago Press (1st ed. 1948).
Frankfort, H., Frankfort, H. A., Irwin, W. A., Jacobsen, T., & Wilson, J. A. (1946). *The intellectual adventure of ancient man: An essay on speculative thought in the ancient near east*. Chicago: University of Chicago Press.
Gadd, C. J. (1945). *Ideas of divine rule in the ancient east*. Munich: Schweich Lectures of the British Academy Kraus Reprint 1980.
Gadd, C. J. (1967). Omens expressed in numbers. *Journal of Cuneiform Studies, 21*. Special volume honouring Albrecht Goetze.
Galter, H. D. (Ed.). (1993). *Die Rolle der Astronomie in den Kulturen Mesopotamiens* (Vol. 3). Graz: Grazer Morganländische Studien.
Gingerich, O. (1984). The origin of the zodiac. *Sky and Telescope*, *67*, 218–220. Reprinted in Owen, G. (1992). *The great Copernicus chase* (pp. 7–12). Cambridge, MA: Sky Publishing.
Gingerich, O. (1989). Reflections on the role of archaeoastronomy in the history of astronomy. In A. F. Aveni (Ed.), *World archaeoastronomy* (pp. 4–44). Cambridge: Cambridge University Press.
Grayson, A. K. (1969). The creation epic-additions to tablets V–VII in Pritchard. In B. James (Ed.), *Ancient near eastern texts relating to the old testament* (pp. 501–503). Princeton: Princeton University Press.
Grayson, A. K. (1975a). *Babylonian historical-literary texts*. Toronto: University of Toronto Press.
Grayson, A. K. (1975b). *Assyrian and Babylonian chronicles*. Locust Valley/New York: J.J. Augustin.
Grayson, A. K. (1980). Histories and historians of the ancient near east: Assyria and Babylonia. *Orientalia, 49*, 140–194.
Greenfield, J. C., & Sokoloff, M. (1989). Astrological and related omen texts in Jewish Palestinian Aramaic. *Journal of Near Eastern Studies, 48*(3), 201–214.
Gurshtein, A. A. (1993). On the origin of the zodiac constellations. *Vistas in Astronomy, 36*(2), 171–190.
Gurshtein, A. A. (1997). The evolution of the zodiac in the context of ancient oriental history. *Vistas in Astronomy, 41*(4), 507–525.
Heidel, A. (1942). *The Babylonian genesis*. Chicago: University of Chicago Press.
Heimpel, W. (1982). *A catalogue of near eastern venus deities*. Malibi: Undena Publications, Monographic Journals of the Near East, 4/3.
Horowitz, W. (1993). Mesopotamian accounts of creation. In N. Hetherington (Ed.), *Encyclopaedia of cosmology* (pp. 387–397). New York: Garland Publishing.
Horowitz, W. (1998). *Mesopotamian cosmic geography*. Winona Lake/Indiana: Einsenbrains.
Hunger, H. (1992). *Astrological reports to Assyrian kings*. Helsinki: Helsinki University Press.
Hunger, H., & Pingree, D. (1989). Mul Apin: An astronomical compendium in cuneiform. *Archiv für Orientforschung, 24*, 1–163.
Jacobsen, T. (1939). *The Sumerian king list* (Assyriological studies, Vol. 11). Chicago: Oriental Institute of the University of Chicago.
Jacobsen, T. (1943). Primitive democracy in ancient Mesoptamia. *Journal of Near Eastern Studies, II*, 159–172.
Jacobsen, T. (1976). *The treasures of darkness: A history of Mesopotamian religion*. New Haven: Yale University Press.
Jacobsen, T., Frankfort, H., William, H. A., Irwin, A., Jacobsen, T., & Wilson, J. A. (1946). *The intellectual adventure of ancient man: An essay on speculative thought in the ancient near east* (pp. 125–184). Chicago: University of Chicago Press.
Jastrow, M. (1910). Astrology. In *Encyclopaedia Britannica* (Vol. 1, pp. 795–800). Cambridge: Cambridge University Press.
Jastrow, M. (1914). *Babylonian-Assyrian birth omens and their cultural significance. Religionsgeschichtliche Versuce und Vorarbeiten XIV, Band. 5. Heft*. Giessen: Verlag von Alfred Toepelmann (vormals J. Ricker).

Jones, A. (1977). Babylonian astronomy and its legacy. *Bulletin of the Canadian Society for Mesopotamian Studies, Quebec, 32*, 11–17.

Jones, A. (1993). Evidence for Babylonian arithmetical schemes in Greek astronomy. In H. D. Galter (Ed.), *Die Rolle der Astronomie in den Kulturen Mesopotamiens* (Grazer Morganländische Studien, Vol. 3, pp. 77–94). Graz: RM-Druck-& Verlagsgesellchaft m.b.H.

Jones, A. (1996). On Babylonian astronomy and its Greek metamorphoses. In F. Jamil Ragep & S. P. Ragep (Eds.), *Tradition, transmission, transformation* (pp. 139–155). Leiden: E.J. Brill.

Koch-Westenholz, U. (1995). *Mesopotamian astrology: An introduction to Babylonian and Assyrian celestial divination* (Carsten Niebuhr institute of near eastern studies). Copenhagen: Museum Tusculunum Press/ University of Copenhagen.

Kramer, S. N. (1943). Man's golden age: A Sumerian parallel to genesis XI.1. *Journal of the American Oriental Society, LXIII*, 191–194.

Kramer, S. N. (1956). *From the tablets of Sumer, Indian hills*. Colorado: Falcon's Wing Press.

Kramer, S. N. (1961). Mythology of Sumer and Akkad. In S. N. Kramer (Ed.), *Mythologies of the ancient world*. Garden City, NY: Falcon's Wing Press.

Kramer, S. N. (1963). *The Sumerians, their history, culture and character*. Chicago: University of Chicago Press.

Kramer, S. N. (1983). *Wolkstein, Diane, Inanna, queen of heaven and earth: Her stories and Hymns from Sumer*. New York: Harper and Row.

Lambert, W. G. (1966). *Babylonian wisdom literature*. Oxford: Oxford University Press.

Lambert, W. G. (1975). The cosmology of Sumer and Babylon. In *Blacker, Carmen and Loewe, Michael, ancient cosmologies* (pp. 62–75). London: Allen and Unwin.

Lambert, W. G., & Millard, A. R. (1969). *Atra-hasis. The Babylonian story of the flood*. Oxford: Oxford University Press.

Landsberger, B. (1978). The conceptual autonomy of the Babylonian World, 1926. (B. F. Thorkild Jacobsen &, H. von Siebenthal, Trans.). Malibu: Undena Publications.

Langdon, S. (1923). *The Babylonian epic of creation*. Oxford: Oxford University Press.

Langdon, S. (1935). *Babylonian menologies and the Semitic calendars*. London: Oxford University Press.

Larsen, M. T. (1987). Language, literature and history. In F. Rochberg-Halton (Ed.), *The Mesopotamian lukewarm mind: Reflections on science, divination and literacy* (pp. 203–226). New Haven, CO: American Oriental Society.

LAS Letters from Assyrian Scholars (see Parpola 1970)

SAA State Archives of Assyria (see Hunger 1992).

Chambers encyclopaedia. London: International Learning Systems.

Leichty, E. (1970). *The omen series Summa Izbu, texts from cuneiform sources* (Vol. 4). Locust Valley, NY: J.J. Augustin.

Lloyd, G. E. R. (1979). *Magic, reason and experience*. Cambridge: Cambridge University Press.

Michalowski, P. (1989). *The lamentation over the destruction of Sumer and Ur*. Winona Lake, IN: Eisenbrauns.

Neugebauer, O. (1950). The alleged Babylonian discovery of the precession of the equinoxes. *Journal of the American Oriental Society, LXX*, 1–8.

Neugebauer, O. (1955a). *Astronomical cuneiform texts* (3 Vols). London: Lund Humphries (reprinted, Springer-Verlag, New York and Berlin, 1983).

Neugebauer, O (1955b). The Egyptian Decans. In A. Beer (Ed.), *Vistas in astronomy* (Vol. 1, pp. 47–49). London. (1983) Reprinted in *Neugebauer, astronomy and history: Selected essays* (pp. 205–209). New York/ Berlin/Heidelberg/Tokyo: Springer.

Neugebauer, O. (1963). The survival of Babylonian methods in the exact sciences of antiquity and middle ages. *Proceedings of the American Philosophical Society, 107*(6), 528–535.

Neugebauer, O. (1969). *The exact sciences in antiquity* (2nd ed.). Copenhagen: Brown University Press.

Neugebauer, O. (1975). *A history of ancient mathematical astronomy* (3 Vols). Berlin: Springer.

Neugebauer, O. (1992). *New encyclopaedia britannica* (15th ed.). Chicago: Chicago University Press.

Nissinen, M. (1998). *References to prophecy in Neo-Assyrian sources, Neo-Assyrian text corpus project*. Helsinki: University of Helsinki Press.

Oppenheim, A. L. (1960). Assyriology-why and how? *Current Anthroplogy, I*, 409–423.

Oppenheim, A. L. (1974a). Divine and celestial observation in the last Assyrian empire. *Centaurus, 14*(1), 97–135.

Oppenheim, A. L. (1974b). A Babylonian diviner's manual. *Journal of Near Eastern Studies, 33*, 197–220.

Oppenheim, A. L. (1977). *Ancient Mesopotamia: Portrait of a dead civilisation* (2nd ed.). Chicago: University of Chicago Press.

Parpola, S. (1983). *Letters from Assyrian scholars to the kings Esarhaddon and Assurbanipal*. Part 1, texts, Verlag Butzon & Bercker Kevelaer, Neukirchen-Vluyn, 1970. Part 2, Commentary, Neukirchen-Vluyn: Verlag Butzon & Bercker Kevelaer.

Parpola, S. (1993a). Mesopotamian astrology and astronomy as domains of the Mesopotamian "wisdom". In H. D. Galter (Ed.), *Die Rolle der Astronomie in den Kulturen Mesopotamiens* (Grazer Morganl ndische Studien, Vol. 3, pp. 47–60). Graz: RM-Druck-& Verlagsgesellchaft m.b.H.

Parpola, S. (1993b). *Letters from Assyrian and Babylonian scholars*. Helsinki: Helsinki University Press.

Pfeiffer, R. H. (1935). *State letters of Assyria*. New Haven, CT: American Oriental Society.

Pingree, D. (1963). Astronomy and astrology in India and Iran. *Isis, 54*, 229–246.

Pingree, D. (1978). Mesopotamian astronomy and astral omens in other civilisations. *Mesopotamien und Seine Nachbarn, 3*(7), 613–631.
Pingree, D. (1987). Venus omens in India and Babylon. In F. Rochberg-Halton (Ed.), *Language, literature and history* (pp. 293–316). New Haven, CT: American Oriental Society.
Pingree, D. (1998). Legacies in astronomy and celestial omens. In S. Dalley (Ed.), *The legacy of Mesopotamia* (pp. 125–138). Oxford: Clarendon.
Ptolemy, T. (1930). (F. E. Robbins, Trans.). Cambridge, MA: Harvard University Press.
Ptolemy, A. (Trans.) & Annot, G. J. (1984). *Toomer*. New York: Springer.
Reiner, E. (1985). The uses of astrology. *Journal of the American Oriental Society, 105*(4), 589–596.
Reiner, E. (1995). *Astral magic in Babylonia*. Philadelphia: American Philosophical Society.
Reiner, E., & Pingree, D. (1975a). *Babylonian planetary omens. Part 1, The venus tablet of Ammisaduqa, Enuma Anu Enlil, tablet 63*. Malibu: Undena Publications.
Reiner, E., & Pingree, D. (1975b). *Babylonian planetary omens. Part 2, Enuma Anu Enlil, tablets 5051, Bibliotheca Mesopotamica, Vol. 4, fasc. 2*. Malibu: Undena Publications.
Roberts, J. J. M. (1977). Nebuchadnezzar I's Elamite crisis in theological perspective. In J. M. de Ellis (Ed.), *Essays on the ancient near east in memory of Jacob Joel Finkelstein* (pp. 183–187). Hamden, CT: Archon Books.
Rochberg-Halton, F. (1984). New evidence for the history of astrology. *Journal of Near Eastern Studies, 43*(2), 115–140.
Rochberg-Halton, F. (1987). The assumed 29th Ahu tablet of Enuma Anu Enlil. In F. Rochberg-Halton (Ed.), *Language, literature and history* (pp. 327–350). New Haven, CT: American Oriental Society.
Rochberg-Halton, F. (1988a). Elements of the Babylonian contribution to Hellenistic astrology. *Journal of the American Oriental Society, 108*(1), 51–62.
Rochberg-Halton, F. (1988b). Aspects of Babylonian celestial divination: The lunar tablets of Enuma Anu Enlil. *Archiv für Orientforschung, 22*, 1–296.
Rochberg-Halton, F. (1989). Babylonian horoscopes and their sources. *Orientalia, 58*(fasc 1), 102–123.
Rochberg-Halton, F. (1991). Between observation and theory in Babylonian astronomical texts. *Journal of Near Eastern Studies, 50*(2), 107–120.
Rochberg-Halton, F. (1993a). Mesopotamian cosmology. In N. Hetherington (Ed.), *Encyclopaedia of cosmology* (pp. 398–407). New York: Garland Publishing.
Rochberg-Halton, F. (1993b). The cultural locus of astronomy in late Babylonia. In H. D. Galter (Ed.), *Die Rolle der Astronomie in den Kulturen Mesopotamiens* (Grazer Morganländische Studien, Vol. 3, pp. 31–46). Graz: RM-Druck-& Verlagsgesellchaft m.b.H.
Rochberg-Halton, F. (1998). Babylonian horoscopes: The texts and their relations. In N. Swerdlow (Ed.), *Ancient astronomy and celestial divination*. Chicago: Chicago University Press.
Rochberg-Halton, F. (2004). *The heavenly writing: Divination and horoscopy, and astronomy in Mesopotamian culture*. Cambridge: Cambridge University Press.
Rogers, J. (1998). Origins of the ancient constellations. *Journal of the British Astronomical Association, 108* (1 part 1), 9–28.
Sachs, A. (1948). A classification of the Babylonian astronomical tablets of the Seleucid period. *Journal of Cuneiform Studies, 2*, 279–280.
Sachs, A. (1952a). Babylonian horoscopes. *Journal of Cuneiform Studies, 6*, 49–75.
Sachs, A. (1952b). A late Babylonian star catalogue. *Journal of Cuneiform Studies, 6*, 146–150.
Sachs, A. (1974). Babylonian observational astronomy. *Philosophical Transactions of the Royal Society, 276*, 43–50.
Sachs, A., & Hunger, H. (1988). *Astronomical diaries and related texts from Babylonia. Vol. 1. 652 B.C. to 262 B.C.* Vienna: Verlag Der österreichisechen Akademie Der Wissenschaften.
Sachs, A., & Hunger, H. (1989). *Astronomical diaries and related texts from Babylonia. Vol. 2. 261 B.C.–165 B.C.* Vienna: Verlag Der österreichisechen Akademie Der Wissenschaften.
Sayce, A. H. (1974). The astronomy and astrology of the Babylonians. *Transactions of the Society of Biblical Archaeology, 3*, 145–339.
Sen, S. N., & Shukla, K. S. (Eds.). (1985). *History of astronomy in India*. New Delhi: Indian National Science Academy.
Snell, D. C. (1997). *Life in the ancient near east 3100–332 BC*. New Haven, CT: Yale University Press.
Speiser, E. A. (1969). The creation epic. In J. B. Pritchard (Ed.), *Ancient near eastern texts relating to the old testament* (pp. 60–72). Princeton, NJ: Princeton University Press.
Starr, I. (1983). *The rituals of the diviner, Bibliotheca Mesopotamica* (Vol. 12). Malibu: Undena Publications.
Starr, I. (1990). *Queries to the Sun God: Divination and politics in Sargonid Assyria*. Helsinki: Helsinki University Press.
Steele, J. M. (2007). *Calendars and years: Astronomy and time in the ancient near east*. Oxford: Oxbow Books.
Steele, J. M., & Imhausen, A. (2002). *Under one sky: Astronomy and mathematics in the ancient near east* (Alter Oient und Altes Testament Band, Vol. 297). Munster: Ugarit Verlag.
Stephenson, F. R. (1970). The earliest known record of a solar eclipse. *Nature, 228*, 651–652.
Stephenson, F. R., & Walker, C. B. F. (Eds.). (1985). *Halley's comet in history*. London: British Museum Publications.

Swerdlow, N. (1998). *The Babylonian theory of the planets*. Princeton, NJ: Princeton University Press.
Thompson, R. C. (1900). *The reports of the magicians and astrologers of Nineveh and Babylon in the British museum* (Vol. 2). London: Luzac and Company.
Toomer, G. J. (1984). *Ptolemy's almagest* (G. J. Toomer, Trans. and Annot.). New York: Springer.
Van der Waerden, B. (1949). Babylonian astronomy II: The thirty six stars. *Journal of Near Eastern Studies, VIII*(1), 216–230.
Van der Waerden, B. (1952a). Das Gross Jahr und die ewige Wiederkehr. *Hermes, LXXX*, 129–155.
Van der Waerden, B. (1952–1953). History of the zodiac. *Archiv für Orientforschung, 16*, 216–230.
Van der Waerden, B. (1974). *Science awakening. 2 vols. II: The birth of astronomy*. Leyden: Oxford University Press.
Van Solt, W. (1995). *Solar omens of Enuma anu Enlil, Tablets 23(24)–29(30)*. Leiden: Nederlands Historisch-Archaeologisch Instituut.
Walker, C. (1982). *Episodes in the history of Babylonian astronomy*. Toronto: The Society for Mesopotamian Studies.
Walker, C. (1989). A sketch of the development of Mesopotamian astrology and horoscopes. In A. Kitson (Ed.), *Astrology and history: Clio and Urania Confer* (pp. 7–14). London: Unwin Hyman.
Walker, C., & Britton, J. (1996). Astronomy and astrology in Mesopotamia. In C. Walker (Ed.), *Astronomy before the telescope* (pp. 42–67). London: British Museum Press.
Weidner, E. F. (1928–1929). Historisches Material in der Babylonischen Omina-Literatur. In B. Meissner (Ed.), *Altorienalische Studien*. Leipzig: Harrassowitz.
Zhitomirsky, S. (1999). 'Aratus' "phaenomena": Dating and analysing its primary source. *Astronomical & Astrophysical Transactions, 17*, 483–500.

Astrology in China

Ho Peng Yoke

In traditional China there was no distinction between astronomy and astrology. The common word *tianwen* covered both. There was also no distinction between astronomy and astrology in Europe before the end of the seventeenth century. According to the *Oxford English Dictionary*, there were two kinds of astrology (a) natural astrology, which involved the calculation and foretelling of natural phenomena, as the measurement of time, fixing of Easter, predictions of tides and eclipses, and also of meteorological phenomena and (b) judicial astrology, which was the art of judging the reputed occult and nonphysical influences of the stars and planets on human affairs, also known as star divination or astromancy. Since the end of the seventeenth century the term natural astrology was replaced by astronomy and meteorology, while judicial astrology became the astrology commonly known today.

Traditional Chinese astrology included the two elements of natural and occult science. The latter provided the motivating force that enabled Chinese astronomers to produce comprehensive and continuous observational records for almost 2,000 years. These records are of interest to modern astronomers, but they were never made with such an intention. They were meant primarily to enable the emperor to have foreknowledge of future events concerning himself, his imperial household, his senior officials, his empire, his subjects, and foreign countries. Astronomical observations also played a part in the calculation of calendars that gave auspicious and ominous times and dates for various kinds of events in daily life, ranging from wedding ceremonies to having a bath or a haircut. Traditional Chinese judicial astrology differs from its counterpart in Europe in that it was tailored exclusively to serve the emperor and not the individual. Officially this system is now obsolete among the Chinese, but unofficially there were some whispers linking the event of the demise of their Great Helmsman to the 1976 Tangshan earthquake. What is popularly known today as Chinese astrology is not the traditional official Chinese astrology referred to above. Official and popular astrology are two different entities.

Official astrology found its place in the "Astronomical Chapters" of the Chinese Dynastic Histories, beginning with the *Shiji* (Historical Memoirs) of Sima Qian (145–186 BCE). Based on the traditional Chinese belief in the close relationship between heaven (*tian*), earth (*di*), and man (*ren*), the emperor was regarded as the representative of heaven on earth – human actions on the part of the emperor and celestial phenomena had mutual effects. Chinese astrologers divided the whole sky visible to them, making the stars and asterisms correspond to geographical regions. Almost all of them corresponded to China and only a few smaller asterisms corresponded to neighboring countries.

The Polar Star, which was supposed to remain stationary, was regarded as the counterpart of the emperor in heaven. Perhaps because there was seldom any bright star near the North Pole, and the scope for making predictions would be much more limited when a star was far away from the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) beyond the reach of the planets, a number of other stars were also designated to represent the emperor. The asterisms in the circumpolar region, known as the *Ziweiyuan* (Purple Subtlety Enclosure), included those that represented the emperor, the empress, the imperial concubines, and the crown prince. There were stars representing his hierarchy of officials, including ministers and military commanders, and there were stars representing the utilities in the palace, for example the kitchen. The region was enclosed by two chains of stars, representing the walls of the Forbidden City. Many parts of the Forbidden City and the circumpolar region shared the same names. Outside the "walls" of the circumpolar region was the Plough (*Beidou*), an important asterism in both Chinese astrology and Daoism.

Next come the asterisms along the ecliptic. Two other special regions, the *Taiweiyuan* (Great Subtlety Enclosure) and the *Tianshiyuan* (Celestial Market Enclosure), were located there. The former again pertained to the emperor, his household, and his official hierarchy and the latter to the general state of economy in his empire. Distributed along the ecliptic were the 28 lunar mansions. They were used to make a wide range of predictions, from flood and drought in the empire to military activities among the border tribal people. The asterisms near the 28 lunar mansions were also significant. The astrologer could observe, for example, four stars in Pisces, called *Yumyu* (Cloud and Rain) to make a forecast for rain, thus performing the task of the modern meteorologist.

The Sun was the most important astrological object, because it represented the emperor. Solar eclipses and sunspots reflected blemishes on the part of the emperor. Likewise lunar eclipses referred to the empress. The astrologer looked for the presence of planets, comets, and novae near a particular star or asterism to predict an event and where it would happen. The astrologer also noted changes in the color or brightness and scintillation due to atmospheric conditions. He also observed aurora borealis and clouds, noting their color and shape. These were particularly important in the battlefield for gaining advanced information on enemy movements and the outcome of the combat. The astronomical bureau also produced an astrological almanac using the art of *zheri* (calculations of auspicious and inauspicious days) to work out days and times that were auspicious or unlucky for certain events in private and social life, for example having a bath or a haircut, meeting a friend, doing a business transaction, moving house, and holding a wedding ceremony.

There were often occasions when the astrologer was required to give an answer to a specific event, for example when something was lost, when a candidate set out to take the civil examinations, when two armies were facing each other preparing for battle, and so on. There were three sophisticated techniques of divination which fell within the syllabus of candidates taking examinations in the astronomical bureau in the Song Dynasty, namely *taiyi* (Supreme Unity), *dunjia* (Concealing the *jias*), and *liuren* (Six *rens*). These three methods did not restrict themselves to the imperial family and the official hierarchy.

Naturally the common people also wished to have foreknowledge of their individual fate and destiny. The Chinese developed many systems for this purpose, but none of them relied on direct astronomical observation. In the strict sense of the word they hardly qualify to be called astrology. However they generally employed the results of astronomical observations and calculations by using some or all the elements of year, month, day, and time. Furthermore, at least one of the systems contains traces of Greek and Hindu astrology. There are two systems of fate calculation in general circulation among the Chinese today, namely the *Ziping* method and the *Ziwei doushu* method. These two systems of fate calculation do not rely on direct observations of the stars and in the *Ziwei doushu* horoscopes are worked out without requiring the practitioner to know how to identify the stars that occur in the horoscope.

The history of fate calculation in China is rather obscure as this was not regarded as an orthodox branch of study, and experts writing on this subject often used imprecise language to put off the uninitiated. By the Han period (206 BCE–AD 220), Confucian scholars were talking about three types of human fate (*sanming*). One was endowed during birth and was the only element that could be calculated. One was under the influence of good or evil deeds, and one was governed by catastrophic events that would overrule the first two. It is interesting to draw comparisons with the Han scholars' contemporaries in Europe where the Romans were adopting Stoicism as their state philosophy, believing in the devotion to duty while leaving things to the inevitable. The Chinese had a different belief in life, by talking about three types of life rather than one. To the Chinese it was only the fated life that was predictable, but any predicted event was by no means inevitable. It might be changed according to one's deeds, or by what we nowadays describe as an "act of God". The Chinese system gave encouragement to lead a good life. In this respect it certainly sounded more attractive than Hellenistic astrology.

At first it seems that only the year of birth of the person concerned was taken into account. Even today some Chinese still speak about the "twelve animal cycle" of the years they were born. As time went by, first the month, then the day, and finally the hours (or rather double hour) of birth were gradually included to develop newer systems. The *Ziping* method is one of the most sophisticated systems of fate calculation. It is attributed to Xu Juyi, said to have lived during the latter half of the tenth century. He was the first to use the time of the day for fate calculation. Many books were also attributed to him, but we do not know exactly which were actually written by him. The most authoritative and comprehensive text that we have on the *Ziping* method is the *Sanming tonghui* (Confluence of the Three Fates) written by Wan Minying during the Ming period (1368–1644). Since then the system has frequently been revised to keep abreast with changes in social structure. This can be testified to by the large number of books written on this subject in China, Hong Kong, Japan, and Korea during the past few decades.

However, back in the third century Indian astrology had entered into China when the *Sārdulakarnāvadāna* was translated, introducing the names of the "Seven Luminaries" (Sun, Moon, and the five planets) and the *nakṣatras* (Moonstations). In the year 718 Gautama Siddhārtha translated the *Navagrāha* calendar and introduced the names of two imaginary heavenly bodies, *Rahu* and *Ketu*. Some time afterward a Nestorian named Adam translated a work called *Simenjing* (lit, Book on Four Departments). This book has long been lost, but it could have been a translation of Ptolemy's *Tetrabiblos*, according to recent Japanese authorities on the subject such as Kiyoshi Yabuuchi. Michio Yano has suggested that another book with the title *Duliyusijing* carried the name of Ptolemy in a corrupted form. Hellenistic astrology also went from Persia to China through Korea. Another important route taken by Hellenistic astrology was through India, where it was modified under the influence of Hindu astrology. Tantric monks played an important role in the introduction of this form of astrology to China. Amoghavajra (705–774) produced a book known under its abridged title *Xiuyaojing* (Book on the *Nakṣatras* and the Luminaries), in which the 12 signs of the zodiac appeared for the first time in China. Thus by the eighth century imported systems of astrology with Hellenistic and also often Hindu roots had become quite popular. A number of actual horoscopes cast during the Tang period are preserved in the *Qinding gujin tushu jicheng* (Imperial Encyclopedia), edited by Chen Menglei et al. in 1726.

Changes took place when new ideas came into the same melting pot with something that was originally in it. Traditional Chinese star names and astrological terms were adopted by the new imports. Gradually the latter became sinicized. One can hardly notice the Hellenistic and Hindu origin of the *Ziwei doushu system* by looking at its name alone. We do not know when exactly the term "*Ziwei*" was first used here. During the Tang period several names were used; among them was the term *Taiyi*. The "star" *Taiyi* played the same role as the "star" *Ziwei* in the modern system, and both have somewhat similar reference to the occupant of the most supreme position below or above. The term *Ziwei doushu* first appeared in the title of a book incorporated in the Daoist *Tripitaka*, the *Xu Daozang* in 1607. Similarly traditional fate calculation methods were at the same time influenced by imported cultures. The Ziping system for example employs a cycle of 12 phases, reminiscent of the 12 *Nidā nas* in Buddhism.

See Also

► Divination: Science, Technology, and the Mantic Arts in Traditional China
► Geomancy in China
► Lunar Mansions in Islam

References

Ho Peng Yoke. (1966). *The astronomical chapters of the Chin Shu*. Paris/Hague, The Netherlands: Mouton.
Ho Peng Yoke. (1988). *Cong li qi shu guandian tan Ziping tuimingfa (The Ziping method of astrology)*. Hong Kong, China: Hong Kong University Press.
Ho Peng Yoke. (2003). *Chinese mathematical astrology: Reaching out for the stars*. London: Taylor & Francis.
Ho Peng Yoke, & Ho Koon Piu. (1985). *Dunhuang canzhuan Zhan yunqi shu yanjiu (The Dunhuang MS Zhan yunqi shu)*. Taipei, Taiwan: Yiwen Press.
Smith, R. J. (1991). *Fortune-tellers and philosophy*. Boulder, CO: Westview Press.
Yano, M. (1986). *Mikkyōno senseijitsu (Astrology of Esoteric Buddhism)*. Tokyo, Japan: Tokyo Bijitsu.

Astrology in India

Vijaya Narayan Tripathi

In India, astrology, *Jyotiṣa*, is defined as *Jyotiṣam sūryādi grahāṇām bodhakamśāstram*, the system which explains the influences of the sun, moon, and planets.

Indian astrology came explicitly to light around 1200 BCE, when the monk Lagadha compiled the *Vedāṅga-Jyotiṣa* on the basis of *Vedas*, in which lunar and solar months are described, with their adjustment by *Adhimāsa* (lunar leap month). *ṛtus* (seasons), years, and *yugas* (eras) are also described. Twenty-seven constellations, eclipses, 7 planets, and 12 signs of the zodiac were also known at that time.

In the period from 500 BCE to the beginning of the Christian era some texts were written on the subject of astrology. Nineteen famous sages composed their *Siddhāntas* (texts). *Candra-prajnapti*, *Sūrya-prajnapti*, and *Jyotiṣakaraṇḍaka* were written. The *Sūryasiddhānta*, the ancient text of Indian astrology, was composed around 200 BCE.

In the first five centuries of the Christian era, there were some important contributions by Jain writers. *Angavijjā* is a large collection about *Śakuna* (omens). *Kālaka* and *ṛṣiputra* also contributed around this time. At the end of the fifth century, Āryabhaṭa I mentioned in his text *Āryabhaṭīya* that the sun and stars are constant and that day and night are based on the movement of the earth.

The period AD 500–1000 was very productive. Lallācārya, the disciple of ► Āryabhaṭa, composed two texts – *Śiṣyadhīvṛdhi* and *Ratnakoṣa* – dealing with mathematical theories. The astrologer ► Varāhamihira composed several texts, and his son Pṛthuyaśā composed a brief horary called *ṣat-Pañcāśikā*. Bhāskarācārya I wrote a commentary on the *Āryabhaṭīya* in the seventh century, and ► Brahmagupta composed the *Brāhmasphuṭasiddhānta* and the *Khaṇḍakhādyaka* around AD 635. Other scholars wrote commentaries on the texts of their predecessors and independent texts of their own.

In 1000–1500, there was a great deal of enhancement to the literature concerning the construction of astronomical instruments for observation. In the twelfth century, Bhāskara composed the famous text *Siddhāntaśiromaṇi*. The Līlāvatī of Rājāditya is another of the texts of that century. In the fifteenth century, Keśava wrote more than ten books, and his son Gaṇeśa composed the *Grahalāghava* at the age of 13.

Many more texts and commentaries were written from the sixteenth century onward. A few noteworthy ones are: *Tājikanīlakaṇṭhī* of Nīlakaṇṭha (sixteenth century), *Meghamahodaya* by Meghvijayagaṇi (seventeenth century), *Janmapatrīpaddhati* by Lābhacandragaṇi (eighteenth century), and the nineteenth century works of astrologer Bāpūdeva Śāstri.

A knowledge of *pañcānga* is a prerequisite to understanding the subject of astrology. This is the fivefold system of *tithi* (lunar day), *vāra* (weekday), *nakṣatra* (asterism), *yoga* (sum of the solar and lunar longitudes), and *karaṇa* (half lunar day). *Tithi*, the lunar date, is the duration of time in which the Moon moves 12°. The 15 *tithis* of the white fortnight (from new moon to full moon) are:

1. *Pratipadā*
2. *Dvitīyā*
3. *Tṛtīyā*
4. *Caturthī*
5. *Pañcamī*
6. *ṣaṣṭhī*
7. *Saptamī*
8. *Aṣṭamī*
9. *Navamī*
10. *Daśamī*
11. *Ekādaśī*
12. *Dvādaśī*
13. *Trayodaśī*
14. *Caturdaśī*
15. *Purṇimā* (15 × 12° = 180°)

In the black fortnight (from full moon to new moon), the 15th day is called *Amāvasyā* and the remainder are the same as above. *Tithis* are classified into five groups: *Nandā* (*tithis* 1,6,11), *Bhadrā* (2,7,12), *Jayā* (3,8,13), *Riktā* (4,9,14), and *Pūrṇā* (5,10,15).

Astrology in India, Table 1 Twenty-seven *nakṣatras* (asterisms)

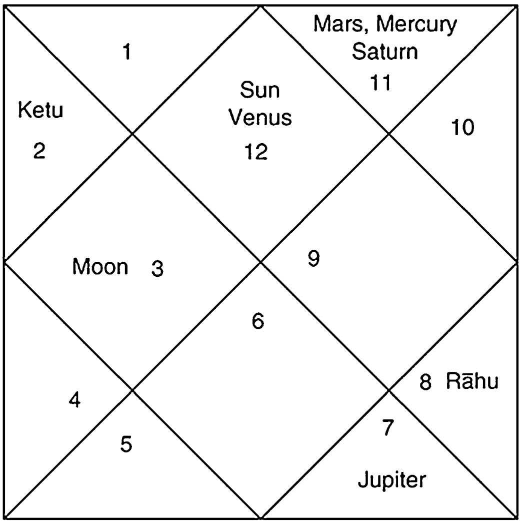
Kṛttikā	*Rohiṇī*
Mṛgaśiras	*Ārdrā*
Punarvasu	*Puṣya*
Āśleṣā	*Maghā*
Pūrvāphālgunī	*Uttarāphālgunī*
Hasta	*Citrā*
Svātī	*Viśākhā*
Anurādhā	*Jyeṣṭhā*
Mūla	*Pūrvāṣāḍhā*
Uttarāṣāḍhā	*Śroṇā*
Śraviṣṭhā	*Śatabhiṣaj*
Pūrva-Bhādrapada	*Uttara-Bhādrapada*
Revatī	*Aśvinī*
Bharaṇī	

The seven *vāras* (weekdays) are based on the names on the *grahas*: Sun, Moon, Mars, Mercury, Jupiter, Venus, and Saturn.

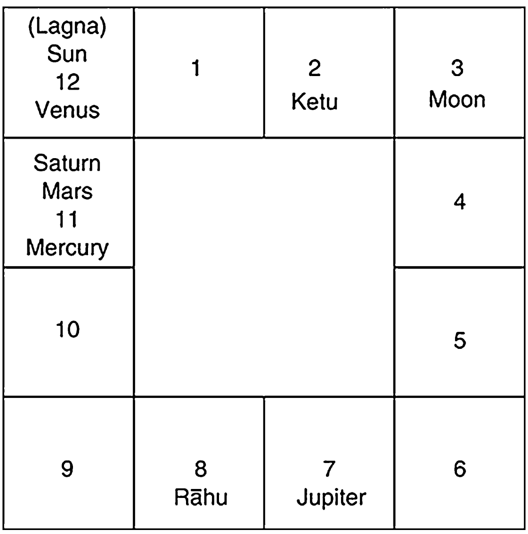
There are 27 *nakṣatras* (asterisms) bifurcating the ecliptic into 27 parts, each of 13.33°. These are mentioned in Table 1.

The ecliptic is again bifurcated into 12 parts through *Rāśis* (signs, each of 30°). The 12 signs are equal to 27 *nakṣatras*, or 1 sign = 2.25 constellations. For example, *Aśvīnī*, *Bharaṇī*, and one-quarter of *Kṛttikā* make the sign *Meṣa* (Aries). The remaining three quarters of *Kṛttikā*, *Rohiṇī*, and half of *Mṛgaśira* make the sign *Vṛṣa* (Taurus). The same pattern holds true for the other signs: *Mithuna* (Gemini), *Karka* (Cancer), *Singh* (Leo), *Kanyā* (Virgo), *Tulā* (Libra), *Vṛś cika* (Scorpio), *Dhanu* (Sagittarius), *Makara* (Capricorn), *Kumbha* (Aquarius), and *Mīna* (Pisces). Thus 27 constellations represent 12 signs.

Yoga is the sum of the solar and lunar longitudes. If the sum of their degrees is between 0 and 13.33°, that is called *Viṣkambha Yoga* – from there until 26.66° it is *Prīti* – up to 40° it is *Āyuṣmāna*. The remaining yogas are *Saubhāgya*, *Śobhana*, *Atigaṇḍa*, *Sukarmā*, *Dhṛti*, *Śūla*, *Gaṇḍa*, *Vṛdhi*, *Dhruva*, *Vyāghāta*, *Harṣaṇa*, *Vajra*, *Siddhi*, *Vyatīpāta*, *Varīyāna*, *Parigha*,



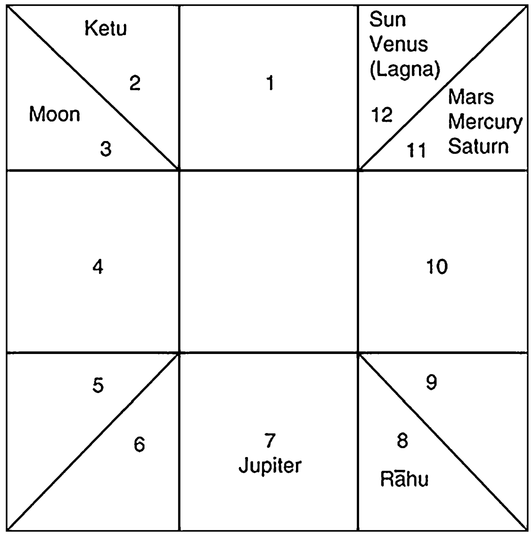
Astrology in India, Chart 1 Ascendant as sketched in northern India



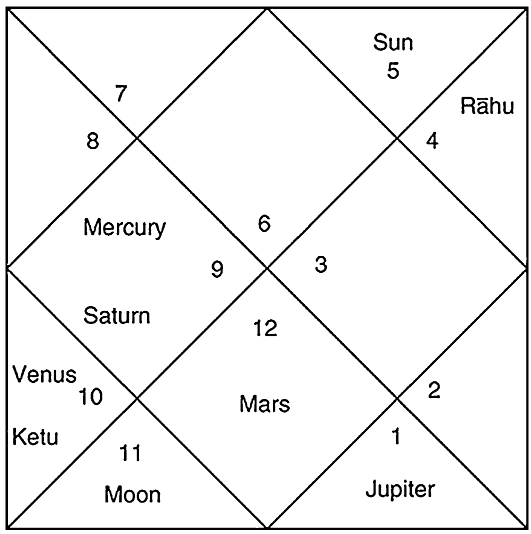
Astrology in India, Chart 2 Ascendant as sketched in southern India

Śiva, *Siddha*, *Sādhya*, *Śubha*, *Śukla*, *Brahma*, *Aindra*, and *Vaidhṛti* (13.33° × 27 = 360°).

Karaṇa (constant or moveable) is the half part of the *tithi*. Constant *Karaṇa Śakuna* belongs to the second half of *Caturdaśī Catuṣpada* and *Nāga* to that of *Āmāvasyā* in the black fortnight, while *Kistughna* exists in the first half of the *Pratipada* of the white fortnight in every lunar



Astrology in India, Chart 3 Ascendant as sketched in eastern India (West Bengal and Orissa)



Astrology in India, Chart 4 Navamanśa chart

month. The remaining 14.5 *tithis* of the white and 13.5 *tithis* of the black fortnight contain eight rounds of seven moveable *Karaṇas*: *Bava*, *Bālava*, *Kaulava*, *Taitila*, *Gara*, *Vaṇija*, and *Viṣṭi*.

The subject matter of astrology may be divided into five groups: *Saṃhitā*, *Siddhānta*, *Jātaka*, *Praśāna*, and *Śakuna*. In ancient India, *Saṃhitā* was the miscellaneous collection of astrological materials out of which the remaining four grew.

Astrology in India, Table 2 Positions of *grahas* (planets) on 21 March 1994 at 6:02 a.m. at Varanasi

Grahas (planets)	Sun	Moon	Mars	Mercury	Jupiter	Venus	Saturn	*Rāhu*	*Ketu*
Rāśi (sign)	11	2	10	10	6	11	10	7	1
Anśa (degree)	6	15	16	9	23	22	8	3	3
Kalā	21	7	57	51	19	13	21	3	3
Vikalā	27	45	18	17	40	8	21	44	44

Siddhānta or *Gaṇita* refers to mathematical calculations about time, distance, and position of the planets. On the basis of the proper positions of 12 signs and 9 planets, a chart containing 12 chambers may be sketched. In northern, southern, and eastern India, astrologers sketch Charts 1, 2, and 3 which are called *Janmāṇga* or ascendant.

Jātaka (native) is the person about whom a prediction is made on the basis of a birth chart. Twelve houses represent the health, wealth, brother/sister, mother, offspring, diseases/enemies, wife/husband, death, fate, father, income, and expenses, as in Chart 1. *Daśās* (periods) are defined in numerous ways. The period of any planet becomes favorable or harmful according to its position and power in the horoscope (Chart 4).

There are many other astrological methods in India. As an example, in the Kerala system, numbers are assigned to alphabets, and the astrologer advises the person to say the names of a flower, river, or god on which the calculation depends.

Astrology is applied to many aspects of Indian life. There are rules concerning times for traveling, planting, and building. Favorable times for the preparation of medicines and treatment are also prescribed (Table 2).

References

Grenet, F., & Pinault G.-J. (1997). Contacts des traditions astrologiques de l'Inde et de l'Iran d'après une peinture des collections de Turfan. In *Comptes Rendus de l'Académie des Inscriptions et Belles-Lettres* (pp 1003–1063).

Herrmann-Pfandt, A. (1997). The so-called 'Dakinikalpa': Religious and astrological medicine according to a north-west Indian collective manuscript. *Journal of the European Ayurvedic Society, 5*, 53–75.

Jagannātha, R. (1994). *Principles and practice of medical astrology*. New Delhi, India: Sagar Publications.

Lokamani, D. (1990). *Bhāratiyajyotiṣaśāstrasyetihāsah*. Varanasi, India: Chaukhambha Surabharti (History of Indian Astrology).

Pingree, D. E. (1997). *From astral omens to astrology: From Babylon to Bikaner*. Roma: Istituto Italiano per l'Africa e l'Oriente.

Prmad, O. S. (1999). *Medical astrology*. New Delhi, India: Gyan Publishing House.

Raghunandanaprasāda, G. (1994). *Ādhunika-Jyotiṣa (modern astrology)*. Delhi, India: Ankur Publications.

Raman, B. V. (1992). *A manual of Hindu astrology*. Delhi, India: UBS Publishers.

Sureṣacandra, M. (1994). *Jyotiśa-Sarvasva (complete Hindu astrology)*. New Delhi, India: Ranjan Publications.

Astrology in Islam

Richard Lemay

A few considerations about the historical development of the term and concept of astrology as an intellectual discipline are in order, so as to avoid the many misconceptions that prevail in this field of historical enquiry.

The first question concerns the terminology applicable in medieval Arabic culture. What we consider astrology in our epistemology has very little connection with its medieval definition. Horoscope-making and interpreting are of course part of the game but with a rather remote bearing on its definition as a science in medieval eyes. In the mind of medieval Arab writers there is but one science of the sky with the moving bodies set in it. It was called *ʿīlm an-nujūm* (science of the stars) and it consisted of two distinct treatments of the subject matter of the heavens: a purely mathematical one or *ʿīlm al-falak* corresponding to our astronomy, and a humanistic but rather conjectural one which aimed at deducing from the celestial motions their probable significance for the evolution of human affairs, more directly what we now call astrology. The name for this latter discipline was *ʿīlm aḥkām an-nujūm* (science of the judgments of the stars): hence the new term *scientia iudiciorum* or judicial astrology in medieval Latin culture. The two methods of treatment were indissolubly linked in the overall picture, and it must be further stressed that the dominating interest of medieval Arabic civilization was the "science of the judgments of the stars." On the practical level, the second portion of this dichotomy was considered an art, and the term *ṣanʿa* applied to it was the equivalent of any other trade or profession.

There were three levels through which Arab authors would approach the study of astrology: a first level through the general science of the stars which could be a predominantly philosophical enquiry bordering on what may be actually labeled cosmology. A second level, purely mathematical, consisted of the consideration of the movements of the spheres, of the celestial bodies they contained, and of phenomena affecting them. This approach corresponded more closely to our astronomy. A third level was in the extension of the above observations to judge their probable impact upon human affairs. The technique of these judgments (*aḥkām*) was determined according to very intricate rules embodied in the age-old lore of astrology proper: but the three levels were considered together to constitute the one science of the stars (*ʿilm an-nujūm*).

This tripartite structure of the science of the heavens among medieval Arab writers was not entirely their creation, for the historical event of early Arab conquests of the entire Middle East had put the young Arab civilization in direct contact with both the still active Hellenistic (Alexandrian) world of thought thriving in Egypt and in the Eastern Mediterranean on the one hand, and the very ancient Babylonian, Persian, and even Hindu cultural traditions on the other. In examining medieval Arabic astrology it is wise to keep in mind these major cultural orientations varying in importance according to the stages of those historical convergences. During the first century of Arab conquests, which corresponds roughly with the rule of the Umayyad Caliphate of Damascus (660–750), the predominant cultural influence came from Syria and Egypt, in which Hellenistic culture and further Christianized Hellenism dominated. Even so, the impact of Greek learning was not directly linked at first with classical Greek science or philosophy, but rather with its late Hellenistic phase heavily marked by neo-Platonic and Alexandrian speculation or mysticism (hermeticism). The full force of the Greek example of learning and of its formative impact on Arabic astrology emerged only under the Abbasid rule (beginning in 750), tentatively at first under al-Mansūr (754–775) and Harūn al-Rashīd (786–809), but dramatically under ▶ al-Maʾmūn (813–833) through the direct importation of the works of thinkers and of scientists such as Aristotle in physics and cosmology, and of Ptolemy in astronomy/astrology. Al-Maʾmūn established at Baghdad an astronomical observatory and *Bayt al-ḥikma* (House of Wisdom) endowed with a great library. It was because of these favorable conditions that the science of astrology, like philosophy and medicine, took its definite hue in Arab literature under the label of *falsafa* (a transliteration of the Greek term philosophy). Maʾmūn's patronage brought scientists and philosophers from all over the Muslim empire. It was likely in the midst of this intellectual fervor that the greatest writer in Arab astrology, Abu Maʿshar, came from his native Balkh in Khurāsān (now Afghanistan) to settle in Baghdad. Although Abū Maʿshar's major work, the *Kitāb al-mudkhal al-kabīr* (Greater Introduction to Astronomy, AD 848) was completed during the generation following the death of al-Maʾmūn (AD 833), its success in molding the framework of Arab astrology that merged the diverse astrological traditions of Greece, Persia, and India must be ascribed to the lively interest in *falsafa* engendered by al-Maʾmūn's sponsorship. With Abū Maʿshar's work, Arab astrology acquired its definitive structure, the result of a syncretism of all Middle East traditions under the umbrella of Aristotelian cosmology and Ptolemaean astronomy/astrology.

Abū Maʿshar came to be quoted as the authority, even by those who criticized him (► al-Bīrūnī, Ibn Ridwān). His *Kitāb al-mudkhal al-kabīr* became the "bible" of Arabic astrology because it buttressed the science with a theoretical foundation based on *falsafa*, with Persian and Hindu traditions more or less coherently merged into it. Yet it provided only the introductory theory of astrology as part of the science of Nature. Further extension of the science of judgments of the stars to the full range of human affairs was seen as a kind of adjustment to their inevitable cosmic framework. Arabic astrological science came to include these five principal divisions.

1. A theoretical or introductory part (*mudkhal*) exploring its foundations in physical science and metaphysics. Here Abū Maʿshar's *Kitāb al-mudkhal al-kabīr* shared ultimate authority together with Ptolemy's *Tetrabiblos*.
2. A section dealing with Nativities (*mīlād*, *mawālīd*) which consisted of drawing up diagrams (horoscopes) of the state of the sky at the time of any beginning. Its most natural occasion was at the time of birth (hence "nativities"), or even of conception when possible, and it would be held as an indication of the probable unfolding of the various life circumstances of the individual person or object for whom it was drawn up. It is not without interest to recall that before the establishment of individual identity status such as birth registers, beginning with the sixteenth century in Europe, natal horoscopes constituted the most reliable record of the chronological span of individual lives. Not every one was born of sufficiently wealthy or honorable stock to be able to afford this luxury. Abū Maʿshar himself lamented the fact that he did not know the exact date of his birth, to compensate for which he had drawn up for himself a "general" (approximative) horoscope.
3. Interrogations (*masāʾīl*) which dealt mostly with enquiries about objects hidden or lost, innermost thoughts or intentions, purposes, etc. A kind of oracle, it aimed to assist individuals in their important decision making or help recover missing objects.
4. Elections or Choices (*ikhtiyārāt*), which were concerned with determining the most favorable moment for starting on important undertakings, such as the construction of cities, opening of hostilities in wartime, investiture or inauguration, or starting on a journey.
5. Weather predictions or meteorology, which were almanacs which astrologers operating for courts, cities, or institutions like universities would issue at the beginning of each new year, as part of their official duties. Weather predictions were of course a prime concern in any predominantly agrarian society.

The art or trade of the astrologer on the other hand was referred to by the term *ṣanʿa* and was treated like any other profession. More specialized applications of astrological science still flourished beside the main stream, particularly in medicine where some Greek treatises of Hippocrates (*On Airs* and *De hebdomadibus* for instance) and Galenic ones about duration of pregnancy were merged into astrological prognostication (*taqdimat al-maʿrifa*) and enjoyed enormous vogue among physicians. Finally all sorts of "predictions" or "interpretation of signs" proliferated in a number of specialized practices of quackery into which some pretense of astrological judgments was introduced. Some of these are chiromancy (interpretation of lines of the hand), spatulomancy (interpretation of form of shoulder blade), and sternutomancy (on sneezing).

An influential sequel to Abū Maʿshar's *Greater Introduction* appeared by Aḥmad ibn Yūsuf, a physician, mathematician, and astrologer of the Tūlūnid era (870–904) in Egypt. Aḥmad wrote a chronicle of this Turkish dynasty and he authored several works of mathematics. He put together an astrological compendium which he entitled *Kitāb aṭh-ṭhamara* (Liber Fructus). Since it comprised 100 short propositions, each one accompanied by a substantial commentary, it came to be designated as *Centiloquium*. In fact its major doctrines are taken straight from Abū Maʿshar's *Kitāb al-mudkhal al-kabīr*. The very passage in Abū

Maʿshar's work which probably gave Aḥmad the inspiration for his forgery is met in a special section of the magnum opus (III, 1–2) where ► Abū Maʿshar enumerates the six benefits to be derived from astrological science, the most alluring of which are the "fructus" (*ṭamara*) to be anticipated from it.

These two works by Abū Maʿshar and by Ibn Yūsuf, respectively, the second in the footsteps of the first, influenced the West from the time of their translation into Latin during the twelfth century until the demise of astrology as a science in the Scientific Revolution of early modern times. The nature, influence, and significance of Arabic astrology in the East and the West during the Middle Ages were polarized around the success of these two major works.

See Also

► Abū Maʿshar
► al-Bīrūnī
► al-Maʾmūn
► Ibn Riḍwān

References

Baigent, M., & Leigh, R. (2001). *L'elisir e la pietra (The elixir and the stone)*. (Silvia Lalia, Trans). Milano, Italy: M. Tropea.
Kennedy, E. S. (1998). *Astronomy and astrology in the medieval Islamic world*. Aldershot, UK: Ashgate, Variorum.
Lemay, R. (1992). L'Islam historique et les sciences occultes. *Bulletin d'Études Orientales*.
Lines of faith: Instruments and religious practice in Islam. (1998). *Sphæra: The newsletter of the museum of the history of science, Oxford*, 7, 4–5, ill.
Makariou, S. (1998). *L'apparence des cieux: Astronomie et astrologie en terre d'Islam*. Paris: Réunion des Musées Nationaux.
Nallino, C. A. (1913–1934). "Astrology" and "Astronomy." *Encyclopedia of Islam* (pp. 494–501). Leiden, The Netherlands: Brill.
Nallino, C. A. (1960). *'Ilm al-falak. Arabian astronomy. Its history during the medieval times*. Baghdad, Iraq: Maktabat al Mathna.
Nauta, L., Vanderjagt, A. (Eds.) (1999). *Between demonstration and imagination: Essays . . . Presented to John D. North* (pp. 101–124). Leiden, The Netherlands: Brill.
Saliba, G. (1978). Astronomy, astrology, Islamic. In J. R. Strayer (Ed.), *Dictionary of the middle ages* (Vol. 1). New York: Scribner's.
Samsó, J. (1340). *Horoscopes and history: Ibn 'Azzuz and his retrospective horoscopes related to the battle of El Salado*.
Steinschneider, M. (1905–1906). *Die Europäischen Übersetzungen aus dem Arabischen bis mitte des 17. Jahrhunderts*. Vienna, Austria: C. Gerold's Sohn.
Ullmann, M. (1972). *Die Natur- und Geheimwissenschaften im Islam*. Leiden, The Netherlands: Brill.

Astronomical Instruments in India

Yukio Ōhashi

Astronomical knowledge in India can be traced back to the Vedic literature (ca. 1500–500 BCE), the earliest literature in India, but no astronomical instrument is mentioned there. Naked eye observations of the sun, moon, and lunar mansions were carried out. It is not clear whether five planets were observed or not.

There is a class of works called *Vedāṅga*, probably composed toward the end of the Vedic period, which is regarded as auxiliary to the Veda. It consists of six divisions, including *Jyotiṣa* (astronomy) and *Kalpa* (ceremonial). The *Kalpa* further consists of four divisions, including *Śulba* (method of the construction of the altar). The earliest astronomical instruments in India, the gnomon and the clepsydra, appear in the *Vedāṅga* literature.

The gnomon (Sanskrit: *śaṅku*) is used for the determination of cardinal directions in the *Kātyāyana-śulbasūtra*. A vertical gnomon is erected on a leveled ground, and a circle is drawn with a cord, whose length is equal to the height of the gnomon, with the center the foot of the gnomon. At the two points where the tip of the gnomon-shadow touches the circle, pins are placed, and they are joined by a straight line. This line is the east-west line.

The annual and diurnal variations of the length of the gnomon-shadow are recorded in the political work *Artha-śāstra* of Kauṭilya, the

Buddhist work *Śārdūlakarṇa-avadāna*, and Jaina works such as the *Sūrya-prajñapti*. These records seem to be based on observations in North India.

The clepsydra is mentioned in the *Vedāṅga-jyotiṣa*, the *Artha-śāstra*, and the *Śārdūlakarṇa-avadāna*. It was like a water jar with a hole at its bottom from which water flowed out in a *nāḍikā* (one-sixtieth of a day).

Toward the end of the *Vedāṅga* astronomy period, certain Greek ideas of astronomy and astrology had some influence in India from the second to the fourth century AD. After that, Hindu astronomy (*Jyotiṣa*) established itself as an independent discipline, and several fundamental texts called *Siddhāntas* were composed. I call this period, from about the end of the fifth to the twelfth centuries AD, the classical *Siddhānta* period. The main astronomers who described astronomical instruments are ► Āryabhaṭa (b. AD 476), ► Varāhamihira (sixth century AD), ► Brahmagupta (b. AD 598), Lalla (eighth or ninth century AD), ► Śrīpati (eleventh century AD), ► Bhāskara II (b. AD 1114), and the anonymous author of the *Sūrya-siddhānta*. The *Siddhāntas* composed by Brahmagupta, Lalla, Śrīpati, and Bhāskara II contain special chapters on astronomical instruments entitled *Yantra-adhyāya*. The Sanskrit word *yantra* means instrument. No observational data are recorded in the *Siddhāntas*, and the extent of actual observations in this period is controversial. Roger Billard maintained that astronomical constants in the *Siddhāntas* were determined by actual observations, while David Pingree argued that they were exclusively borrowed from Greek astronomy. In this connection, we should note that the method of determination of astronomical constants by means of observations was correctly explained by Bhāskara II. Let us see the instruments in this period.

The gnomon (*śaṅku*) was continually used in this period. The theory of the gnomon – such as the relationship between the length of gnomon-shadow, the latitude of the observer, and time – was developed in this period, and a special chapter called *Tripraśna-adhyāya* in the *Siddhāntas* was devoted to this subject. Trigonometry, invented in India, was fully utilized for this purpose.

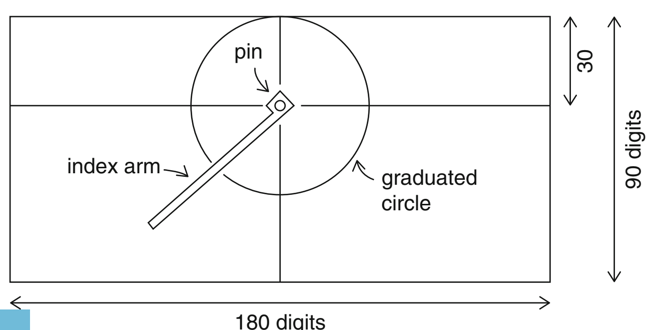
The staff (*yaṣṭi-yantra*) is a simple stick, used to sight an object. There are some variations of the staff, such as V-shaped staffs for determining angular distance with the help of a graduated level circle.

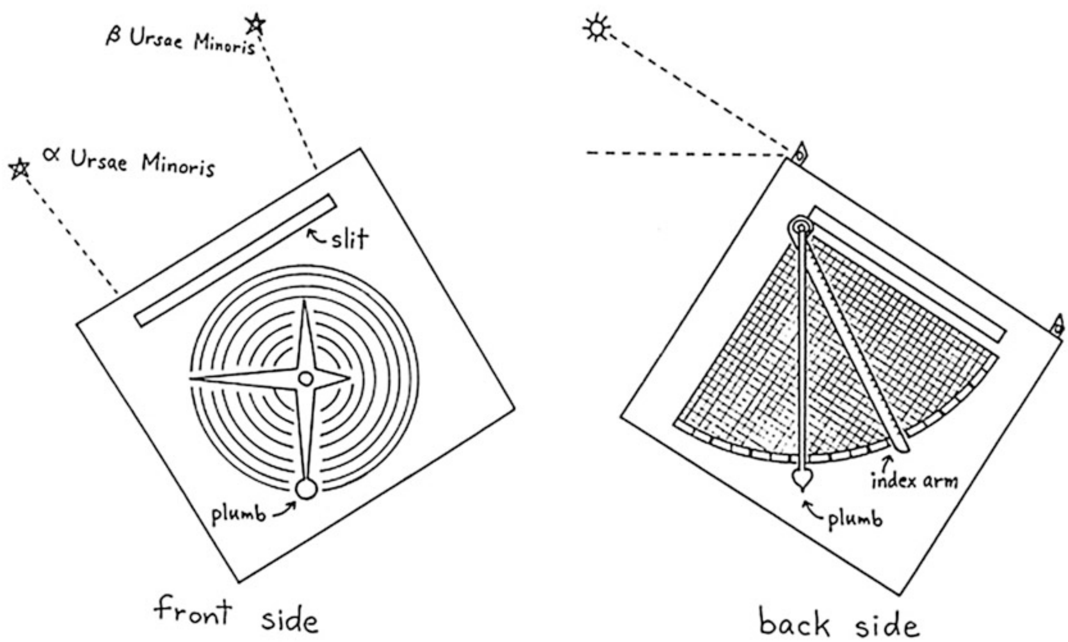
The circle instrument (*cakra-yantra*) is a graduated circular hoop or board suspended vertically. The sun's altitude or zenith distance is determined, and time is roughly calculated from it. Variations of the circle instrument are the semicircle instrument (*dhanur-yantra*) and the quadrant (*turya-golaka*).

A circular board kept horizontally with a central rod is the chair instrument (*pīṭha-yantra*), and a similar semicircular board is the bowl instrument (*kapāla-yantra*). They determine the sun's azimuth, and time is roughly calculated from them.

A circular board kept in the equatorial plane is the equator instrument (*nāḍīvalaya-yantra*). It is a kind of equatorial sundial. The combination of two semicircular boards, one of which is in the equatorial plane, is the scissors instrument (*kartarī-yantra*). Its simplified version is the semicircular board in an equatorial plane with a central rod.

Astronomical Instruments in India, Plate 1 The armillary sphere in the Government Museum, Jaipur (**a**), and in Rao Madho Singh Museum, Kota (**b**), (both in Rajasthan)

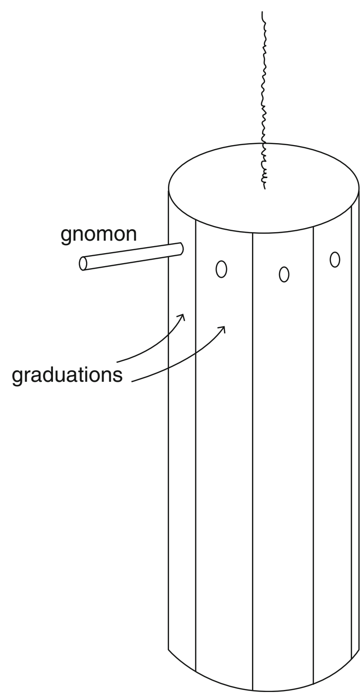




Astronomical Instruments in India, Plate 2 The clepsydra preserved in Rao Madho Singh Museum, Kota (Rajasthan)

The Indian armillary sphere (*gola-yantra*) was based on equatorial coordinates, unlike the Greek armillary sphere, which was based on ecliptical coordinates, although the Indian armillary sphere also had an ecliptical hoop. Probably, the celestial coordinates of the junction stars of the lunar mansions were determined by the armillary sphere since the seventh century or so (see Plate 1). There was also a celestial globe rotated by flowing water.

The clepsydra (*ghaṭī -yantra*) was widely used until recent times. Unlike the clepsydra of the *Vedāṅga* period, which was the outflow type of water clock, the clepsydra of this period is a bowl with a hole at its bottom floating on water. Water flows into the bowl, and it sinks after a certain time interval. The Chinese Buddhist traveler Yijing (AD 635–713) recorded the actual use of the clepsydra of this type. The clepsydra can be seen in use in a museum at Kota (Rajasthan) (see Plate 2). Several astronomers also described water-driven instruments such as the model of fighting sheep.



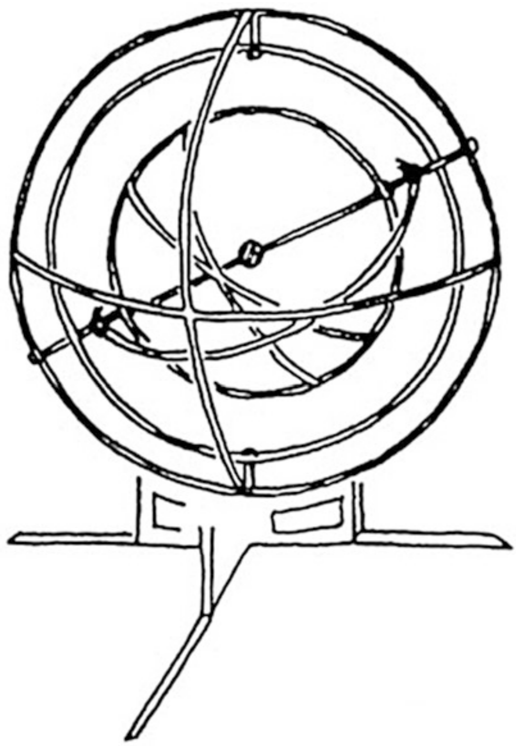
Astronomical Instruments in India, Fig. 1 *Phalaka-yantra*

Astronomical Instruments in India, Fig. 2 *Dhruva-bhrama-yantra*

The board instrument (*phalaka-yantra*) invented by ► Bhāskara II is a rectangular board with a pin and an index arm, used to determine time graphically from the sun's altitude (see Fig. 1). This is an ingenious instrument based on the Hindu theory of the gnomon.

The astrolabe was introduced into India from the Islamic world at the time of Fīrūz Shāh (r. AD 1351–1388) of the Tughluq dynasty. Fīrūz Shāh's court astronomer Mahendra Sūri composed a Sanskrit work on the astrolabe entitled *Yantra-rāja* (King of Instruments, the Sanskrit term for the astrolabe) in AD 1370. This is the earliest Sanskrit work on Islamic astronomy. Use of the astrolabe rapidly spread among some Hindu astronomers, and Padmanābha (AD 1423) and Rāmacandra (AD 1428) described the astrolabe in their works.

Some new instruments were made in the Delhi Sultanate and Mughal periods. Padmanābha invented a kind of nocturnal instrument called *dhruva-bhrama-yantra* (polar rotation instrument) (see Fig. 2). It was a rectangular board with a slit and a set of pointers with concentric graduated circles. Adjusting the slit to the direction of α and β Ursae Minoris, time and other calculations could be obtained with the help of pointers. Its backside was made as a quadrant with a plumb and an index arm. Thirty parallel lines were drawn inside the quadrant, and trigonometrical calculations were done graphically. After determining the sun's altitude with the help of the plumb, time was calculated graphically with the help of the index arm.



Astronomical Instruments in India, Fig. 3 *Pratoda-yantra*

Later, Cakradhara described the quadrant as an independent instrument, and a more exact method to calculate time was explained.

Astronomical Instruments in India, Plate 3 Jai Singh's observatory at Jaipur (Rajasthan), Viewed from its larger Samarāṭ-yantra

Astronomical Instruments in India, Plate 4 The larger Samarāṭ-yantra in Jai Singh's observatory at Jaipur

Another new type of instrument in this period was the cylindrical sundial called *kaśā-yantra* (whip instrument) by Hema (late fifteenth century AD) or *pratoda-yantra* (whip instrument) by Ganeśa (b. AD 1507) (see Fig. 3). It is a cylindrical rod having a horizontal gnomon and graduations of time according to the vertical shadow below the gnomon.

The quadrant and the cylindrical sundial exist in the Islamic world also, but the possibility of their influence on these Indian instruments is still to be investigated.

The Mahārāja of Jaipur, Sawai Jai Singh (AD 1688–1743), constructed five astronomical observatories at the beginning of the eighteenth century. The observatory in Mathura is not extant, but those in Delhi, Jaipur, Ujjain, and Banaras are (Plate 3). There are several huge instruments based on Hindu and Islamic astronomy. For example, the *samrāṭ-yantra* (emperor instrument) is a huge sundial which consists of a triangular gnomon wall and a pair of quadrants toward the ► east and west of the gnomon wall. Time has been graduated on the quadrants (Plates 4).

By this time, European astronomy had begun to be introduced into India, and Jai Singh had certain information about it. The earliest

Astronomical Instruments in India, Plate 5 Image of the sun projected on the ṣaṣṭāṁśa-yantra in Jai Singh's observatory at Jaipur

Astronomical Instruments in India, Plate 6 The Miśra-yantra in Jai Singh's observatory at Delhi

European style astronomical observatory in India is a private one of William Petrie, an officer of the British East India Company, which was set up in 1786 at his residence in Madras (Plates 5 and 6).

See Also

- ► Armillary Spheres in India
- ► Āryabhaṭa
- ► Astrolabe
- ► Bhāskara II
- ► Brahmagupta
- ► Clocks and Watches
- ► Globes
- ► Gnomon in India
- ► Jai Singh
- ► Lalla
- ► Lunar Mansions in Islam
- ► Mahendra Sūri
- ► Observatories in India
- ► Quadrant
- ► Śrīpati
- ► Śulbasūtras
- ► Trigonometry in Indian Mathematics
- ► Varāhamihira

References

Billard, R. (1971). *L'astronomie indienne*. Paris, France: École française d'extrême-Orient.

Kaye, G. R. (1918). *The astronomical observatories of Jai Singh*. Calcutta, India: Superintendent Government Printing. Rpt. New Delhi: Archaeological Survey of India, 1982.

Kochhar, R. K. (1985). Madras observatory: The beginning. *Bulletin of the Astronomical Society of India, 13*(3), 162–168.

Ōhashi, Y. (1986–1987). Sanskrit texts on astronomical instruments during the Delhi sultanate and Mughal periods. *Studies in History of Medicine and Science 10–11*, 165–181.

Ōhashi, Y. (1993). Development of astronomical observation in Vedic and post-Vedic India. *Indian Journal of History of Science, 28*(3), 185–251.

Ōhashi, Y. (1994). Astronomical instruments in classical siddhāntas. *Indian Journal of History of Science, 29*(2), 155–313.

Ōhashi, Y. (1997). Early history of the astrolabes in India. *Indian Journal of History of Science, 32*(3), 199–295.
Ōhashi, Y. (1998). The cylindrical sundial in India. *Supplement to Indian Journal of History of Science, 33* (Suppl. 4), S147–S205.
Ōhashi, Y. (2000). Early history of the water- driven clock in the east. *Technology and History, 1*(1), 37–67.
Pingree, D. (1978). *History of mathematical astronomy in India* (Dictionary of Scientific Biography, Vol. 15, pp. 533–633). New York: Scribners.

Astronomical Instruments in Japan

Nakamura Tsuko

Beginning around the sixth century, Japan was under the strong cultural influence of China (via Korea), and astronomy was no exception. Although by the beginning of the eighth century an institutional form of the Chinese Astronomical Office had been introduced into the Japanese court government along with primitive gnomons and water clocks, astronomy as a science did not become part of Japanese society, and only the astrological aspects of Chinese astronomy survived. This situation continued for many centuries throughout medieval times, partially due to the domestic turmoil caused by frequent civil wars. It was not until after the shogun Tokugawa Ieyasu finally ruled over Japan in 1615 that the Japanese people could afford to nurture their own culture. In the mid-sixteenth century, European astronomy was first brought by the Christian missionaries from Portugal and Spain, though their influence did not last long. The reason was that the shogunal government ousted them because it suspected that the true aim of the Christian missionary activities in Japan was political occupation. Thereafter, import of foreign books relating to the Western religion and culture was strictly prohibited, and only Dutch traders were allowed to come to Nagasaki.

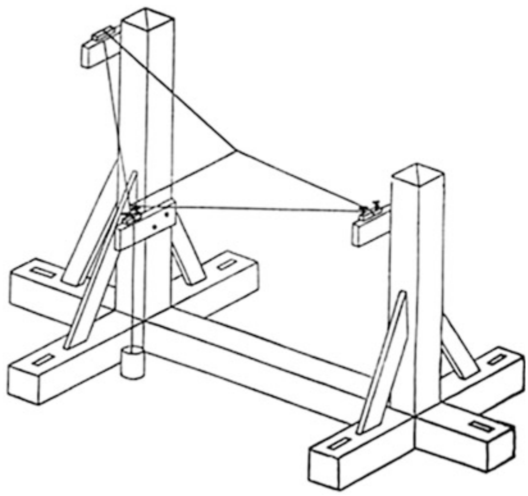
Astronomy as a science and the development of astronomical instruments started from the seventeenth century in Japan (Nakayama, 1969). In the 1680s, ► Shibukawa Harumi was nominated to be the first astronomical officer of the shogunate, after the government adopted his proposed new luni-solar calendar. For observations in this calendar reform, he made a gnomon with an apparatus to sharpen the blurred shadow of the sun. He also constructed an armillary sphere of 90 cm in diameter which was a simplified version of the traditional Chinese armillary sphere, and he measured the positions of many stars with it to produce the first Japanese star map. His compiled star catalog reveals that the observational error of his armillary sphere was about half a degree, though this instrument has since been lost. The only existing armillary sphere actually used for astronomical observations is the one preserved at Sendai City Observatory, which is about 100 cm in diameter and made of bronze with scales of half a degree interval.

After Harumi, there was no one to inherit and develop his scientific achievements till the advent of the eighth shogun Tokugawa Yoshimune in the 1710s. He was deeply interested in the natural sciences and made efforts to organize and cultivate the study of science. In 1729 he relaxed the ban of importing Chinese books written by Jesuit priests in China and also allowed Dutch interpreters at Nagasaki to learn Dutch books. This was because, he recognized the superiority of Western astronomy over Chinese traditional astronomy and planned a calendar reform using Western astronomy. He took some astronomers and mathematicians to the shogunal astronomical office and ordered an optician from Nagasaki to devise good telescopes for astronomical observations. Yoshimune himself was also engaged in astronomical observations by inventing a few new armillary spheres and transit quadrants. Despite Yoshimune's enthusiasm, his intended calendar reform was unsuccessful, due to the poor abilities of the shogunal astronomers and the opposition of the court astronomers based at Kyoto.

Because of the hereditary system for the position of the shogunal astronomers, the scholastic ability of some amateur astronomers overpowered that of the shogunal astronomers around the end of the eighteenth century. The shogunate eventually summoned the two civil astronomers of Osaka, Takahashi Yoshitoki and ▶ Hazama Shigetomi, to take leadership for a new calendar reform as the shogunal astronomers (Watanabe, 1987). The former was superior in theoretical astronomy and the latter in developing astronomical instruments. Before their nomination to the position, they already possessed some knowledge of Copernican and Keplerian theories of planetary motions learned through Sino-Jesuit astronomical books, and they also devised accurate astronomical instruments by consulting *Lingtai Yizhi* (Astronomical Observatory Instruments, by Verbiest et al. (1674)). This book described with many detailed illustrations the structure and usage of several new astronomical instruments constructed by the Jesuit astronomers serving the Qing Dynasty, which were hybrids of the traditional Chinese instruments and European ones invented by people such as Tycho Brahe.

The principal instruments among the ones produced by the Takahashi-Hazama group were the quadrant of 195 cm in radius with a telescope and the wire meridian transit of about 3.6 m in height, both installed at the shogunal observatory of Edo (ancient Tokyo). The quadrant was equipped with a diagonal subscale, which was reinvented by Brahe, so that it could measure stellar positions (altitudes) with an error of 10–15 arcsec. For measuring the meridian-transit time of stars, they used an astronomical pendulum clock which was also devised by the Takahashi-Hazama group with hints from *Lingtai Yizhi*. This astronomical clock could give stellar-transit timings with an accuracy of about 1 s. Although several such astronomical clocks made before 1850 still exist, all the instruments used at the shogunal observatory of Edo were lost or destroyed in the disorder of the Meiji Restoration in 1868.

▶ Ino Tadataka, one of Takahashi's disciples, conducted a large-scale land survey all over the Japanese archipelago starting from 1800. This was the first scientific expedition of geodesy conducted in Japan. Although the methods of mapmaking and measuring



Astronomical Instruments in Japan, Fig. 1 Transportable wire meridian transit used by Ino Tadataka in his land survey expedition of Japan (Otani, 1932)

instruments by Ino were not innovative ones, his 16-year-long enthusiasm led him to complete the entire map of Japan. For the fieldwork, he designed and constructed a few portable quadrants for astronomical latitude observations; the most frequently used one has the quadrant whose radius is 115 cm. Analysis of his field notes shows that the accuracy of single observations with this quadrant was about 20–30 arcsec. Ino also used a transportable wire transit (Fig. 1) for observing the meridian passage of stars along with a pendulum clock. This transit instrument was not useful for determining longitudes of triangulation points because of the lack of a precise chronometer, but it was mainly used for maintaining the local time. As for azimuth measurements, he devised semicircular magnetic compasses with an alidade. His 57-volume azimuthal catalog of more than 2,200 triangulation points reveals that the typical error of Ino's azimuth measurements was 5′. All of those instruments are now preserved at Ino's memorial museum. Astronomers of the Takahashi-Hazama group including Ino did not adopt the Vernier subscale but exclusively adhered to the diagonal subscale for precise measurements.

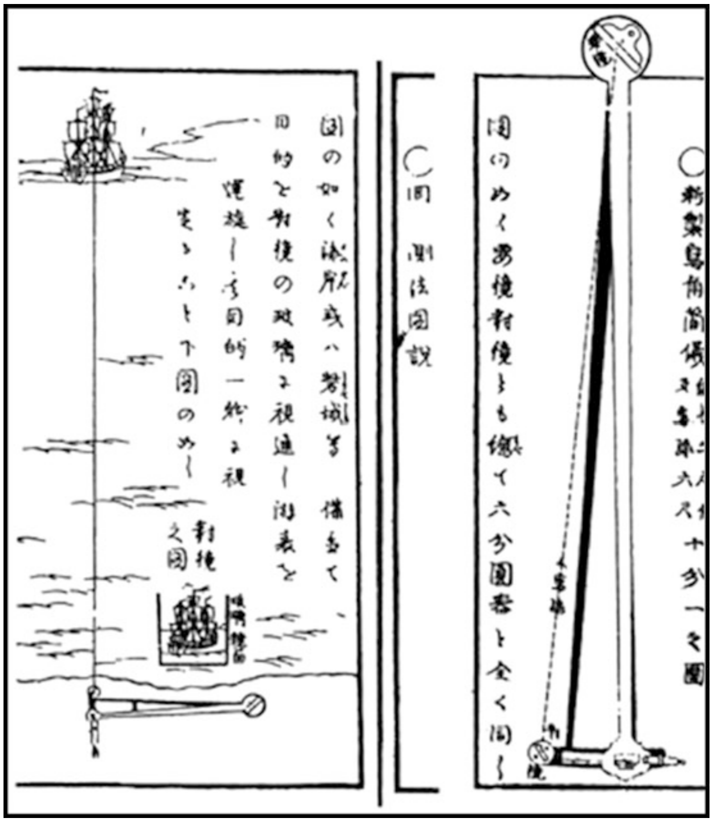
Telescopes

Telescopes in Japan have a fairly long history. As far as historical records tell us, the first introduction of a telescope into Japan goes back to 1613, when a captain of the British East India Company offered a telescope to the first Shogun Tokugawa Ieyasu for trade promotion; this telescope does not seem to exist now. The earliest existing telescope in Japan was the one owned by Tokugawa Yoshinao, the ninth prince of Ieyasu (now preserved at the Tokugawa Fine Arts Museum). Since Yoshinao died in 1650, it means that his telescope was produced in or before that year. Our recent investigation made clear that this telescope was of the Schyrlean type, made of four convex lenses giving erect images, with a magnifying power of about four. Analysis of the design, the fabrication method, the surface decoration of the telescope, and the relating historical episodes all suggest that it was not a Western make at all but produced around the southern coastal area of China, or Taiwan, or Nagasaki, by the East Asians. In the 1720s, the optician of Nagasaki, Mori Nizaemon, responding to the order of the Shogun Yoshimune, produced at least several telescopes for astronomical observations, a few of which still exist. The largest one has a tube length of 340 cm with an objective lens diameter of 73 mm, giving the magnifying power of about ten. It is likely that the shogunal astronomers used this telescope for observations of the planetary surfaces.

Around the 1790s, Iwahashi Zenbei of Osaka started production of refractor telescopes on a commercial basis. His telescopes were characterized by special decorative patterns on the tube surface, so that plenty of imitations and fakes with similar decorations appeared at later times. High-quality telescopes by Iwahashi gave the magnifying power of more than 10–20. Because the Iwahashi's family continued to fabricate their telescopes for four generations, they are most commonly seen in museum collections and antique markets. All the telescopic tubes and caps from Yoshinao's to Iwahashi's were produced by the traditional technique called *Ikkan-bari*, which utilizes paper and thin wood glued with urushi lacquer. In 1834, the gunsmith, Kunitomo Tobei, succeeded in completing his first Gregorian reflector telescope for the first time in Japan (Yamamoto, 1937). Currently four brass telescopes of nearly the same size (with an inner tube diameter of 62 mm) are identified as his products. Although it is quite unknown how he could polish the bronze primary mirrors without knowledge of Western modern optics and a mirror-grinding machine, Foucault's method of mirror testing has revealed that at least a few of Kunitomo's telescopes possess parabolic surfaces nearly as accurate as those of contemporary Gregorian telescopes. With one of them, Kunitomo made continuous observations of sunspots for more than 1 year, and during that time he independently discovered the penumbra of the sunspot. It is a shame that his excellent engineering could not find any successors, as pioneering achievements like Kunitomo's have often had a similar fate in the history of Japan.

Octants and Sextants

Octants and sextants are certainly worth mentioning in the history of Japanese astronomical instruments. Dutch sailors first brought octants, superb handy navigational and astronomical instruments, into Japan in the 1770s. Because of having no previous information on the principle of an octant and the Vernier subscale inscribed on its arc, both the issues greatly annoyed Japanese astronomers (Nakamura, 2002). Only the practical usage of an octant on the sea had been known since 1782, through a Japanese translation of the Dutch book on octants written by Cornelis Douwes (1749). It was not before 1800–1810 that scholars in Japan began to understand how an octant works and the principle of the Vernier subscale. Since at that time the shogunal government kept a strict seclusion policy and prohibited construction of ships large enough to enable remote voyages, the Japanese had no chance to use octants and sextants in ocean navigation. This motivated some people to apply octants in



Astronomical Instruments in Japan, Fig. 2 Drawing of Murata's range finder (1852)

measuring angles of distant targets on the ground. Several books explaining how to use octants and sextants in land surveying were written up to the middle of the nineteenth century. One problem with an octant in measuring angles of ground targets was systematic errors due to the parallax caused by a separation between the two mirrors comprising major components of an octant. On the contrary, some land surveyors, like Murata Sajuro, made positive use of the parallactic problem. He introduced, in his book of 1852, a range finder which is a heavily deformed octant having a very wide mirror separation (Fig. 2); Murata's book describes range finders with mirror separations of 1.8, 3.6, and 5.4 m. The left panel of Fig. 2 indicates that this instrument was invented for military purposes to measure the distance of a ship on the sea. After the Meiji Restoration of 1868, modern astronomical instruments imported from Europe soon replaced all the Japanese ones.

See Also

► Ino Tadataka

References

Cornelis, D. (1749). *Beschryvinge Van het octant en deszelfs gebruik*. Leiden, Netherlands.

Nakamura, T. (2002). Acceptance and adaptation of octants and sextants in Japan during the eighteenth and nineteenth centuries. *Journal of Astronomical History and Heritage, 5*, 9–20.

Nakayama, S. (1969). *A history of Japanese astronomy*. Cambridge, MA: Harvard University Press.

Otani, R. (1932). *Tadataka Ino, the Japanese land-surveyor*. Tokyo: Iwanami Publ. Co.

Verbiest, F., et al. (1674). *Lingtai Yizhi* (Astronomical observatory instruments).

Watanabe, T. (1987). *Kinsei Nihon Tenmongakushi (Pre-modern history of Japanese astronomy, in Japanese)* (Vol. 2). Tokyo: Koseisha Koseikaku Co.

Yamamoto, I. (1937). Kunitomo and his astronomical activities in the pre-Meiji era. *Isis, 26*, 330–335.

Astronomical Instruments in Korea

Young-Ho Hahn

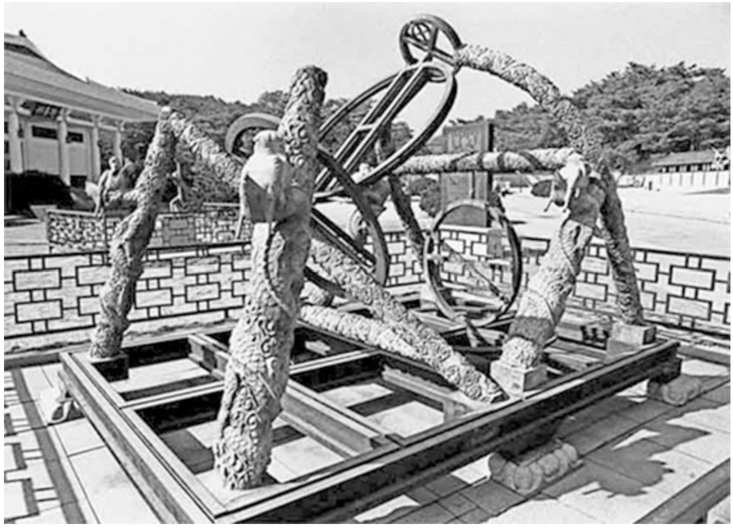
As a country which shares its border with China, ancient Korea also shared many of her neighbor's astronomical achievements. Korea adopted Chinese calendars as a standard and kept identical seasons of the year. But rulers of the Korean peninsula had also tried to establish an independent calendar system, especially during the Chosun dynasty (1392–1910). They attempted to bring out their own almanac at the same level of precision as the Chinese one. Several astronomical projects carried out under the initiative of King Sejong are the best-known examples of such efforts. From 1432 to 1439 a platform, *Ganeuidae*, for the royal observatory was built in the palace and every necessary astronomical instrument was added to it.

Korea has one of the world's oldest observatories, *Chomsungdae*, shown in Fig. 1. It was built in the early seventh century. Another observatory was constructed in the early tenth century and is also extant. Unfortunately only a small number of astronomical instruments and records prior to the fifteenth century have survived. But, as these observatories show, there had been many attempts to read heavenly phenomena even before the Chosun began.

Astronomical Instruments in Korea, Fig. 1 World's oldest observatory, *Chomsungdae* in Kyongju

All the astronomical instruments mentioned in this article, although many of them have been lost and are known only through records, are those made during the Chosun period. King Sejong's projects were very important to Korean astronomy. In addition to establishing the first independent calendar, *Chiljeongsan*, various instruments, such as equatorial torquetums [the torquetum or turquet is an instrument designed to take and convert measurements made in three sets of coordinates: horizon, equatorial, and ecliptic], armillary spheres, celestial ► globes, sundials, and auto-striking clepsydras, were introduced. Some of them were made after Chinese models and others were original. The most comprehensive description of Sejong's instruments is in Needham's *The Hall of Heavenly Records* (1986).

When Japan invaded Korea in 1592 and burnt down the royal palaces in Seoul, almost every instrument was lost, and Sejong's astronomical instruments were burned. Parts of these were restored after the war according to original designs. While the Court of Chosun was struggling to rebuild after successive raids by Manchurian Qing, Jesuit missionaries in China worked to change the Chinese calendar system to that based on Western astronomy. Officials and scholars of Chosun had to confront unfamiliar Western mathematics and astronomy to catch up with the advanced Chinese calendar. Using projection geometry, they made planar instruments such as astrolabes and sundials for themselves. Finally at the end of the eighteenth century,



Astronomical Instruments in Korea, Fig. 2 Reconstructed model of simplified instrument *Ganeui* in Yeoju

the Korean royal observatory was able to create a pair of unique Western-style sundials.

Each instrument that follows is classified according to its structure and function.

Equatorial Torquetums

An approximately 7 m high, 10 m long and 7 m broad platform of the royal observatory was named *Ganeuidae*, because the equatorial torquetum, *Ganeui*, the largest representative of Sejong's observing instruments, was installed on it.

The Korean *Ganeui* was based on Guo Shou-Jing's *Jianyi*, shown in Fig. 2. Guo, of the Chinese Yuan dynasty, invented a new instrument by taking equatorial and meridian rings out and eliminating ecliptic and selenic rings from the traditional armillary sphere. Details of *Jianyi* (literally, simplified instrument) are described and illustrated in Needham's *Science and Civilisation in China*, vol.3 (1959).

Sejong's officials made a wooden prototype and checked the exact polar elevation of Seoul. They completed a bronze-cast *Ganeui* in 1433. Although much simpler in shape than an armillary sphere with multiple-layered rings, the full-scale Simplified Instrument was too large to handle easily. In 1434 King Sejong ordered his scholars to make a smaller version, and they made two copies of the portable *Soganeui* (Small Simplified Instrument), shown in Fig. 3.

Sejong's astronomers also created a unique observing device, *Ilseongjeongsieui* (Sun-and-Star Time-Determining Instrument). As its name implies, this instrument was both a sundial and stardial. With triple equatorial dial plates, double axially protruded polar-sighting rings, an alidade, and two sighting threads, the direction of the sun and some specified stars near the north pole could be read. This in turn revealed the time of observation. Figure 4 shows the reconstructed model of the round-the-clock time-determining instrument.

Armillary Spheres, Celestial Globes, and Astronomical Clocks

After Guo Shou-Jing's *Jianyi*, armillary spheres in East Asia were based on the Simplified Instrument, not on platforms of observatories. They became the driving mechanism of the indoor astronomical clock. Although the first Chinese astronomical clock dates back to the second century AD, it was at the end of the eleventh century that Su Sung's *Shuiyunyixiangtai* (Water-Powered Sphere and Globe Tower), appeared in China. The inner rings of the armillary sphere and

Astronomical Instruments in Korea, Fig. 3 Reconstructed model of small simplified instrument *Soganeui* in Yeoju

Astronomical Instruments in Korea, Fig. 4 Sun-and-star time-determining instrument *Ilseongjeongsieui* reconstructed

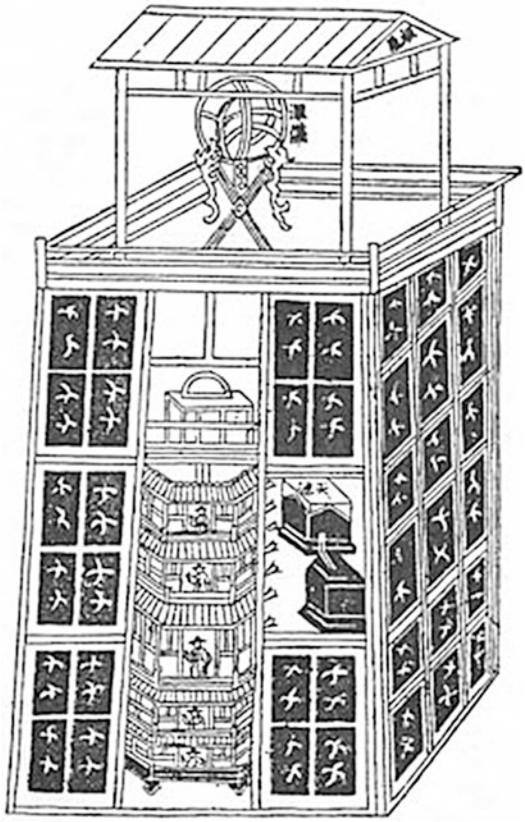
the star-embedded sphere of the celestial globe were rotated by a water wheel in accordance with each heavenly body. The sketch of the clock tower in Fig. 5 is taken from Su Sung's book, and more details of this gigantic clock may be found in Needham's *Heavenly Clockwork* (1986).

China's long tradition of astronomical clocks culminated in Su Sung's work in the Sung dynasty. During the succeeding Yuan period, such water-driven clocks as Guo Shou-Jing's Lantern Clepsydra and Emperor Shun-Ti's Palace Clepsydra were made. But they were not classified as astronomical clocks because they did not have any devices like spheres or ► globes to indicate heavenly motions.

King Sejong revived the East Asian tradition of astronomical clocks in Korea by equipping a water-operated sphere and globe near his observatory. Except for the layout and size of the instruments, the basic structure of Sejong's clock is thought to be the same as Su Sung's.

In 1438 the artisan Jang Young-Sil made one more water-powered astronomical clock, *Heumgyonggaknu*, close to King Sejong's inner palace. The Clepsydra of the Respectful Veneration Pavilion, although it vanished long ago, is one of the most spectacular astronomical clocks ever made in Korea.

A ball-shaped golden figure moved round the 7 ft. high mountaintop while keeping the same polar distance and directions of rising and setting to the sun for each season. Below the sun image



Astronomical Instruments in Korea, Fig. 5 Su Sung's water-powered sphere and globe tower

stood four jade female gods at the four cardinal points, each with an animal-figured direction god. The ringing of a golden bell in the hand of a god and the turning of the accompanying animal god announced the beginning and middle of the double hours. There was a high platform at the southern foot of the mountain, on which hammers struck their respective instruments to announce the assigned double hour or night watch. On the ground level 12 jade gods surrounded the mountain, paired with each hour god. In addition to the extra platform carrying an inclined vessel, there were paintings of rural scenery during the four seasons and wooden carvings of men, birds, and plants.

This splendid clepsydra was totally destroyed and restored twice over 200 years. Two decades after the abolition of *Heumgyonggaknu*, Yi Min-Cheol made an armillary clock as the successor of Jang Young-Sil's clockwork in the mid-seventeenth century. The new armillary clock was derived from Sino-Korean astronomical clepsydras, but it had a considerably different appearance. Yi built a cabinet in which water-operated driving mechanisms and a time-announcing apparatus were contained. An armillary sphere, as a part of astronomical clock, was installed on the plinth connected to the box.

Song Yi-Young, in close cooperation with Yi Min-Cheol, made an additional weight-driven armillary clock at the same time in 1669. Instead of Yi's water-powered device he adopted the driving mechanism that had been applied to Western mechanical clocks. Fortunately, as shown in Fig. 6, an improved version of Song's armillary clock has survived and is preserved in the Museum of Korea University, Seoul. Needham devoted one whole chapter of *The Hall of Heavenly Records* (1986) to describing this clock; he wrote that the Song Yi-Young/Yi Min-Cheol clock deserved widespread recognition as a landmark in the history of East Asian horology.

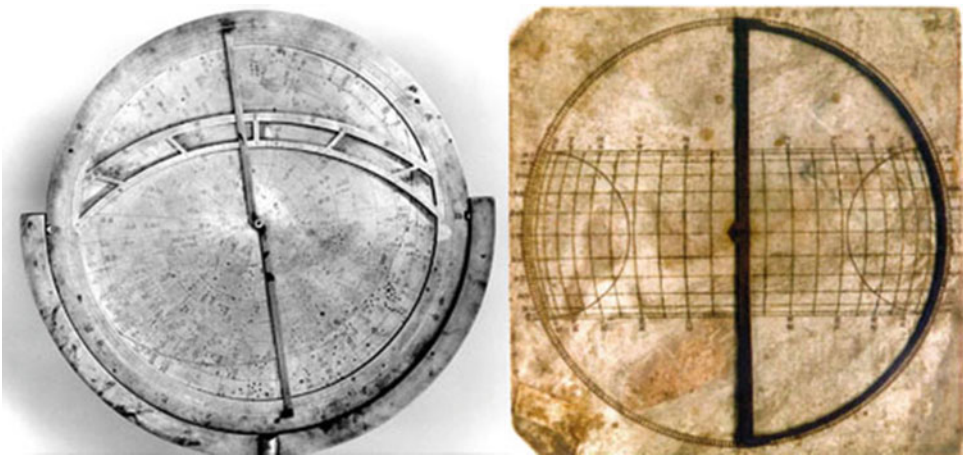
Western astronomy and astronomical instruments began to spread to Korean scholars from the early part of the eighteenth century. Hong Dae-Yong made the last astronomical clock in East Asia. He coupled a mechanical clock directly with the sidereal components of his armillary sphere and attached kinds of differential gears to distinguish solar and lunar motions from sidereal movement.

In 1789 the royal observatory made an equatorial armillary sphere to correct the records of meridian transits. Taking a Westernized, Chinese armillary sphere as a model, Kim Young made Chosun's first observing armillary sphere that could measure heavenly bodies at the accuracy level of 15 s.

Astrolabes

The early Jesuit missionaries introduced astrolabes to China. Books on planispheric or universal astrolabes had been published in Chinese

Astronomical Instruments in Korea, Fig. 6 Armillary clock in the Museum of Korea University, Seoul



Astronomical Instruments in Korea, Fig. 7 Korean relics of celestial planisphere (*left*) and universal astrolabe (*right*)

during the first quarter of the seventeenth century. However, the actual astrolabes did not arouse as much interest from Chinese scholars as the books introducing those instruments. Thus China did not leave any trace that showed practical uses for Western-style astrolabes except the celestial planisphere, *Pinghunyi*.

More than 100 years later, Korean scholars made all the Western planar instruments for themselves from reading these foreign books. But the planispheric astrolabe was uncommon in Korea too. The plate of the Western astrolabe was replaced with the planispheric star chart in *Pinghunyi*, and the rete was revised simply to an arc of horizon on the eastern instrument as shown in Fig. 7. Although several celestial planispheres have been handed down, universal astrolabes are very rare. Moreover, no planispheric astrolabe has survived.

Sundials

Ancient Korea contributed to the diversity of sundials by adding her unique shadow-tracking instruments. Especially during King Sejong's

Astronomical Instruments in Korea, Fig. 8 A scaphe sundial *Angbuilgui*

reign, several distinguished solar devices were invented and equipped. The best-known representative is the scaphe sundial, *Angbuilgui*. This sundial, shown in Fig. 8, has a hemispherical surface of grid lines. Since the end point of the gnomon coincides with the center of the sphere, the shadow of the sharp end is cast to the grid surface always at a right angle and can be read clearly and accurately even at times near sunrise and sunset. The scaphe sundial was used as a main time indicator throughout the Chosun dynasty.

During the eighteenth century a few horizontal sundials were made; they replaced the role of the scaphe sundial in the Court. The new Western-origin sun trackers had the simple appearance of a flat slab, although the construction of the shadow lines was not easily attainable. Once the geometrical essentials to construct foreign sundials became known, the royal observatory preferred to make horizontal instruments rather than the scaphe sundial with its hemispherical surface of shadow lines.

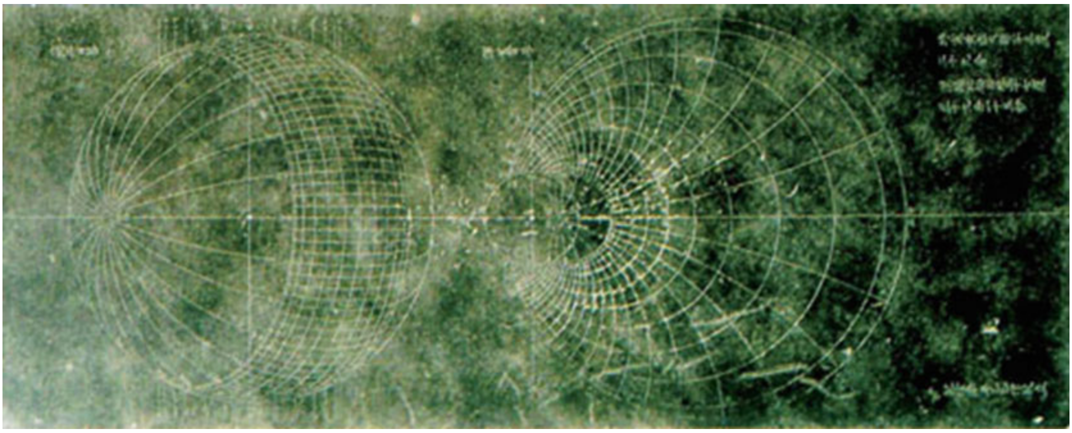
Among these horizontal sundials, *Ganpyongilgui* and *Hongaeilgui* are quite unique. In 1785 these two were carved side by side on the same 1.3 m-long stone table as shown in Fig. 9. The stone slab with 52 cm width is now preserved in the Royal Relic Exhibition Hall of Deoksu Palace in Seoul.

Ganpyongilgui was based on a Rojas type universal astrolabe and *Hongaeilgui* on a planispheric astrolabe. But the way they were developed was far from simply duplicating the original instruments. The inventor of these sundials, probably one of the high officials of the royal observatory, must have been a master of the principles of planispheric projection to carry out significant modifications for these particular horizontal instruments.

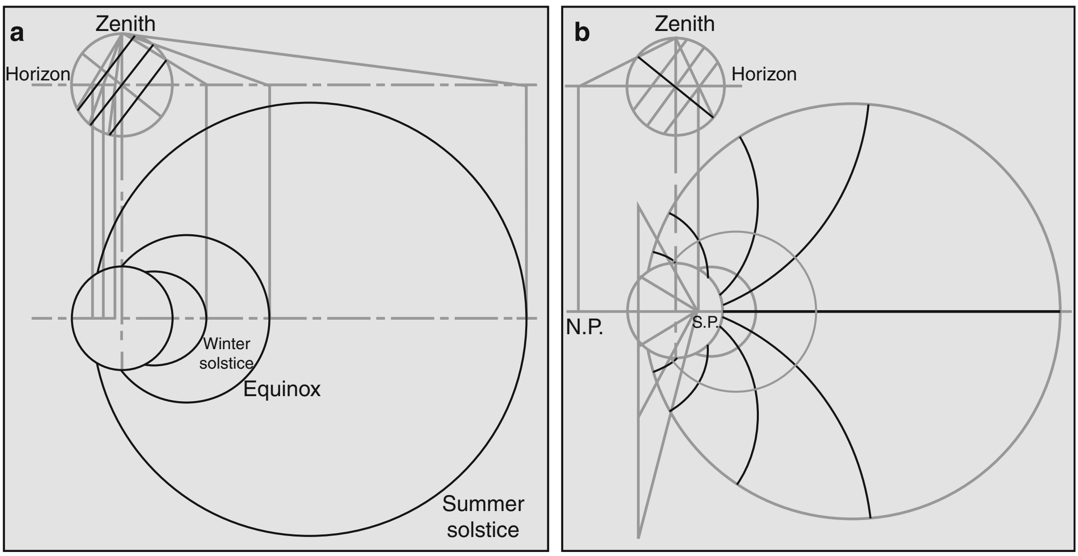
The grid lines of the Rojas type universal astrolabe, *Ganpyongeui* in Korean, can be obtained by an orthographic projection, whose center of projection is at infinity outside the equinox of the celestial sphere. By analogy, it can be said that *Ganpyongilgui* is a Rojas type sundial since its grid lines were also drawn by orthographic projection. The center of projection of this sundial was located at infinity outside the zenith of Seoul. As the center of projection was moved from infinity outside the equinox to that of local zenith, the straight season lines of the astrolabe *Ganpyongeui* were transformed to parallel ellipses of the sundial *Ganpyongilgui* because the inclined circles were projected orthographically.

The name of the other sundial was *Hongaeilgui*. Its origin can be traced from the name *Hongaetongheon*, the planispheric astrolabe. The ecliptic on the rete and the lines on the plate of a planispheric astrolabe are obtained by stereographic projection from the south celestial pole. The same rule of projection was followed to get the star chart of a celestial planisphere. Moreover, the season and hour lines of *Hongaeilgui* were also drawn by stereographic projection.

The way to get the grid lines for *Hongaeilgui* is sketched briefly in Fig. 10. Unlike having the center of projection at infinity as in an orthographic projection, the center of the stereographic projection remains on the surface of the celestial sphere. Whenever curves on a sphere are mapped onto a flat surface, there are two characteristic features of the stereographic projection. One is



Astronomical Instruments in Korea, Fig. 9 *Ganpyongilgui* (*left*) and *Hongaeilgui* (*right*)



Astronomical Instruments in Korea, Fig. 10 Stereographic projection of *Hongaeilgui*; (**a**) season lines, and (**b**) hour lines

the preservation of the circle and the other the rule of conforming. Every circle on the sphere maps onto a plane as a circle by the rule of preserving the circle. And, according to conforming, two circles that intersect at a certain angle will intersect at the same angle on the mapped surface.

The sun is traced for the Korean planispheric sundial, *Hongaeilgui*. The altitudinal and azimuthal data are cast as shadows of the gnomon onto the surface of the sun tracker. Season and hour lines were constructed as grids on the sundial. By shifting the center of projection to the local zenith, the horizontal coordinates of the sphere were transformed to the polar coordinates. The equatorial coordinates were mapped to the sundial as the bipolar coordinates of the season and hour lines as shown in Fig. 10. The direction of the shadow directly gives an azimuthal coordinate and its length; the altitude of the sun yields a radial coordinate through a simple transformation:

$$\frac{r}{R} = \tan\left(\frac{90^\circ + \beta}{2}\right) = \frac{1 + \sin\beta}{\cos\beta}$$
$$= \frac{1}{a} + \sqrt{1 + \frac{1}{a^2}}$$

where r is the radial coordinate, R is the radius of the base circle representing horizon, β is the altitude of the sun, and a is the length of the shadow when the height of the gnomon equals unity. With the polar coordinates of the shadow in hand, the point that specifies the current date and hour would be located from the bipolar coordinates.

This Korean horizontal sundial is more of a graphical calculator than a mere time indicator. Most problems concerning the position of the sun throughout a year could be answered straightforwardly without any further calculation. While keeping the geometric characteristics and drawing procedure unchanged, the well-established astrolabe was completely modified by a Korean expert to an extraordinary sundial.

References

Hahn, Y.-. H. (2001). Introduction of Western Geometry into Chosun and Hong Dae-Yong's Chuhaesuyong. *The Yoksa Hakbo (Journal of the Korean Historical Association), 170*, 53–89 (in Korean).

Hahn, Y.-. H. (2003). Astronomical clocks of Nongsugak. *The Yoksa Hakbo (Journal of the Korean Historical Association), 177*, 1–32 (in Korean).

Hahn, Y.-H., & Nam, M.-H. (1997). Reconstruction of the Armillary spheres of Mid-Chosun: The Armillary clocks of Yi Minchol. *Hanguk Kwahaksa Hakhoeji (Journal of the Korean History of Science Society), 19*(1), 3–19 (in Korean).

Hahn, Y.-. H., et al. (1999). Hong Dae-Yong's universal astrolabe, Cheugguanui. *The Yoksa Hakbo (Journal of the Korean Historical Association), 164*, 125–164 (in Korean).

Hahn, Y.-. H., et al. (2000). Astronomical clocks of Chosun Dynasty: King Sejong's Heumgyonggaknu. *Kisulgwa Yoksa (Journal of the Korean Society for the History of Technology and Industry), 1*(1), 99–140 (in Korean).

Nam, M.-. H. (1995). *Korean water-clocks*. Seoul, Korea: Konkuk University Press (in Korean).

Needham, J., et al. (1986a). *The hall of heavenly records: Korean astronomical instruments and Clocks 1380–1780*. Cambridge: Cambridge University Press.

Needham, J., et al. (1986b). *Heavenly clockwork: The great astronomical clocks of Medieval China*. Cambridge: Cambridge University Press.

Astronomical Instruments in the Islamic World

David A. King
Frankfurt University, Frankfurt am Main, Germany

Most Islamic observational instruments are lost and known to us only through texts. The state of documentation of the other, smaller Islamic astronomical instruments that do survive leaves much to be desired. Many of the most important instruments are still unpublished, and much that has been written on instruments is on a very amateur level. For these reasons a project has been underway in Frankfurt to catalogue all Islamic instruments (and European ones) to ca. 1550 as well as various historically significant later Islamic pieces.

Also the most important writings on instruments have not yet received the attention they deserve. For example, a hemispherical observational instrument for a fixed latitude was devised by the tenth century astronomer ► al-Khujandī, the leading instrument maker of the early period, and this was modified in the twelfth century to serve all latitudes. There are no surviving examples, and the available manuscripts have yet to be studied. An important work on instruments was compiled in Cairo ca. 1280 by Abū ʿAlī al-Marrākushī – this has yet to be subjected to a detailed analysis. The author collected all of the treatises on instruments known to him and incorporated them into his book. An exciting find of the 1980s was a treatise by the early fourteenth century Cairo astronomer Najm al-Dīn al-Misrī. In this the author described and illustrated over 100 different instrument types, including every kind of instrument known to him as well as those he invented himself. This treatise is now published with an exhaustive commentary. The same holds for the earliest surviving corpus of texts on the astrolabe, quadrant, and sundials by ► al-Khwārizmī.

Armillary Spheres and Globes

In the eighth century al-Fazārī wrote a treatise on the armillary sphere, called *dhāt al-ḥalaq*, which means "the instrument with the rings." No early Islamic armillary spheres survive, but several other treatises on it were compiled over the centuries. The earliest treatise in Arabic dealing with the celestial globe, called *dhāt al-kursī* (the instrument with the stand) or simply *al-kura* (sphere), was written by ► Qusṭā ibn Lūqā in the ninth century. This treatise by Qusṭā, who was one of the most important translators of Greek works into Arabic, remained popular for a millennium. Of the various surviving celestial ► globes, which number over 100, none predates the eleventh century.

The spherical astrolabe, unlike the armillary sphere and the celestial globe, appears to be an Islamic development. Various treatises on it were written from the tenth to the sixteenth century, and only one complete instrument, from the fourteenth, survives. In the ninth century Ḥabash wrote on the spherical astrolabe, the armillary sphere, and the celestial globe, as well as on various kinds of planispheric astrolabes.

Astrolabes

Al-Fazārī also wrote on the use of the astrolabe (Arabic *asṭurlāb*). The tenth century bibliographer Ibn al-Nadīm states that al-Fazārī was the first Muslim to make such an instrument – he also informs us that, at that time, the construction of astrolabes was centered in Harran and spread from there. Several early astronomers, including Ḥabash, al-Khwārizmī, and ► al-Farghānī, wrote on the astrolabe, and introduced the features not found on earlier Greek instruments, such as the shadow squares and trigonometric grids on the backs and the azimuth curves on the plates for different latitudes, as well as the universal plate of horizons. Also extensive tables were compiled in the ninth century to facilitate the construction of astrolabes.

Another important development to the astrolabe occurred in Andalusia in the eleventh century, when al-Zarqāllu devised the single universal plate (*ṣafīḥa*) called *shakkāziyya* and the related plate called *zarqālliyya* with two sets of *shakkāziyya* markings for both equatorial and ecliptic coordinate systems. The latter was fitted with an alidade bearing a movable perpendicular straight edge (transversal). Several treatises on these two instruments exist in both Western and Eastern traditions of later Islamic astronomy – the Europeans knew of them as the *saphea*. Ibn al-Zarqāllu's contemporary, ʿAlī ibn Khalaf, wrote a treatise on a universal astrolabe that did not need plates for different latitudes. This treatise exists only in Old Spanish in the *Libros del Saber*, and was apparently not known in the Islamic world outside Andalusia. The instrument was further developed in Syria in the early fourteenth century: Ibn al-Sarrāj devised in Aleppo a remarkable astrolabe that can be used universally in five different ways.

The astrolabes made by Muslim craftsmen show a remarkable variety within each of several clearly defined regional schools. We may mention the simple, functional astrolabes of the early Baghdad school – the splendid astrolabe of ► al-Khujandī of the late tenth century, which started a tradition of zoomorphic ornamentation that continued in the Islamic East and in Europe for several centuries – the very different astrolabes of the Andalusian school in the eleventh century and the progressive schools of Iran in the thirteenth and fourteenth centuries – and the remarkable instruments from Mamluk (thirteenth and fourteenth century) Egypt and Syria. In the early fourteenth century Ibn al-Sarrāj of Aleppo, a school unto himself, produced the most sophisticated astrolabe ever made. After about 1500 the construction of astrolabes continued in the Maghrib, in Iran, and in India until the end of the nineteenth century. Many of these instruments, especially those from Iran, were beautiful objects of the finest workmanship.

Quadrants

Another category of observational and computational devices to which Muslim astronomers made notable contributions was the quadrant, of which we can distinguish three main varieties. Firstly there is the sine quadrant with an orthogonal grid. This instrument, in a simpler form, had already been described by ► al-Khwārizmī and was widely used throughout the Islamic period. Some Islamic astrolabes display such a trigonometric grid on the back. The grid can be used together with a thread and movable marker (or the alidade of an astrolabe) to solve all of the standard problems of spherical astronomy for any latitude. Secondly there is the horary quadrant with fixed or movable cursor. This instrument is described already in an anonymous ninth century Iraqi source and was likewise commonly used for centuries (albeit usually without the cursor, which is not essential to the function of the device). A set of arcs of circles inscribed on the quadrant display graphically the solar altitude at the seasonal hours (approximately, according to an Indian formula). Other Islamic quadrants from the ninth century onwards had markings for the equinoctial hours. The instrument can be aligned towards the sun so that the time can be determined from the observed altitude using the grid. Again this kind of marking was often found on the back of astrolabes. Thirdly there is the astrolabic quadrant displaying one-half of the altitude and azimuth circles on an astrolabe plate for a fixed latitude, and a fixed ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The effect of the daily rotation is achieved by a thread and bead attached at the center of the instrument rather than by the movable astrolabe rete. The quadrant with astrolabic markings on one side and a trigonometric grid on the other generally replaced the astrolabe all over the Islamic world (with the notable exceptions of Iran, India, and the Yemen) in the later period of Islamic astronomy.

Sundials

We learn from Islamic tradition that the pious Umayyad Caliph ʿUmar ibn ʿAbd al-ʿAzīz (fl. Damascus, 718) used a sundial to regulate the times of the daytime prayers in terms of the seasonal hours. The earliest sundials described in the Arabic astronomical sources are planar, usually horizontal, but also vertical and polar. The mathematical theory for computing the shadow for the seasonal hours at different times of the year and the corresponding azimuths was available from Indian sources, which seem to have inspired the Islamic tradition more than any of the available Greek works. The treatise on sundial construction by al-Khwārizmī contained extensive tables displaying the polar coordinates of the intersections of the hour lines with the solstitial shadow traces on horizontal sundials for 12 different latitudes. The treatise on sundial theory by Thābit ibn Qurra contains all the necessary mathematical theory for constructing sundials in any plane – likewise impressive from a theoretical point of view is the treatise on gnomonics by his grandson Ibrāhīm.

The earliest surviving Islamic sundial, apparently made in Córdoba about the year 1000 by the Andalusian astronomer Ibn al-ṣaffār, displays the shadow traces of the equinoxes and solstices, and the lines for the seasonal hours as well as for the times of the two daytime prayers. There is a world of difference between this simple, carelessly constructed piece and the magnificent sundial made in the late fourteenth century by Ibn al-Shāṭir, so devised that it can be used to measure time with respect to any of the five daily prayers. In the late period of Islamic astronomy a sundial was to be found in most of the major mosques.

Miscellaneous

Muslim astronomers devised several multipurpose instruments. Notable examples are the rule (*mīzān*) of al-Fazārī, fitted with a variety of non-uniform scales for various astronomical functions, and the compendium of Ibn al-Shāṭir, comprising a magnetic compass and qibla-indicator, a universal polar sundial, and an equatorial sundial. Of particular interest is three circular qibla-indicators made in Isfahan ca. 1675 (but invented much earlier) which consists of a cartographic grid with Mecca at the center, so devised that the qibla can be read off the outer scale and the distance from Mecca can be read off the non-uniform scale on the diametrical rule.

There are several Islamic treatises on eclipse computers and planetary equatoria for determining the positions of the planets for a given date. With these the standard problems of planetary astronomy dealt with in *zījes* are resolved mechanically, without calculation. Treatises on eclipse computers are known from the early tenth century, and ► al-Bīrūnī in the early eleventh describes such an instrument in detail. A newly discovered manuscript (not yet available for research) contains a treatise by the tenth century Iranian astronomer ► Abū Jaʿfar al-Khāzin describing an equatorium called ► Zīj al-Safāʾiḥ (the Zīj of Plates). The only known example of this instrument, made in the twelfth century, is incomplete: it is in the form of an astrolabe with tables engraved on the *mater* and additional markings for the foundation of an equatorium. Otherwise the only known early Islamic treatises on planetary equatoria are from eleventh century Andalusia. The most interesting aspect of the equatorium described by al-Zarqāllu is the ellipse drawn on the plate for the center of the deferent of Mercury – it seems that he was the first to notice this characteristic of Mercury's deferent. Al-Kāshī, the leading astronomer of early fifteenth century Samarqand, has left us a description of a planetary equatorium with which not only ecliptic longitudes but also latitudes could be determined and eclipses calculated.

See Also

► al-Farghānī
► Al-Fazārī
► Al-Kāshī
► al-Khujandī
► al-Khwārizmī
► Armillary Spheres in China
► Astrolabe
► Astronomy
► Globes
► Ibn al-Shāṭir
► Ibn Al-Zarqāllu
► Maps and Mapmaking: Celestial Islamic Maps
► Quadrant
► Sundials in China
► Thābit ibn Qurra

References

Charette, F. (2003). *Mathematical instrumentation in fourteenth-century Egypt and Syria – The illustrated treatise of Najm al-Din al-Misri*. Leiden, The Netherlands: Brill.

Charette, F., & Schmidl, P. G. (2001). A universal plate for timekeeping with the stars by Habash al-Hasib: Text, translation and preliminary commentary. *Suhayl Journal for the History of the Exact and Natural Sciences in Islamic Civilisation (Barcelona), 2*, 107–159.

Charette, F., & Schmidl, P. G. (2004). al-Khwarizmi and practical astronomy in ninth-century Baghdad. The earliest extant corpus of texts on the astrolabe and other portable instruments. *SCIAMVS Sources and Commentaries in Exact Sciences (Kyoto Hokuto), 5*, 101–198.

Gunther, R. T. (1932). *The astrolabes of the world* (Vol. 2). Oxford, UK: Oxford University Press. Rpt. in 1 vol. London: The Holland Press, 1976. (Full of errors and long outdated, but still useful.).

King, D. A. (1987). *Islamic astronomical instruments*. London: Variorum.

King, D. A. (1994). Astronomical instruments between east and west. In H. Kühnel (Ed.), *Kommunikation zwischen Orient und Okzident – Alltag und Sachkultur* (pp. 143–198). Vienna, Austria: Österreichische Akademie der Wissenschaften.

King, D. A. (1999). *World-maps for finding the direction and distance to Mecca. Innovation and tradition in Islamic science*. Leiden, The Netherlands: Brill.

King, D. A. (2004). *Synchrony with the heavens: Studies in astronomical timekeeping and instrumentation in medieval Islamic civilization* (The call of the Muezzin (studies I-IX), Vol. 1). Leiden, The Netherlands: Brill. Vol. 2: Instruments of Mass Calculation (Studies X-XVIII). Leiden: Brill, 2005.

King, D. A., & Samsó, J. (2001). With a contribution by Bernard R. Goldstein, astronomical handbooks and tables from the Islamic world (750–1900): An interim report. *Suhayl Journal for the History of the Exact and*

Natural Sciences in Islamic Civilisation (Barcelona), *2*, 9–105 (Includes surveys of tables for constructing instruments).
Mayer, L. A. (1956). *Islamic astrolabists and their works*. Geneva, Switzerland: A. Kundig.
Savage-Smith, E. (1985). *Islamicate celestial globes – Their history, construction, and use*. Washington, DC: Smithsonian Institution Press.

Astronomical Monuments in Polynesia and Micronesia

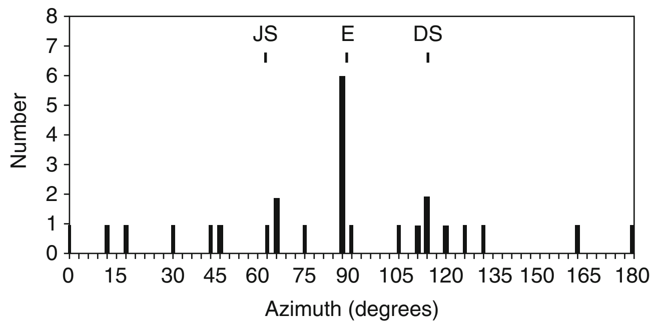
César Esteban
Instituto de Astrofísica de Canarias, La Laguna, Santa Cruz de Tenerife, Spain

The pre-European inhabitants of the Pacific Islands were skillful and frequent interisland navigators. The most accurate directional indicators used by the Polynesian and Micronesian islanders – still used today in several parts of Oceania – were the rising and setting positions of stars (Akerblom, 1968; Gladwin, 1970; Goodenough, 1953; Grimble, 1931; Lewis, 1994). The measurement of stellar positions and their movement over the celestial sphere was an important task for the ancient seafarers. In fact, astronomy was treated as a branch of navigation by the ancient Tongans (Collocott, 1922), and, as the Jesuit priest Fr. Cantova reported from castaways from Woleai (Caroline Islands) at Guam in 1721, "The only thing they learn are some vague principles of astronomy to which most apply themselves due to its usefulness in navigation" (Lewis, 1994, p. 112). The navigators defined the sailing directions by the use of "star compasses," which divide the horizon into a number of parts identified by the rising and setting positions of the stars. There is ample evidence of the use of a 32-direction "star compass" by the ancient and contemporary navigators of the Caroline Islands (Goodenough, 1953, pp. 5–24; Gladwin, 1970, pp. 147–165; Lewis, 1994, pp. 102–111). The references for the use of a "star compass" in Polynesia are ancient and scarce. The most detailed one is by Andía y Varela, who led a Spanish expedition to Tahiti in 1774 (Corney 1913–1919, 2, pp. 284–285; Lewis, 1994, p. 84).

There are few ethnohistoric references about systematic observation of the Sun or Sun worshiping in Polynesia. For example, Behrens, in 1737, says that in the early morning, Easter Island inhabitants "had prostrated themselves towards the rising sun and had kindled some hundreds of fires which probably betokened a morning oblation to their gods" (Behrens, 1908, p. 133). There are some vague indications of solstitial observation in pre-European Pukapuka and New Zealand (Beaglehole & Beaglehole, 1938, p. 349; Makemson, 1941, pp. 85–86) and the more explicit ones are in Hawaii (see Kirch, 2004a, and references therein). However, the most clear evidence of Sun observations is in Mangareva (Gambier Islands), where Buck (1938, pp. 414–415) indicates that "two stones were set up to form sights" to determine the solstices exactly.

There are several ethnological studies about Polynesian names of stars, constellations, and the calendar, the most important compilations being those by Makemson (1941) and Johnson and Mahelona (1975). A new revised work by Johnson, Mahelona, and Ruggles is expected to appear in 2014. In a recent synthesis of historical anthropology, Kirch and Green (2001, pp. 260–276) have reconstructed essential aspects of ancient Polynesian time reckoning and ritual cycle. They describe:

1. An annual seasonal cycle divided in two parts originally based on a wet–dry seasonality and the yam cultivation cycle.
2. A sidereal cycle based on the observation of the heliacal and acronychal rising of the Pleiades (named Mataliki in Proto-Polynesian).
3. An agricultural annual lunar calendar of 13 months.
4. A system of intercalation for keeping the synchronization between the lunar calendar and solar year. This system was based on the observation of Pleiades risings but, in some cases, at least in Mangareva and Hawaii, also on solar observations at solstices.



Astronomical Monuments in Polynesia and Micronesia, Fig. 1 Number histogram of the orientations of the perpendicular to the long side of 26 *ahu* within 500 m of the coast and with long axes skewed by more than 20° to the adjacent shoreline of Easter Island measured by Liller (2000b). Data are binned in 3° interval. JS, E, and DS indicate the azimuths of the rising sun at June solstice, the equinoxes, and December solstice, respectively. Note the overwhelming tendency of east–west orientations (Diagram adapted from Liller (2000b))

It is surprising that there have been rather few attempts to correlate the ethnographic material about celestial lore and the alignments of the ubiquitous ceremonial stone structures across the whole Pacific area.

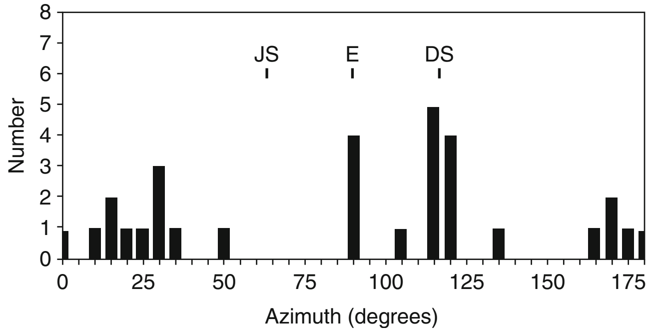
There are few archaeoastronomical studies in Polynesia and they are not systematic except for Easter Island and – in recent years – Hawaii. In the case of Micronesia, the situation is even worse. As far as I know, there has been no archaeoastronomical fieldwork on orientations of prehistoric Micronesian stone monuments except the works by Esteban (2007, 2014). In the following, I will review the main results of different research works in the Pacific area. Not all the islands groups are included because an important number of them are lacking any kind of archaeoastronomical study.

Ferdon (1961) made the first report of astronomical alignments in Polynesia as part of the investigations of the Norwegian Archaeological Expedition to Easter Island in 1955–1956. This author proposed that a group of cup-marked boulders (the so-called Sun stones) at the village of Orongo was oriented astronomically; however a reanalysis made by Lee and Liller (1987) has shown that such claims can be discounted. The archaeologist Mulloy (1975) discovered the unusual orientation of one of the scarce inland *moai* platforms (the moai are the large imposing Easter Island statues): Huri A Urenga, which faces the point where the Sun rises at the June solstice. Liller and Duarte (1986) performed an excellent analysis of the orientations located at this monument, reinforcing the astronomical interest of the site and finding other possible astronomical orientations. Mulloy (1961) and Smith (1961) also reported possible solar alignments in other coastal *moai* platforms of Easter Island, such as those of Vinapu 1 and 2 (December solstice sunrise and equinox sunrise, respectively) and Tepeu (December solstice sunrise).

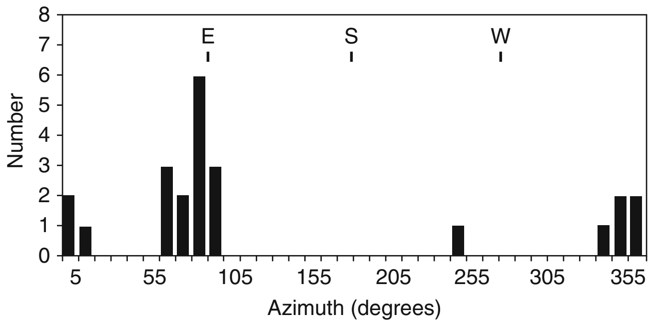
Liller (1989) has made a systematic study of orientations defined by several hundred *ahu* (an *ahu* is a raised platform inside a temple) and *moai* platforms on Easter Island, finding that there is marginal evidence of alignments related to the solstices or equinoxes. He finds a definite trend among coastal *ahu* being oriented parallel to the coast (approximately 90 %), with the sculptures or *moai* facing out to sea. Considering the *ahu* with long sides nonparallel to the shoreline (a sample of 26 *ahu*), there is an overwhelming tendency for these monuments to be oriented in the direction of the equinox rising points and an extra one or two *ahu* aligned in the direction of the solstice rising points (Fig. 1). Regarding the inland platforms, Liller finds there is a weak tendency to have the *moai* look in the direction of the rising of the Sun at the June solstice, and Huri A Urenga stands out as the most remarkable case. More recently, Edwards and Belmonte (2004), considering the outstanding ethnographic importance of Matariki (the Pleiades star cluster see, e.g., Tilburg, 1994, pp. 100–103) and Tautoru (Orion's Belt) as markers of ceremonies and agricultural activities in the traditional calendar of Easter Island and the absence of solar references or cults, propose that the aforementioned solstitial and equinoctial alignments of the *ahu* platforms could be interpreted as being instead alignments to the Pleiades and Orion's Belt risings or settings. The declination of those asterisms is incidentally very similar to those of the Sun at the June solstice (Pleiades) and to the Sun at the equinoxes (Orion's Belt).

Since the pioneering studies of the Hawaiian stone temples (*heiau*) by Stokes in 1906–1909 (published in 1991: Stokes, 1991), Emory (1924) and Bennett (1931) it has been usually considered that the orientation of the *heiau* was determined by the local topography and environmental considerations, commonly facing the sea or valley. Moreover, as Kirch (2004a) has pointed out, the rich Hawaiian ethnohistory is largely silent about *heiau* orientations. Only the native Hawaiian scholar Malo (1951) indicates that the cardinal directions could have been important for the positioning of the audiences in the *heiau* during the ceremonies. Chauvin (2000) defends the low probability of premeditated solar alignments in the stone temples considering that neither solstices nor equinoxes played any role in the Hawaiian calendar or in religious practices. On the other hand, Kirch (2004a) indicates that the major Hawaiian deities were associated with particular directions and seasonal orientations on the basis of what is known of traditional Hawaiian theology. This assertion suggests that the finding of astronomical alignments in temple platforms may not be disregarded. On the other hand, Ruggles (2001) is also optimistic, at least in the possibility of some symbolic celestial connections in the *heiau* taking into account the large number of names of stars and other celestial objects in the traditional Hawaiian names for places in the landscape. Ethnographical data give evidences of solar observations among the ancient Hawaiians. For instance, Kamakau (1976, pp. 13–14) indicates the existence of persons who observe the stars and a class of priests who advised concerning building and locating temples who were skilled in reckoning the months of the year and following the Sun movement. This author (1976, p. 14) also describes solar observation from the island of Kauai based on the rising or setting of the Sun over relevant topographic features of the horizon in particular moments of the year.

Rubellite Johnson carried out the first archaeoastronomical studies in Hawaii in the 1980s. Da Silva and Johnson (1982) first suggested a possible "astronomical-directional register" in the Ahu a 'Umi Heiau, a platform located on the island of Hawaii, the highest and the farthest inland heiau of the Hawaiian archipelago. Johnson (1993) also studied the small island of Kahoolawe, where oral tradition suggested that it had once been a place of important astronomical and navigational activity. Meech and Warther (1996) have made an interpretation of some *hula* or sacred chants of the Hawaiians in terms of astronomical alignments that can be found in the archipelago, specially related to the solstices. However, reassessments based on more precise measurements have shown that the alignments claimed by those authors are not sufficiently precise in most cases (Ruggles, 1999). Moreover, the results obtained by Ruggles seem to indicate an interest in solar zenith passage as much as and perhaps more than in the solstices. In a subsequent paper, Ruggles (2001) presents a systematic study in Kaua'i trying to correlate ritual and sky traditions with the architectural alignments of a large sample of *heiau*, a promising new approach in Polynesia where many traditions are still alive or collected in the rich ethnological legacy. In this last study, Ruggles finds no consistent patterns with regard either to orientation upon topographic features or to orientation upon celestial objects, although some intriguing relationships are found in some particular sites. However, other works have been successful in finding rather clear astronomical orientations in ancient Hawaiian temples. Liller (2000a) has studied the orientations of 32 stone temples in the tiny Necker Island. This island has two relevant particularities: (a) it has an astonishingly large number of temples considering the small size of the island and (b) the island center



Astronomical Monuments in Polynesia and Micronesia, Fig. 2 Number histogram of the orientations of the perpendicular to the back side of 32 *stone temples* of Necker Island (Hawaii Archipelago) measured by Liller (2000a). Data are binned in 5° intervals. JS, E, and DS indicate the azimuths of the rising sun at June solstice, the equinoxes, and December solstice, respectively. Note that the *temples* show two preferred orientations: one east–west and the other around the December solstice sunrise (Diagram adapted from Liller (2000a))



Astronomical Monuments in Polynesia and Micronesia, Fig. 3 Number histogram of the orientations of 23 *heiau* at Kahikinui (Maui Island, Hawaii Archipelago) measured by Kirch (2004a). Data are binned in 10° intervals. The position of the cardinal points is indicated by letters. The data show three clear concentrations: one facing the east, another facing east–north–east, and a third one facing north, Kirch (2004a) believes these orientations were deliberate and likely related to a particular god of the Hawaiian pantheon

is located almost exactly at the latitude of the Tropic of Cancer in the year AD 1000. This last particularity implies that the ancient inhabitants of Necker would have realized that the Sun was directly at their zenith at midday of the June solstice. In fact, Liller has found that 9 of the 32 temples of Necker are aligned with the setting June solstice and/or the rising December solstice (Fig. 2). Finally, Kirch (2004a) has performed an analysis of the orientations of a sample of 23 *heiau* of Kahikinui (Maui Island). This author has found that temple foundations tended to have three preferred orientations: east, east–north–east, and north (Fig. 3). Kirch has correlated these results with ethnohistoric and ethnographic data proposing that:

1. The east orientations may be associated with god Kane, because this deity was associated with the Sun and the east direction.
2. The east–north–east cluster of orientations may be related to either the summer solstice sunrise or the rising of the Pleiades. In fact the acronychal rising of this asterism determined the onset of the Makahiki season and the new year; this group of temples may be dedicated to the god Lono, who was linked to the annual rising of the Pleiades.
3. The temples oriented to the north face the summit of the high mountain Haleakala ("House of the Sun") and may be dedicated to Ku, a deity linked to high mountains, to the sky, and to forest.

Archaeoastronomical studies in islands of Eastern Polynesia, apart from the aforementioned ones for Easter Island and the Hawaiian archipelago, are very scarce. Liller (1993) presents an analysis of orientation data (obtained from direct measurements by the author and from good quality topographical maps) of over 50 ceremonial stone platforms in various archipelagos of Polynesia (Society Islands, Hawaiian Islands, Rarotonga, and the Trilithon of Tonga) finding no clear astronomical trends except perhaps in some isolated cases. In a subsequent paper, Liller (2000b) gives an excellent review of archaeoastronomical fieldwork carried out in Polynesia and presents some new results based on the reanalysis of large sets of published plans from the literature and some other new data obtained by the author. Concerning the archipelagos of Eastern Polynesia, Liller presents histograms of orientations of temples belonging to the Tuamotus (52 temples) and the Society Islands (105 temples) as well as some preliminary and sparse data of Mangareva, the Cook Islands, and the Austral Islands. The general conclusion of that paper is that the orientation of the Polynesian ceremonial platforms was controlled by the physical situation. Most of the monuments are located on the shore and lie parallel or perpendicular to the immediate shoreline. Astronomical alignments are present only in some isolated cases. The remarkable *mara'e*. (*Mara'e*, also spelled *mala'e* or *maa'e*, are stone or coral slab temples) Tapu-tapu-a-tea, possibly one of the most important in all Polynesia, located on Raiatea (Society Islands) has its long inland-facing wall oriented to an azimuth of 6. °3′. Liller (2000b) suggests that the perpendicular to the wall may be oriented to the rising point of the southern portion of the constellation of Orion: perhaps Orion's Belt or Rigel. Other important *marae* of the Society Islands, such as those of Tainu'u (Rai'atea), Matairea-rahi and Anini (Huahine), Marotetina (Borabora), Mahaiatea (Tahiti), and Tetii (Mo'orea), are also oriented to within a few degrees of that of Tapu-tapu-a-tea (Liller, 2000b). This finding could be relevant in the context of the ethnohistorical accounts of Henry (1928, p. 363) who writes the following concerning the birth of heavenly bodies in ancient Tahitian tradition: "the chiefs of the skies… were royal personages… from the period of darkness, and they each had a star. They bore the names of those stars, and those names have been perpetuated in their temples in this world." This account suggests that the finding of stellar alignments in the *mara'e* cannot be considered strange (Kelley & Milone, 2005, p. 347). On the other hand, unpublished archaeological surveys of *mara'e* in the Faaroa Valley (Raiatea) and Matairea Hill (Huahine) carried out by Edmundo Edwards indicate that a fraction between 20 % and 30 % of the monuments show solstice orientations, although Liller (2000b) considers that Edward's results, at least for Huahine, are only circumstantial.

As in the case of the aforementioned Necker Island in the Northern Hemisphere, there are several islands of Eastern Polynesia located close to – in this case – the Tropic of Capricorn. Tubuai (Australs) was located only 23 km north of this tropic in AD 1000 (Liller, 2000a). Vérin (1969) found that four out of six mara'e reported on this island show alignment with the December solstice sunset. However, Edwards (2003) indicates that those presumed orientations could be only accidental considering that the nearby shoreline has precisely the same orientation. This last author reports a survey of 92 *mara'e* on Raivavae (Austral Islands), an island also very close to the Tropic of Capricorn, finding that about 14 % of the monuments are astronomically oriented. In particular, the large *mara'e* Unuaru (whose walls are not parallel to the shoreline) as well as other mara'e of Raivavae are oriented very close to the true north.

The Mangareva Islands (also known as Gambier Islands) are the only case in Polynesia where there is unequivocal ethnohistoric evidence for systematic solar observations. The account of the priest Honoré Laval provides a description of traditional Mangarevan time reckoning and the methods of solar observations at solstices and the places where they were performed (Laval, 1938, pp. 213–215). Peter Buck (1938) gives another detailed ethnographic account about these activities. Here are some relevant astronomical information (see Kirch, 2004b):

1. Solstice observations were used to keep the lunations in sequence with the solar year and to divide the year into two seasons.
2. The locations for solstitial observations are given. The observatory at Atituiti, named Te Rua Ra (the pit of the Sun), is said to be the "most favorable position" for this purpose.
3. In at least one site, upright stones are used to mark the rising Sun at December solstice, and the backsight was a big flat stone.
4. The observation of solar risings and settings on distant topographic markers was used to achieve precision.
5. The movement of a shadow cast by a certain mountain was also used as a solstitial marker.

Kirch (2004b) has rediscovered the precise site of the Atituiti observatory, finding an uncommon platform oriented along the cardinal directions and the central flat boulder where observations were performed. That author has been able to confirm the most important aspects of the ethnohistoric records. For example, the position of the December solstice sunset coincides with the western edge of the high cliff Ana Tetea (the burial place of two renowned high chiefs of Mangareva) on Agakauitai Island; the shadow of Auorotini (Mount Duff) is also cast onto the central flat boulder during the June solstice.

In recent years, the Centre d'Investigation en Ethnoastronomie Locale (CIEL) of Tahiti led by L. Cruchet is carrying out ethno- and archaeoastronomical studies in the area of East Polynesia. In his last work, Cruchet (2013) presents results for a number of *mara'e* and archer platforms in the Society Islands. He proposes that they are oriented to the rising and setting of certain important stars in Tahitian mythology (the so-called pillar stars) and that these relationships can be explained in the light of linguistic and ethnographic data and even attending to their relation with the traditional landscape. Although, in my opinion, these studies have certain methodological deficiencies, the importance of some stellar alignments seems rather plausible.

In the Kingdom of Tonga, we have a remarkable and unique monument in Polynesia: the Ha'amonga a Maui (Burden of Maui) trilithon which according to tradition, was built in AD 1200 (see Fig. 4). (A trilithon is a structure consisting of two large vertical stones supporting a third stone set horizontally across the top) In 1967, the current monarch, King Taufa'ahau Tupou IV, discovered that the lintel is aligned along the sunrise at December solstice; this was later confirmed by Liller (1993) and Esteban (2002–2003). According to Collocott (1922), "the Tongan year is said to have begun at about the same time as the Christian year" and this fact would indicate a possible calendrical importance of the December solstice. As has been commented before, Makemson (1941) and other authors state that in most of the Polynesian archipelagos (including Tonga), the new year began in late November or early December with the first Moon after the acronychal rising of the Pleiades. These dates are not far off but obviously do not coincide with the December solstice. In any case, as Esteban (2002–2003) has suggested, the solstitial orientation of the trilithon may be accidental because its axis is roughly parallel to other related archaeological structures and to the nearby shoreline. Some controversy was raised by the presence of an enigmatic zigzag figure carved into the top of the lintel of the trilithon whose axes point roughly to the two rising solstice directions. However, Dhyne (1994) argues that there are reasons to believe that the marks were made relatively recently.

The most common archaeological features of Tonga are round or rectangular mounds of earth with considerable size range. These mounds can be house platforms, burial mounds, *esi* mounds (resting places for members of the chief's family), and mounds for pigeon snaring (McKern, 1929). The *esi* and pigeon mounds are usually situated upon natural rises that command a splendid view of the surrounding countryside. The anthropologist Wragge (see Liller, 2000b; McKern, 1929, p. 17) reported that the *esi* platform called Makahokovalu in Uiha Island (Ha'apai group) was a religious site connected with ancient Sun worshipping. However, McKern (1929, p. 17) and Gifford (1924, p. 68) failed to find any archaeological or ethnological evidence of Sun worship in the island.

Astronomical Monuments in Polynesia and Micronesia, Fig. 4 *Left*: The Ha'amonga a Maui trilithon seen from the south (Heketa, Tongatapu Island, Kingdom of Tonga). This is a unique monument in Polynesia that stands about 5 m tall. *Right*: View of the eastern horizon as seen from the lintel of the trilithon. The position of the rising points of the Sun at solstices and equinoxes has been cleared of vegetation by the Tongan authorities. The lintel is aligned approximately along the December solstice. The current Tongan monarch, King Taufa'ahau Tupou IV, discovered this alignment (Images taken from Esteban (2002–2003). Reproduced with permission of University of Texas Press)

Liller (2000b) reports that in McKern's plan of Makahokovalu, the long axis is oriented at an azimuth of 2° (perpendicular 92°), suggesting some solar relation, but this is also the orientation of the nearby shoreline. Esteban (2002–2003) has estimated the approximate orientation of the ramps of the mounds from the plans published by McKern finding no clear trends.

Since the burial mounds of Tongan commoners are just earth mounds, the sites relating to the chief and royal family have stone facing and are often loosely called *langi*. The *langi* are large rectangular monuments with stone slab retaining walls, generally consisting of a number of terraces in the manner of truncated pyramids. One of Collocott's (1922) informants suggested a connection between the skies and the great burials at Mu'a (Tongatapu Island) and elsewhere, and it is worthy of note that the sky and vault are called by the same name: *langi*. In a detailed study of the largest collection of *langi* at Mu'a, Esteban (2002–2003) finds that the general disposition of the tombs is parallel to the shoreline, although much less probable stellar orientations related to sailing directions are also discussed by that author.

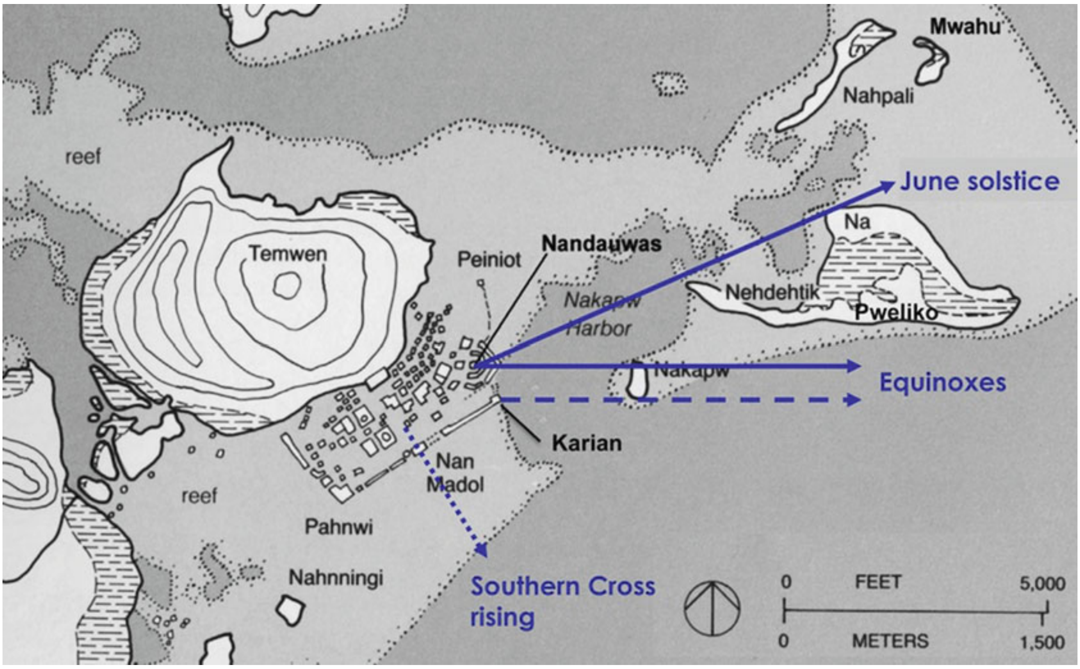
Bellwood (1978) reports that Samoan ethnographic records indicate the existence of open spaces for ceremonies (*mala'e*) as well as god houses. Scattered among Samoan settlements are the so-called star mounds. They are large, raised platforms with several rounded projections extending from the central area and built with a loose rubble of basaltic stones. The interpretation of star mounds has been controversial. Modern informants tend to view them as pigeon-snaring mounds. No evidence of use for habitation or burial was found. The mounds were perhaps also used for religious purposes, as some ethnological references have pointed out (Davidson, 1979), and also for some divination rituals, as it is indicated in the information panels of the Tia Seu Lupe (literally "earthen mound to catch pigeons") star mound in Tutuila Island (American Samoa). Esteban (2002–2003) considers it impossible to define useful alignments in these kinds of mounds taking into account their common irregular shape and large number of rounded irregular projections.

The island of Sava'i (Independent Samoa) has what is quite probably the largest surviving prehistoric monument in Polynesia, the Pulemelei stone mound. It is a huge flat-topped and roughly rectangular structure that covers 60 by 50 m at the base and is 12 m high. There are slightly sunken ramps to the top on the eastern and western slopes. The monument was built between 1100 and 1300 AD. There are several oral traditions about its purpose. Some tell that the mound was used to catch pigeons, while others say it was the residence of former chiefs of the island. Moreover, no few local traditions consider Pulemelei as the residence of gods and spirits. In any case, the archaeological investigations point out its ceremonial character (Martinsson-Wallin, Wallin, & Clark, 2007). This huge monument is part of a large complex of more or less contemporary structures as smaller mounds and traditional footpaths. It is located within a coconut plantation and almost completely covered with vegetation, making it very difficult to make accurate measurements of the orientation of the structure or the horizon without an extensive clearing of vegetation. This took place during the 2002–2004 excavations led by Swedish and Australian archaeologists (see Martinsson-Wallin et al., 2007). Talbot and Swaney (1998, p. 141) and Esteban (2002–2003) indicated that the sides of Pulemelei were oriented approximately along to the cardinal axes, which can be graphically confirmed on the detailed plans of the archaeological site published by Martinsson-Wallin et al. (2007, Fig. 3a) and after correcting for magnetic declination. Clarke and De Biran (2007) report that several of the other large mounds of Samoa also show their major axes oriented along the east–west line, as does the stone platform known as Kine He'e in the relatively nearby island of Rotuma (Fiji), culturally related to Samoa.

The largest island of the Republic of Palau (in Micronesia) is Babeldaob. From the astronomical point of view, the most interesting prehistoric remains known in Palau are the unique sculpted stone faces at Melekeok, on the eastern coast of Babeldaob. They are nine stones ranging from 1 to 2.5 m in height and arranged very precisely in two rows parallel to the nearby shoreline. All the surviving stones are facing the sea. Morgan (1988, pp. 14–15) collected the following legend concerning the origin of these stones: Odalmelech, the god of Ngermelech Village in Melekeok, "and his councilmen set out to lay a huge stone work over the village ground. That night, they started bringing in huge reef stones for the project, but the work was only partially completed when dawn approached. Odalmelech, seeing that his cohorts could not accomplish the project before daylight, called his crew together and told them of the shame of being caught working in the morning sun. So he ordered his crew to carve all their faces on the monoliths and place them to eternally face the rising sun." This story indicates the possible astronomical motivation of the site. Esteban (2002–2003) finds that the orientation of the faces may be close to the June solstice rising based on the site plan published by Morgan (1988, p. 13). Direct measurements and additional ethnographic data on the site are necessary to check this suggestive finding.

Nan Madol, in Pohnpei Island (Federated States of Micronesia), is the largest archaeological site in Micronesia and perhaps of all the Pacific Islands. It consists of 92 human-made rectangular islets separated by many waterways. The islets are generally surrounded by retaining walls of long, naturally prismatic basalt which are often built up over foundations of immense basalt boulders. The site was constructed on a reef located in the southeast side of Pohnpei which is called Sounahleng or "Reef of Heaven."

Esteban (2007, 2014) has analyzed the orientations of several mortuary enclosures of the monumental megalithic city of Nan Madol, finding that the most relevant one, Nan Douwas – the tomb of the former rulers of Pohnpei, located at the easternmost edge of the city – is rather closely oriented with respect to the cardinal points. Towards the eastern horizon, Nan Douwas is facing a narrow channel between two nearby small islands, Nahkapw and Pweliko. Sunrise at the equinoxes or the midpoint in time between solstices occurs just on the north tip of Nahkapw. Some legends tell that the islet of Pweliko – to where Nan Douwas is oriented – is a sacred area, a transit place for the souls of the dead on their way to the final judgment (see Esteban, 2014 and references therein). According to Eastlick (1995), the division between the dry and wet seasons in the traditional Pohnpeian calendar occurs in March and September, approximately at the time of equinoxes. All these facts suggest that the location and orientation of Nan Douwas were carefully planned and that this huge enclosure had a rich ritual, funerary, and perhaps even calendrical symbolism. Another possible astronomical marker on the eastern horizon seen



Astronomical Monuments in Polynesia and Micronesia, Fig. 5 Map of the southeast edge of Pohnpei including Temwen Island, Nan Madol area, and several small reef islands (Na, Pweliko, Nahkapw, and others, map adapted from Morgan, 1988, p. 60; courtesy of the author and the University of Texas Press). The location of the two largest funerary enclosures, Nan Douwas and Karian, is also indicated. The continuous and *long-dashed blue arrows* indicate relevant astronomical orientations defined for Nan Douwas and Karian, respectively. The *short-dashed arrow* indicates the orientation of the perpendicular to the long axis of the outer wall of Nan Madol, which represents the dominant orientation of the southwest part of the city and coincides with the rising point of the Southern Cross (Figure taken from Esteban (2014))

from Nan Douwas is the northern tip of the island of Na, which coincides with the point where the sun rises in the June solstice. An alternative astronomical interpretation also formulated by Esteban (2007, 2014) for the orientations found in Nan Douwas is based on the rising of stars or asterisms at the time of the construction of Nan Madol (about 1200 d. C.). The monument is pointing approximately to the area of the horizon where the stars of Orion's Belt rise. This was an important asterism around the Pacific and one of the directional points of the sidereal compass used by the traditional Micronesian navigators. On the other hand, the northern tip of the island of Na could be related to the rising point of the Pleiades, the most important constellation for the Pohnpeians. Like elsewhere in the Pacific, the heliacal rising of this group of stars has a relevant calendrical significance (Fig. 5).

See Also

► Astronomy in Hawai'i

References

Akerblom, K. (1968). *Astronomy and navigation in Polynesia and Micronesia* (Etnografiska Musset, publication 14). Stockholm: The Ethnographical Museum.

Beaglehole, E., & Beaglehole, P. (1938). *Ethnology of Pukapuka* (Bernice P. Bishop Museum Bulletin No. 150). Honolulu: Kraus Reprint.

Behrens, C. F. (1908). Der Wohlversüchte Süd-Länder, das ist: Ausfürliche Reise-Beschreibung um die Welt. Trans. In B. G. Corney (Ed.), *The voyage of captain Don Felipe González in the ship of the line San Lorenzo, with the Frigate Santa Rosalía in Company, to Easter Island in* 1770–1771 (Hakluyt Society Publication, Second Series, No. 13, pp. 131–137). Cambridge: Hakluyt Society.

Bellwood, P. (1978). *The Polynesians. Prehistory of an island people*. London: Thames and Hudson.

Bennett, W. C. (1931). *Archaeology of Kauai* (Bernice P. Bishop Museum Bulletin No. 80). Honolulu: Kraus Reprint.

Buck, P. (1938). *Ethnology of Mangareva* (Bernice P. Bishop Museum Bulletin No. 157). Honolulu: Kraus Reprint.

Chauvin, M. E. (2000). Useful and conceptual astronomy in ancient Hawaii. In H. Selin (Ed.), *Astronomy across cultures: The history of non-western astronomy* (pp. 91–125). Dordrecht: Kluwer.

Clarke, G., & De Biran, A. (2007). Geophysical investigations at the Pulemelei Mound. In H. Martinsson-Wallin (Ed.). *Archaeology in Samoa. The Pulemelei Investigations* (Archaeology in Oceania, Vol. 42, Supplement, pp. 60–70).

Collocott, E. E. V. (1922). *Tongan astronomy and calendar* (Occasional papers of the Bernice P. Bishop Museum of Polynesian ethnology and natural history, Vol. III, No. 4). Honolulu: Kraus Reprint.

Corney, B. G. (1913–1919). *The quest and occupation of Tahiti by emissaries of Spain during the years 1772–1776* (Vol. 3). London: Hakluyt Society.

Cruchet, L. (2013). *Les dons du ciel des anciens Polyné siens. Archéoastronomie en Polynésie française* (Collection Lettres du Pacifique, Vol. 47). Paris: L'Harmattan.

Da Silva, A., & Jonson, R. K. (1982). Ahu a 'Umi Heiau: A native Hawaiian astronomical and directional register. In A. A. Aveni & G. Urton (Eds.), *Ethnoastronomy and archaeoastronomy in the American tropics* (Vol. 385, pp. 313–331). New York: Annals of The New York Academy of Sciences.

Davidson, J. N. (1979). Samoa and Tonga. In J. D. Jennings (Ed.), *The prehistory of Polynesia* (pp. 82–109). Cambridge: Harvard University Press.

Dhyne, J. (1994). Tonga's Trilithon: A calendric device to mark the seasons? *Rapa Nui Journal, 5*(4), 58–61.

Eastlick, P. (1995). Astronomy and the cultural crossroads. *Mercury, 24*(5), 16–18.

Edwards, E. (2003). *Archaeological survey of Ra'ivavae*. Los Osos: Easter Island Foundation.

Edwards, E., & Belmonte, J. A. (2004). Megalithic astronomy of Eastern Island: A reassessment. *Journal for the History of Astronomy, 35*, 421–433.

Emory, K. P. (1924). *The island of Lanai: A survey of native culture* (Bernice P. Bishop Museum Bulletin No. 12). Honolulu: Bishop Museum Press Reprints.

Esteban, C. (2002–2003). Some notes on orientation of prehistoric stone monuments in western Polynesia and Micronesia. *Archaeoastronomy: The Journal of Astronomy in Culture, 17*, 31–47.

Esteban, C. (2007). Orientación y astronomía en Nan Madol (Pohnpei, Micronesia). In J. Francisco & A. Burgos (Eds.), *Tradiciones y nuevas realidades en Asia y Pacífico* (pp. 65–73). Madrid: Asociación Española de Estudios del Pacífico.

Esteban, C. (2014). Orientations and astronomy in prehistoric monumental tombs of Nan Madol (Pohnpei, Micronesia). In H. Martinsson-Wallin, & T. Thomas (Eds.), *Monuments and people in the pacific* (Studies in global archaeology, Vol. 19). Uppsala: Uppsala Universitet (in press).

Ferdon, E. N., Jr. (1961). The ceremonial site of Orongo. In T. Heyerdahl & E. N. Ferdon (Eds.), *Reports of the Norwegian archaeological expedition to Easter Island and the East pacific, volume 1: Archaeology of Easter Island* (Monographs of the School of American Research and The Museum of New Mexico, No. 24, Part I, pp. 221–255). London: George Allen and Unwin.

Gifford, E. W. (1924). *Tongan myths and tales* (Bernice P. Bishop Museum Bulletin No. 8). Honolulu: Bernice P. Bishop Museum.

Gladwin, T. (1970). *East is a big bird. Navigation and logic on Puluwat Atoll*. Cambridge, MA: Harvard University Press.

Goodenough, W. H. (1953). *Native astronomy in the central Carolines*. Philadelphia: University Museum, University of Pennsylvania.

Grimble, A. (1931). Gilbertese astronomy and astronomical observances. *Journal of the Polynesian Society, 40*, 197–224.

Henry, T. (1928). *Ancient Tahiti* (Bernice P. Bishop Museum Bulletin No. 48). Honolulu: Bernice P. Bishop Museum.

Johnson, R. K. (1993). *Kaho'olawe's potential astroarchaeological resources*. (Kaho'olawe Island Conveyance Commission, Consultant Report No. 9). Wailuku: Kaho'olawe Island Conveyance Commission.

Johnson, R. K., & Mahelona, J. K. (1975). *Na Inoa Hoku. A Catalogue of Hawaiian and Pacific star names*. Honolulu: Topgallant Publishing.

Kamakau, S. M. (1976). *The works of the people of old: Na Hana a ka Po'e Kahiko* (Bernice P. Bishop Museum special publication No. 61). Honolulu.

Kelley, D. H., & Milone, E. F. (2005). *Exploring ancient skies. An encyclopedic survey of archaeoastronomy*. New York: Springer.

Kirch, P. V. (2004a). Temple sites in Kahikinui, Maui, Hawaiian Islands: Their orientations decoded. *Antiquity, 78*, 102–114.

Kirch, P. V. (2004b). Solstice observation in Mangareva, French Polynesia: New perspectives from archaeology. *Archaeoastronomy: The Journal of Astronomy in Culture, 18*, 1–19.

Kirch, P. V., & Green, R. C. (2001). *Hawaiki, ancestral Polynesia: An essay in historical anthropology*. Cambridge: Cambridge University Press.

Laval, H. (1938). *Mangareva: l'histoire ancienne d'un peuple polynésien*. Paris: Libraire Orientaliste Paul Geuthner.

Lee, G., & Liller, W. (1987). Easter Island's "sun stones": A re-evaluation. *Archaeoastronomy, 11*(Supplement to Journal for the History of Astronomy 18), S1–S11.

Lewis, D. (1994). *We, the navigators. The ancient art of landfinding in the Pacific* (2nd ed.). Honolulu: University of Hawai'i Press.
Liller, W. (1989). The archaeoastronomy of Easter Island. *Archaeoastronomy, 13*(Supplement to Journal for the History of Astronomy 20), S21–S48.
Liller, W. (1993). Orientations of religious and ceremonial structures in Polynesia. In C. Ruggles (Ed.), *Archaeoastronomy in the 1990s* (pp. 128–135). Loughborough: Group D Publications.
Liller, W. (2000a). Ancient astronomical monuments in Polynesia. In H. Selin (Ed.), *Astronomy across cultures: The history of non-western astronomy* (pp. 127–160). Dordrecht: Kluwer.
Liller, W. (2000b). Necker Island, Hawai'i: Astronomical implications of an Island located on the Tropic of Cancer. *Rapa Nui Journal, 14*(4), 103–105.
Liller, W., & Duarte, J. D. (1986). Easter Island's "solar ranging device", Ahu Huri A Urenga and vicinity. *Archaeoastronomy, 9*, 38–51.
Makemson, M. W. (1941). *The morning star rises. An account of Polynesian astronomy*. New Haven: Yale University Press.
Malo, D. (1951). *Hawaiian antiquities (Moolelo Hawaii)* (Bernice P. Bishop special publication No. 2). Honolulu.
Martinsson-Wallin, H., Wallin, P., & Clark, G. (2007) The excavation of Pulemelei site 2002–2004. In H. Martinsson-Wallin (Ed.). *Archaeology in Samoa. The Pulemelei investigations* (Archaeology in Oceania, 42, Supplement, pp. 41–59).
McKern, W. C. (1929). *Archaeology of Tonga* (Bernice P. Bishop Museum Bulletin No. 60). Honolulu.
Meech, K. J., Warther, F. X., & Kahi, K. (1996). First beginnings: Astronomy and cosmic architecture in ancient Hawai'i. In V. Koleva & D. Kolev (Eds.), *Astronomical traditions in past cultures* (pp. 25–33). Sofia: Bulgarian Academy of Sciences.
Morgan, W. N. (1988). *Prehistoric architecture in Micronesia*. London: Kegan Paul International.
Mulloy, W. T. (1961). The ceremonial center of Vinapu. In T. Heyerdahl & E. N. Ferdon Jr. (Eds.), *Reports of the Norwegian archaeological expedition to Easter Island and the East pacific, volume 1: Archaeology of Easter Island* (Monographs of the School of American Research and The Museum of New Mexico, No. 24, Part I, p. 93). London: George Allen and Unwin.
Mulloy, W. T. (1975). A solstice-oriented Ahu on Easter Island. *Archaeology and Physical Anthropology in Oceania, 10*, 1–39.
Ruggles, C. L. N. (1999). Astronomy, oral literature, and landscape in ancient Hawai'i. *Archaeoastronomy: The Journal of Astronomy in Culture, 14*(2), 33–86.
Ruggles, C. L. N. (2001). Heiau orientations and alignments on Kaua'i. *Archaeoastronomy: The Journal of Astronomy in Culture, 16*, 46–82.
Smith, C. (1961). A temporal sequence derived from certain Ahu. In T. Heyerdahl & E. N. Ferdon Jr. (Eds.), *Reports of the Norwegian archaeological expedition to Easter Island and the East pacific, volume 1: Archaeology of Easter Island* (Monographs of the School of American Research and The Museum of New Mexico, No. 24, Part I, pp. 181–219). London: George Allen and Unwin.
Stokes, J. F. G. (1991). *Heiau of the Island of Hawai'i: A historic survey of native Hawaiian temple sites* (Bernice P. Bishop Museum bulletin in anthropology, Vol. 2). Honolulu: Bishop Museum Press.
Talbot, D., & Swaney, D. (1998). *Samoa* (3rd ed.). Hawthorn, Australia: Lonely Planet Publications.
Van Tilburg, J. A. (1994). *Easter Island: Archaeology, ecology and culture*. London: British Museum Press.
Vérin, P. (1969). *L'ancienne civilisation de Rurutu* (Asian and Pacific archaeology series, Vol. 5). Paris: O.R.S.T.O.M.

A

Astronomy

Roger B. Culver

Astronomy, the study of celestial objects, is a universally human endeavor whose roots lie deeply buried in prehistory. For the sky-watcher devoid of optical aid, the heavens can be thought of as a sort of earth-centered celestial sphere on to which have been sprinkled hundreds of tiny points of light we have called the stars. Half of this inverted bowl of blackness is almost completely dominated by the dazzling presence of the sun, the most prominent and important of the celestial objects. Such is the sun's brilliance that any attempt to view this object directly is to risk serious eye damage or even total blindness. As a result of the earth's spinning motion or rotation, an observer at a given location on the earth sees a sky that alternates between a daytime sky dominated by the sun and a nighttime sky characterized by its absence. As the earth turns on its axis, the sun appears to rise up from a given observer's eastern horizon, pass through a "high noon point" or maximum angle above the horizon, and then descend toward the western horizon. Approximately one half an earth rotation later, the sun once more rises to repeat the cycle. This rising and falling effect is not limited to the sun. As the earth rotates relative to all celestial objects, they too appear to go through the rising and falling diurnal motions of the sun. Since the rate of the earth's rotation is very nearly constant, this diurnal motion of the sun and stars has long been employed as an important and reliable way of measuring time. The earth's rotation also creates the illusion that the stars of the celestial sphere seem to revolve about two imaginary points located exactly opposite each other. One, the south celestial pole, is visible only from the southern hemisphere of the earth, while the other, the north celestial pole, is visible only from the northern hemisphere. The earth's long-term precessional motion carries the locations of these celestial poles along a 47° diameter circular path among the stars once every 26,000 years. From time to time, a relatively bright star can be found near the position of one of the celestial poles for a few centuries. Such is the case at present for the north celestial pole, which is currently located near the fairly bright star Polaris, the Pole Star.

In addition to its daily rising and setting, the sun also appears to travel along a great circle on the celestial sphere, which is called the ecliptic. This latter movement is the direct result of the earth's orbital motion about the sun. As the earth arcs along in its orbital path, the apparent position of the sun relative to the more distant background stars appears to change. For an observer on the earth, the sun thus seems to creep gradually from west to east among the stars, completing an entire 360° journey around the ecliptic in exactly the same 1 year time interval it takes the earth to complete one orbital revolution about the sun. The background stars hence appear to be gradually overtaken in the western sky by the sun as it moves eastward along the ecliptic, engulfed by the solar glare for a month or so, and then reemerge in the predawn sky as the sun leaves them behind in its ongoing easterly movement. The overall result of this annual movement of the sun is a seasonal parade of the heavens in which different stars are visible at different times of the night at different times of the year.

The earth's axis of rotation is also found to be tilted at an angle of 23 1/2° off the vertical to the earth's orbital plane. As the earth orbits the sun, this tilt causes the sun to shine alternately more directly on the northern hemisphere and less on the southern hemisphere and then vice versa over the span of a simple year. This effect is observable as a yearly variation of the sun's highest altitude above the horizon at a given location, and as a change in the time that the sun spends above the horizon. Thus when the sun is shining most directly on the northern hemisphere at the time of the summer solstice, the sun's diurnal motion in the northern hemisphere is characterized by long days and short nights, and in the southern hemisphere by short days and long nights. Half an orbital revolution or 6 months later at the time of the winter solstice, when the sun is shining more directly on the southern hemisphere, the lengths of night and day are reversed. Halfway between these extremes the sun shines directly down on the earth's equator twice each year. On these dates, the lengths of the days and nights all over the earth are equal, except at the poles, and hence these dates are said to be the equinoxes. It is this combination of the tilt of the earth's axis of rotation and the earth's orbital motion that gives rise to our cycle of seasons here on the earth.

Firmly entrenched in second place in the brightness hierarchy of celestial objects is the moon. Although not as important as the sun, the moon, none the less, exerts several significant influences on the earth, most notably as the chief agent by which tides are produced in the world's oceans. The reflected sunlight we receive from the moon is over one million times fainter than that emanating from the sun, and as a result, the moon can be readily viewed against the backdrop of the stars of the night sky. As the moon orbits the earth in space, it appears to traverse a great circle about the celestial sphere in a fashion not unlike the annual motion displayed by the sun. There are however some important differences between the lunar motion and that of the sun. The moon swings along an apparent path that is tilted at an angle of about 5° to the ecliptic and takes one-twelfth of the sun's time to make a single journey about the celestial sphere. The moon thus moves at an average rate of about half a degree per hour relative to the background stars, an angular speed easily detectable over the course of a single night by a naked eye observer.

Although the moon's half degree angular diameter is almost exactly the same as that of the sun, the diminished brightness of the moon permits us to look directly upon its face without fear or danger. As a result, the moon presents a number of most interesting and fascinating phenomena to the naked eye observer. Perhaps the most familiar of these is the set of seeming shape changes or phases exhibited by the moon as it journeys about the celestial sphere. These phases arise from the fact that as the moon orbits the earth, the half of the moon's spherical surface which faces the sun, and is hence illuminated by the sun's light, is viewed at different angles by an observer situated on the earth. When the moon is very nearly lined up between the earth and the sun, almost all of the moon's sunlit hemisphere faces away from the earth, and all we see of the moon is a very thin crescent of light. As the moon moves toward progressively larger angular distances from the sun, the thickness of the crescent grows or waxes until the angle between the moon and the sun as seen from the earth is 90°. At this point we see exactly one half of the moon's sunlit surface and the moon appears to have a semicircular or "quarter-moon" shape. As the sun-moon angular separation increases past 90°, the moon takes on a bulging or gibbous shape whose thickness continues to grow until the moon is very nearly opposite the sun in the sky. When this configuration occurs, the entire sunlit hemisphere of the moon faces the earth, and the now circular-shaped moon is said to be a "full" moon. After passing through the full phase, the moon's shape changes now proceed in reverse order, successively passing through waning gibbous phases, a second or last quarter phase, and finally a waning crescent phase as the angle between the moon and the sun decreases from 180° to nearly zero. The waning crescent moon eventually slides into the predawn solar glare for a few days and then reemerges as a silvery crescent-shaped "new" moon in the postsunset twilight.

The moon is also unique among celestial objects in that it is the only one for which surface detail can be easily viewed with the unaided human eye. This detail manifests itself in the form of the dark areas on the moon's disk which are called maria or seas and the light areas called continents. This terminology dates back to the Western European Renaissance observers of the moon who imagined the lunar surface to be divided between bright land and dark waters.

In addition to the sun and moon, human beings have recognized since prehistoric times that five other naked eye objects also move about the sky relative to the back-ground stars. These star-like wanderers are called planets, and historically have enjoyed the appellations of the gods and goddesses of ancient Greek and Roman mythology. The five so-called naked eye planets have been named, in order of their increasing distance from the Sun, Mercury, Venus, Mars, Jupiter, and Saturn. A sixth planet, Uranus, possesses a brightness which is just at the limit of naked eye visibility, but the planetary nature of this object does not seem to have been recognized until the English astronomer William Hershel accidentally stumbled upon it in 1781.

Two of the planets, Mercury and Venus, have orbits about the sun which are interior to that of the earth. As a result of this orbital geometry and the sun's gravitationally induced faster orbital speeds, these planets exhibit a marked pattern in their appearances in the earth's sky. In a typical cycle, the planet is first visible as an evening "star" in the west after sunset, then appears to move out to a maximum angle of greatest elongation away from the sun before retreating back into the sun's light. After several days or weeks, the planet reemerges from the solar glare, but this time as a morning "star" in the predawn sky. The planet once more moves out to an angle of greatest elongation and then drops back into the solar light. The swiftly moving planet Mercury goes through a complete cycle of appearances or synodic period in about 4 months, while Venus, whose orbital speed is more closely matched to that of the earth, takes a year and a half for its cycle of appearances. Typically Mercury's appearances as a morning or evening star last about 3 weeks, while those of Venus extend over several months at a time.

Visually, the plant Mercury appears in the sky as a sparkling object having a somewhat reddish-orange tint. Its apparent brightness is actually comparable to the brightest stars, but because it is almost always observed in twilight, it is usually not as impressive an object as it otherwise might be. The most spectacular of the naked eye planets and the third brightest object in the sky behind only the sun and moon is the planet Venus. The orbital path of Venus can carry it out to an angle of greatest elongation as large as 47°, or about twice that exhibited by the planet Mercury. Thus it is possible to observe this splendid object for as long as 4 h after sunset or before sunrise. At its greatest brilliancy, the soft white light of Venus has even been observed to cast very faint shadows as it gleams in the darkness of the predawn or postsunset night sky.

The three remaining naked eye planets Mars, Jupiter, and Saturn, move in vast orbits about the sun which are exterior to the orbit of the earth. As a result, these planets appear most of the time to move about the celestial sphere in a fashion similar to the west to east movement exhibited by the sun and moon. The times required for each of these planets to make a complete cycle about the celestial sphere, however, are far longer than those for the sun and moon. Mars, for example, completes a single journey around the celestial sphere in just under 2 years, while Jupiter and Saturn require nearly 12 and 30 years, respectively, to complete similar journeys. As the faster moving earth catches up to and passes one of these exterior planets, the planet exhibits an illusionary phenomenon in the earth's sky called retrograde motion in which the given planet seems to stop its normal west to east motion among the stars, moves "backward" or east to west for several months, stops again, and then resumes its direct or west to east movement. In the midst of its retrograde motion, a given planet will appear to be opposite the sun's position in the celestial sphere as sun from earth. When such a configuration occurs, the planet is said to be "in opposition to the sun," or more simply, "at opposition." At the time of a given planet's opposition, the earth makes its closest approach to the planet, and as a result, the planet shines more brightly than at any other time. Moreover, at opposition the planet rises at sunset, sets at sunrise, and is thus visible throughout the night.

Visually, the planet Mars is perhaps the most remarkable of the exterior planets owing to its distinctly reddish hue. At times of closest approach to the earth, the apparent brightness of this ruddy world is exceeded only by that of the sun, Moon, and Venus. When Mars is not at a close opposition, the fourth brightest object in the sky is the yellowish-white planet Jupiter which shines some ten times more brightly than the average of the brightest of the background stars. The golden-colored planet Saturn is the most distant of the naked eye planets from both the earth and the sun, and thus exhibits a reduced apparent brightness which is comparable to the average of the brightest background stars.

While the paths of the planets about the celestial sphere are not coincident with the ecliptic, they are, none the less, nearly coplanar with it. As a result, the sun, moon, and five naked eye planets move about the celestial sphere in a relatively narrow band of sky centered on the ecliptic which is called the zodiac. Because the sun, moon, and planets move along the zodiac at differing rates, it is possible for objects in the sky to appear to pass close to other objects along the zodiac. When such a passage occurs, the resulting configuration of the two objects is said to be a conjunction. Conjunctions can occur among the sun, moon, and planets, as well as between these moving objects and the bright stationary stars which are to be found along the zodiac. From time to time conjunctions can involve three or more objects, and on rare occasions a conjunction can be so close that the two objects cannot be seen as separate with the unaided eye.

In addition to the imaginary band of planetary paths that is the zodiac, there exists a quite real band of diffuse light, called the Milky Way, which is stationary relative to the stars and girds the celestial sphere like a gigantic faintly glowing heavenly belt. The Milky Way is the naked eye manifestation of the vast galactic system of gas, dust, and stars in which our sun is located.

The Milky Way Galaxy, as this system is called, is in the shape of a huge, flat pinwheel which has a substantial bulge at its center. Our sun is situated about two-thirds of the way toward the outer edge of this system, and as a result, our view of the summertime Milky Way in the northern hemisphere is the more prominent one, since at this time we are looking toward the direction in which most of our galaxy is located. On the other hand, in the northern hemisphere winter, our view is now directed away from the galactic center toward the less prominent regions of the galaxy, with the visual result that the wintertime Milky Way is much fainter than its summertime counterpart.

Off the plane of the Milky Way, there exist approximately a dozen or so lesser diffuse objects which are visible to the naked eye and are also set in fixed positions among the stars. Modern telescopic observations reveal that these “fuzzy patches of light” are in reality quite a diverse lot, including clouds of glowing gas, star clusters, and even other galaxies well outside of our Milky Way.

From time to time transitory apparitions and events occur in the sky which can be as awesome as they are spectacular. One such event is a total eclipse of the sun. When the moon passes directly between the earth and the sun, a moving shadow of the moon about 240 km wide is cast upon the surface of the earth. An observer located in the shadow’s path will see the sun’s disk gradually covered by the dark lunar disk until the sun’s light is almost completely blotted out. During this “total” phase of the eclipse, only the light from the sun’s outermost atmospheric layers is visible and a darkness comparable to a full moon night descends on the land for a time period ranging from a few seconds to as long as 7 min. Finally the moon moves out of its direct alignment between the earth and the sun, and the sun reemerges to its full disk and full brightness.

The sun, earth, and moon can also align in such a way that the moon passes into the earth’s shadow, thereby producing a total eclipse of the moon. When such an event occurs, an observer on the earth sees a full moon gradually enter the curved shadow of the earth. When the moon is totally immersed in the earth’s shadow, it can take on a variety of ruddy hues ranging from an almost totally darkened red to a bright coppery shade of red-orange. This illumination even at the total phase of a lunar eclipse is caused by sunlight being refracted on to the moon’s surface by the earth’s atmosphere. The variety of colorations exhibited during various lunar eclipses is thus the direct result of the weather conditions in the earth’s atmosphere, especially the degree of cloud cover at key locations around the earth. Typically the eclipsed moon spends an hour or so in the total phase before reemerging from the earth’s shadow and regaining its full moon brilliance.

Every few years or so the night sky is visited by a strange apparition, a diffuse “long-haired” star-like object called a comet. Comets are known to be collections of ices, dust grains, rocks, and frozen gases which wheel about the sun in huge elongated orbits which alternately carry them from relative proximity to the sun out to the most distant parts of the solar system, thousands of earth-sun distances away. As a comet approaches the sun, the sun’s radiant energy causes the ices and frozen gases to evaporate into a glowing coma which surrounds the dust and rocks at the comet’s nucleus. As this diffuse, star-like object draws ever closer to the sun, the solar proton wind and radiation pressure drive material out of the diffuse head into a long, streaming tail which can extend over millions of miles of space. For several weeks, like a cosmic messenger, a comet will approach the sun, blossom with a flowing tail, and then fade into the cold blackness that is the periphery of the solar system.

The debris left behind by both these interlopers as well as from the formation process of the solar system permeates the interplanetary medium. As the earth sweeps along its orbit, it is constantly bombarded by objects ranging in size from tiny grains of dust up to small asteroids several kilometers in diameter. Fortunately collisions with the latter are extraordinarily rare! When a given interplanetary particle, called a meteoroid, strikes the earth, it does so at speeds as high as 50 km s $^{-1}$. At such speeds, friction with the earth’s atmosphere causes the object to heat up quickly and glow brilliantly as it falls toward the earth. An observer at the earth’s surface sees this event as a “falling star” or “shooting star.” Most of the time, such objects disintegrate in the upper layers of the earth’s atmosphere, but occasionally a meteoroid is able to traverse the earth’s atmosphere and strike the earth’s surface. Such an object is then referred to as a meteorite.

Occasionally the earth passes through a large stream of meteoric debris left behind by a comet. Under these conditions, large numbers of meteors can be seen in the form of a meteor “shower.” During a typical meteor shower, one can see anywhere from 15 to 60 meteors per hour above the normal sporadic or background meteor counts of about six meteors per hour. About three or four times per century the earth strikes a particularly large and dense aggregate of meteoroids. Under these circumstances, thousands of meteors per hour flash across the heavens in a display of celestial fireworks which is unmatched anywhere else in the natural world.

From time to time in the remote recesses of interstellar space a star will end its life in a spectacular event called a supernova explosion. For a few days the energy output of this dying object rivals that of all the stars in an entire galaxy. If a supernova detonation occurs at a distance sufficiently close to the earth, the observed result is the transitory appearance of a “new” star in the terrestrial night sky. For time periods ranging from a few days to several months, the star shines at or near its maximum brightness before fading back into naked eye invisibility. One of the more notable of these objects was observed in the year AD 1054. At its maximum brightness, the supernova of 1054 was nearly three times brighter than the planet Venus and could be readily seen in broad daylight. The remains of this stellar blast can be telescopically viewed today as the tattered and twisted gaseous cauldron called the Crab Nebula.

Unlike the mathematical and monolithic universality which characterized the scientific philosophy emergent from the Western European Renaissance, the explanations tendered for the considerable array of celestial phenomena by non-western cultures as well as those of pre-Renaissance Europe and the Mediterranean were far more qualitative in nature and represented a diversity of ingenious viewpoints that were nearly as numerous as the cultures from which they sprang. Generally such explanations appear in a given culture in the form of myths, legends, and folklore, and pay considerable homage to the observed characteristics of the sky and its resident objects. As such, they represent the beginning attempts on the part of human beings to provide rational explanations consistent with observations for the variety of events which occur in the physical world, thereby making that world more comprehensible.

Perhaps the most familiar example of this process in action is to be found in the myths and legends pertaining to the fixed stars. Out of the more or less random distribution of stars in the night sky, one can imagine a variety of figures, shapes, and patterns not unlike the variety of faces and forms that one often fancies in the puffy clouds of a springtime sky. In some instances, a given pattern of stars can bear a striking resemblance to a familiar terrestrial entity. For virtually every culture, such similarities were not fortuitous, but in fact were intrinsic characteristics of the sky which were significant and demanded explanation. The most common approach was to regard the sky as a kind of “Celestial Hall of Fame” into which various legendary characters from a given culture’s folklore had been inducted for various reasons. Such “inductees” thus became figures outlined in stars or constellations. The outline of some of the constellations are so compelling in their shapes that a variety of far-flung cultures would often envision very similar portraits for a given star group. Thus, the stars of the highly prominent wintertime constellation of Orion, for example, seem to outline a very fit and trim individual possessed of considerable physical strength. Thus Orion, the mighty hunter of Greek mythology is also al-Babādur (The Strong One) for the Arabs, the great hunter “Bull of the Hills” for the Blackfoot Tribe of the western Canadian plains, and the “Slender First One” to the Navajos of the American southwest. As one might expect, there is also a considerable amount of variation in the sky pictures of various cultures. Even though the J-shaped array of summertime stars which we call Scorpius the Scorpion has been widely depicted as a celestial version of its earthly arachnid namesake, there are many other interpretations of this asterism from other cultures. The Polynesians, for example, saw this star group as the fishhook of their great hero Maui, while the Chinese viewed it as the noble Azure Dragon, the Bringer of Spring. To the Mayas of Central America these stars represented the death god Yalahau, the lord of blackness and waters.

The constellations through which the sun, moon, and planets travel in their respective journeys about the celestial sphere were quite naturally assigned a particularly significant status as the constellations or signs of the zodiac. Traditionally there are 12 such constellations, each of roughly equal extent along the zodiac, and which include Aries the Ram, Taurus the Bull. Gemini the Twins, Cancer the Crab, Leo the Lion, Virgo the Virgin, Libra the Scales, Scorpius the Scorpion, Sagittarius the Centaur-Archer, Capricornus the Sea-Goat, Aquarius the Water Carrier, and Pisces the Fishes. In addition to the standard 12 constellation zodiacs employed by a majority of the world's cultures, the zodiac has been variously divided throughout human history into as many as 28 constellations by the Chinese and as few as six by the early Euphratean cultures. The denizens of the zodiac exhibit a considerable variation from culture to culture. The Aztec zodiac was graced with the starry presence of a frog, a lizard, a rattlesnake, and a jaguar, while that of the Incas contained a tree, a bearded man, a puma, and the sacred cantua plant.

Numerous explanations were offered for the observed movement of the sun, moon, and planets along the zodiac, virtually all of which centered on the basic idea that only gods and goddesses could possess the power to move among the stars. In the case of the sun the concept was further reinforced by the fact that to look directly on the face of the sun's disk was to incur the sun deity's wrath in the form of severe damage to one's eyes. Thus the sun was the sun god Amon-Ra to the Egyptians and the sun goddess Amaterasu to the early Japanese, and so on.

Eclipses and conjunctions in the sky have also inspired a number of mythologically based explanations. In the Hindu culture, for example, the mortal Rāhu is said long ago to have attempted to partake of the forbidden nectar of immortality. The god Viṣṇu was told of Rāhu's transgression by the sun and moon, and as punishment Viṣṇu proceeded to decapitate Rāhu. Ever since, Rāhu has sought to take vengeance on the sun and moon by pursuing them across the sky in an attempt to eat them. Once in a while, at the time of an eclipse, Rāhu actually catches either the sun or the moon and attempts to devour his prey. As the sun or moon is devoured, it gradually disappears into Rāhu's throat for a time before reappearing at the base of his severed neck as Rāhu attempts to swallow. The entire event is observed here on the earth as an eclipse of the sun or moon.

The sky watchers of antiquity were able to identify a number of basic characteristics relating to the background objects of the celestial sphere. The recognition of the variety of intrinsic colors that characterize the stars, for example, is manifested in names for stars such as the Arabic *Qalb alʿ Aqrab* (Heart of the Scorpion) for the bright red star Antares located at the center of Scorpius and the Hindu *Rohini* (Red Deer) for the ruddy star Alphard in the chest of the constellation of Hydra the Sea Serpent.

Bright stars near the celestial poles have held great meaning and significance to the watchers of the sky. In the third millennium BCE the north celestial pole was located in the constellation of Draco the Dragon near a second magnitude star called Eltanin. Because the heavens of the day appeared to rotate about this star, it was quite literally regarded as an object of pivotal importance. As a result, Eltanin was worshipped by a number of cultures, including the Egyptians who used this star to align a number of their important buildings and structures. As the earth's axis of rotation has precessed, other stars have taken on the mantle of Pole Star, most notably by the stars Thuban in the constellation of Draco and Kochab in the constellation of Ursa Minor, the Lesser Bear, and in more recent cultures by the star Polaris at the tip of the tail of Ursa Minor. Both Kochab and Polaris were regarded by the Chinese as Da Di the Great Imperial Ruler of the heavens, about whom the other stars circled in homage. The Pawnee tribe of the American plains named Polaris "The Star That Does Not Walk Around." To the Pawnee this star was related to the god Tirawahat, and as such, was chief over all the other stars. It was this star that saw to it the other stars did not lose their way as they moved across the sky.

Attempts to explain the true nature of the diffuse objects that dot the sky are understandably less prolific in light of the difficulties that are often encountered in observing them. The major exception is, of course, the Milky Way. Of the diffuse objects detectable in the heavens with the unaided eye, the Milky Way is far and away the most extensive and prominent. This delicate band of light which is also highlighted by an array of brighter stars has thus inspired a variety of explanations which include its portrayal as a celestial river by the Chinese and Japanese, as a Path of Souls to an eternal home by the Algonquin tribe of the Lake Ontario region of southern Canada, and as a band of glowing cinders by which one could find one's way home when lost in the darkness by the Bushmen of Africa's Kalahari Desert.

As imaginative and rational as they were, however, the explanations advanced by different cultures for the variety of celestial phenomena observed in the heavens generally became intertwined with the religious beliefs and societal mores of these cultures. As a result, there was a marked tendency for the explanations of celestial phenomena to take on dogmatic qualities in which they were seldom questioned or challenged by alternate points of view. Moreover, the lack of a telescopic astronomy placed severe and fundamental limitations on the level of insight that was possible regarding the nature of celestial objects. Thus the explanations proposed for various celestial phenomena tended to remain largely unchanged in a given culture, and whatever changes that did occur were not so much the result of additional observational insights, but rather due to a gradual evolution brought on as these explanations were passed on from generation to generation or from culture to culture. Even while armed with an impressive instrumental technology, however, human beings still continue to struggle with questions relating to the fundamental nature of what we see in the sky.

Certain observable aspects of the heavens readily lend themselves to practical usage here on the earth, and the greatest levels of achievement enjoyed by non-western astronomers have come in the discovery, recognition, and application of these characteristics. Systematic observations of the sky reveal, for example, that many celestial phenomena, most notably the diurnal and annual motions of the sun and the cycle of lunar phases, occur with precise and predictable regularity. This observable fact of the heavens has thus been employed by cultures worldwide as a method of accurate time keeping.

The diurnal rising and setting of the sun, with its alternating cycle of daylight and darkness, is the shortest and most convenient unit of astronomical timekeeping, and as a result human beings the world over have employed it, quite literally, as an integral part of their daily lives. A second, much longer unit of astronomical time is defined by one complete journey of the sun around the ecliptic. This annual astronomical cycle is of considerable importance owing to the fact that it is intimately related to the cycle of seasons which occur here on the earth. The cycle of seasons, in turn, is virtually identical to the cycle of vegetative growth and those of some animal activity and migrations. Thus agricultural methods and hunting techniques developed by various cultures were necessarily tied deeply to the cycle of seasons and the sun's annual journey along the ecliptic. Intermediate in length between the day and the year is the time interval required for the moon to pass through one complete cycle of its phases. The lunar cycle is particularly attractive as a timing cycle due to the fact that the ever-changing shape of the moon is readily observable on a daily basis. Sequences of shapes inscribed on Cro-Magnon cave walls and artifacts strongly suggest their use as lunar phase timing devices in just this fashion. Similar sequences carved by the inhabitants of Nicobar Island in the Bay of Bengal are known with certainty to be employed for this purpose.

Unfortunately these cycles are not quite numerically compatible with each other. For example, there are about 365 days in a year, but in reality it takes the sun precisely 365.242199 days to complete one cycle around the ecliptic. Similarly there are 29.530588 days to a cycle of lunar phases and 12.36827 cycles of lunar phases in a year. These discrepancies can create difficulties if one wishes to reckon the time of the year, the start of a given season, or the date of an important religious holiday by simply counting the number of days which have elapsed from some defined starting point such as the day of a solstice or equinox. If one counts the number of days as the year progresses, for example, one would find that after 365 days had passed, the sun would not quite yet have completed its journey around the ecliptic, and after 366 days had elapsed, the sun would have moved slightly past one complete cycle. Over several years' time such an effect can add up to a significant discrepancy between the sun's actual position along the ecliptic and the position dictated by the day count. As a result, a variety of schemes, called calendric systems or calendars, have been developed by various cultures around the world which are designed to synchronize two or more astronomical cycles. The most familiar of these is the addition of 1 day to our calendar every fourth or leap year in order to keep the day count in a given year in agreement with the sun's actual position along the ecliptic.

A number of ingenious techniques were developed by various cultures to monitor the astronomical timekeeping process. The Aztec Temple Mayor, now buried beneath modern Mexico City, was designed in the fifteenth century with two spires that provided a V-shaped notch through which the rays from a sun rising at the time of an equinox shone on to the temple of Quetzalcoatl. At no other times of the year would a rising sun produce this effect. Thus the Aztec temples served quite nicely and deliberately as a device with which the Aztec calendar could be corrected whenever necessary. Similar structural alignments are to be found at Stonehenge in England, in the temples of ancient Egypt, and among the buildings of the ancient peoples of the American Southwest. The Mayas of ancient Mesoamerica developed not only astronomical alignments for many of their structures, but also an incredibly accurate but somewhat complicated astronomical calendar which was based on the annual solar cycle and the synodic period of the planet Venus. The Maya calendar was accurate to within 1 day every 5,000 years. By contrast, the simpler Gregorian calendar used by contemporary society is accurate to within 1 day in 3,300 years.

In addition to the structural alignments, various cultures have also employed natural terrain as calendar correctors. On the top of Fajada Butte at the mouth of Chaco Canyon in the American Southwest, for example, there stand three rock slabs, each of which is about 3 m in height. On the rock wall behind these slabs a first millennium AD people called the Anasazi carved a spiral petroglyph in such a way that precisely at noon of the day of the summer solstice, a dagger-shaped beam of sunlight would neatly slice the petroglyph exactly through its center. Through this clever manipulation of sunlight, the Anasazi were able to mark the time of the summer solstice precisely.

The Hopi and Zuni tribes, also of the American Southwest, make use of a so-called sunrise horizon calendar. As the sun moves along the ecliptic, the points of sunrise and sunset along the horizon at a given location exhibit an annual cyclic shift in which the sunrise and sunset points appear to migrate along the horizon from south to north while the sun is moving from the winter solstice to the summer solstice and then north to south along the horizon while the sun is moving from the summer solstice to the winter solstice. As the sunrise and sunset points pass over various key landmarks along the horizon, each passage is taken as a signal to begin the appropriate agricultural activity such as planting various crops, harvesting, etc.

In addition to timekeeping, earth-sky relations can also be employed to find one's way about the surface of the earth. Such techniques are referred to overall as celestial navigation and have been of considerable importance to human cultures, particularly those which are maritime in nature. There are a number of aspects of the heavens which readily lend themselves as navigational aids. As the earth spins on its axis, for example, a star at or near the celestial pole will not appear to change its position in the sky significantly. More importantly, the point on the horizon directly beneath such a star will also remain in a relatively fixed position as well. Thus for observers in the northern hemisphere, the relatively bright star Polaris is located very close to the north celestial pole, and the point on the horizon directly beneath this signpost star has been used for centuries by northern hemisphere peoples to mark the direction we call north.

Other cultures took advantage of the fact that the angular distance of the pole star above the horizon as well as the locations of the rising and setting points of bright stars and constellations along the horizon changed with one's location on the earth's surface. Thus the Caroline Islanders of the central Pacific skillfully navigated by means of this star compass in which 32 points on the horizon were defined by the rising and setting points of bright stars and constellations such as Vega, the Pleiades, Antares, and the Southern Cross. The Polynesians employed a device called the sacred calabash, which was a gourd into which four holes were bored at the same height near the neck. The gourd was then filled with water to the level of the holes. Using the water level as a horizon, altitudes of stars were then measured by sighting through one of the holes over the opposite edge of the gourd. Thus armed with what was in effect the equivalent of our modern sextant, the Polynesians became most adept at deep-water navigation.

Systematic observations of the heavens also reveal that there exist a number of correspondences between celestial events and configurations and natural phenomena here on the earth. For example, the Egyptians recognized that the annual flooding of the all-important Nile River was at hand when the bright star Sirius made its heliacal rising or first appearance out of the predawn solar glare. The Incas of the South American Andes Mountains noticed that the cantua plant blossomed beautifully each year when the sun was located in our zodiacal constellation of Cancer, but which they named appropriately from their observations as the asterism of the sacred cantua plant. The heliacal risings of the bright stars Rigel, Aldebaran, and Sirius served to warn the tribes of the high plains of western America that cold weather was at hand. In light of such readily observable earth-sky correspondences, it was very logical to assume that similar correspondences exist between celestial phenomena and human affairs. Thus evolved the endeavor which we now call astrology.

Whether the astrological leap of logic from earth-sky to human-sky correspondences is a valid one has, of course, been a topic of considerable debate for many centuries, and since the 1600s the premise that such human-sky correlations exist has been emphatically rejected by western science. Nevertheless, astrology, more so than either timekeeping or celestial navigations, demands access to careful and ongoing observations of the entire heavens for the purpose of interpreting the significance here on earth of what is seen to occur in the sky, and whenever possible, to predict future events in the sky as well. Thus a well-developed ► astrology in China was certainly an important factor in the preparation of the earliest known star catalog in the fourth century BCE, and in the recording of a variety of celestial events, most notably the transitory appearances of sunspots and astrological omens such as comets, which were referred to as *huixing* (broom stars or sweeping stars) and of novae and supernovae explosions, which were called *kexing* (guest stars or visiting stars). So detailed were the records of the Chinese, Japanese, and Korean observations of the supernova event of AD 1054, for example, that modern astronomers were easily able to identify its present remains as the Crab Nebula in the constellation of Taurus, despite the fact that the event went virtually unobserved and unrecorded in Western Europe.

From some cultures, most notably those of the Mayas, Egypt, China, and the Islamic world, careful observations of the sky combined with centuries of relative social and political stability to make possible the discovery of much more subtle and long-term astronomical cycles. The Mayas, for example, were aware of the long-term reappearances of the planet Venus and built the planet's 584-day synodic period into their calendar. Both the Chinese and Islamic observers were aware of the fact that the lunar nodes, or the points on the celestial sphere where the moon's orbit crosses the ecliptic, drift in a westerly direction along the ecliptic at a rate of one complete revolution every 18.6 years and used this knowledge to predict the occurrences of both lunar and solar eclipses.

The Chinese and Islamic observers also recognized that the sun's equinox points drift in a westerly direction along the ecliptic at a rate of nearly 1° per year and made appropriate adjustments in their respective star catalogs and calendric systems in order to account for the protracted effect of this equinoctial precession. Awareness of the shifting equinoxes may have also been the province of the Egyptians as well. A number of additions and reconstructions are found to exist in Egyptian temples and other structures which strongly suggest an architectural response to just such long-term changes in the positions of the equinoxes.

See Also

▶ Celestial Vault and Sphere
▶ Time

References

Abell, G. (1964). *Exploration of the universe*. New York: Holt, Rinehart, and Winston.
Allen, R. N. (1963). *Star names*. New York: Dover Publications.
Culver, R. B., & Ianna, P. A. (1984). *The gemini syndrome*. Buffalo, NY: Prometheus Books.
Jobes, G., & Jobes, J. (1964). *Outer space*. New York: Scarecrow Press.
Krupp, E. C. (1991). *Beyond the blue horizon*. New York: Oxford University Press.
Krupp, E. C. (Ed.). (1978). *In search of ancient astronomies*. New York: McGraw-Hill.
Lockyer, J. N. (1964). *The dawn of astronomy*. Cambridge, MA: MIT Press.
Ruggles, C., & Saunders, N. (1993). *Astronomies and cultures*. Boulder, CO: University of Colorado Press.
Temple, R., & Needham, J. (1986). *The genius of China*. New York: Simon and Schuster.
Williamson, R. (1984). *Living the sky*. Norman, OK: University of Oklahoma Press.
Willis, R. (1993). *World mythology*. New York: Henry Holt and Company.
Zeilik, M., & Gaustad, J. (1983). *Astronomy: The cosmic perspective*. New York: Harper and Row.

Astronomy in China

Ho Peng Yoke

Chinese astronomy became a subject of long debate among historians and astronomers in the first half of the twentieth century. Some based their argument on the *Shujing* (Book of Documents) and concluded that Chinese star clerks had already made astronomical observations between 2000 and 3000 BCE. Richard Schlegel even asserted that they knew about the 28 lunar mansions as long ago as the year 1600 BCE. Others doubted the reliability of the records in the *Shujing* claiming that Chinese astronomy could not have originated earlier than 500 or 600 BCE. Some said that Chinese astronomy originated from India, others said from Arabia, and there were yet those who said that it was from Mesopotamia. Joseph Needham, for example, favors a Mesopotamian origin.

Recent archaeological studies carried out in China have thrown more light on early Chinese astronomy and enabled scholars to re-examine some of the old interpretations. Archaeologists have been hard at work during the last two decades to establish the Xia dynasty, which, according to tradition lasted from the twenty-first century BCE to the sixteenth century BCE, and which has until now been regarded as legendary. They have yet to recover written records of that period. Erlitou in Henan province, where bronze vessels dating back to the year 1700 BCE were recovered in 1971, is one of their important sites. Even the records in the *Shujing* have recently been re-examined by comparison with computed ancient astronomical phenomena.

In the oracle bone writings we can find records of eclipses, novae, and names of stars and some asterisms. The records indicate that the Yin people between the fourteenth and twelfth centuries BCE were already using a lunisolar calendar, where 1 year consisted of 12 moons or lunar months of either 29 or 30 days each, with an extra month known as the intercalary month added about every 3 years. From about the sixth century BCE until the use of the telescope for astronomical observations in Europe in the seventeenth century, Chinese star clerks kept the most consistent and continuous astronomical records on eclipses, comets, novae, sunspots, and aurora borealis in the whole world. Star catalogs were produced during the Warring States period (481–221 BCE) by ► Gan De, Shi Shen, and Wu Xian. Chinese astronomical records have found many applications in modern astronomy. One application is in the calculations of the period of Halley's comet. The Crab Nebula has been identified with the supernova observed in China in the year 1054. The first pulsar was discovered in 1967. It was found to be near a site where a "guest star" was recorded by the Chinese. A "guest star" in Chinese astronomy could refer to a supernova or nova, but it could also mean a comet or even a meteor, depending on the context. In this case it refers to a supernova or nova. As a result some astronomers made use of Chinese records in their attempts to discover other pulsars. Chinese records on sunspots have been used to determine sunspot cycles, and recently they were used in the study of the variation of the earth's period of rotation. There are many other applications for Chinese astronomical records, such as in a recent study of the Star of Bethlehem in the Bible.

There has been a prolonged dispute since the last century over the question of the origin of the 28 Chinese lunar mansions. These are 28 asterisms distributed along the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course). The moon changes its position among the stars night after night, and appears successively in each of these asterisms, appearing from the earth as if it changes its lodging each night. Hence they were known as lunar mansions or lodges. Chinese astronomers also picked one of the stars in every lunar mansion as a reference point from which distances of other stars in its vicinity were measured. The stars used as reference points were called determinant stars. In ancient Hindu astronomy there were 27 *nakṣatras*, each of which had a principal star (*yogatara*). Nine of the *yogataras* are identical with the Chinese determinant stars. Some thought that the lunar mansions and the *nakṣatras* had a common origin, often with Sinologists and Indianists taking opposite sides. Before a conclusion was reached came a third contender, the *al-manāzil*, the moon-stations in Muslim astronomy. Then it was argued that Muslim astronomy was predated by Hindu astronomy. During the middle of the twentieth century the most favored candidate was Mesopotamia, from which ancient Chinese astronomy and others were thought to be originated. This is the view favored by Joseph Needham. The argument against China's favor until then was that all the names of the 28 lunar mansions were not found earlier than the fourth century BCE. However, in the year 1978 the names of all the 28 lunar mansions were found inscribed on the lid of a lacquer casket of the early Warring States period, showing that the 28 lunar mansions were already there in China not later than the fifth century BCE. Chinese archaeological discoveries in the second half of this century and recent archaeological excavations carried out in India have also shown that both Chinese and Indian civilizations existed much earlier than they were thought. Whether the lunar mansions in Chinese astronomy were influenced by the Hindu *nakṣatras* or whether it was the other way round is an open question. Perhaps there was no influence between the two systems at all. The important thing in the study of history of science and civilization is to learn about mutual exchange of ideas among different cultures rather than to engage in futile disputes, claiming priorities and making scores in meaningless contests, in which there is no prize for the winner other than false pride.

The earliest existing Chinese documents on astronomy are two silk scrolls discovered in the Mawangdui tombs in Changsha, Hunan province in the year 1973. One of them, the *Wuxingzhan* (Astrology of the Five Planets) contains records of Jupiter, Saturn, and Venus, the accuracy of which suggested the use of the armillary sphere for measurement. These records were made between 246 and 177 BCE. The other, the *Xingxiangyunqitu* (Diagrams of Stellar Objects and Cloud-like Vapors of Various Shapes) illustrates different types of comets. Among the ancient astronomical instruments discovered by archaeologists are the bronze clepsydra from the tomb of Liu Sheng of the second century BCE and a bronze sundial of the Eastern Han period (25–220). The title of an early Chinese book on astronomy and mathematics, the ► Zhoubi suanjing (Mathematical Manual of Zhoubi), calls to mind either the Zhou dynasty or the circumference of a circle, and the vertical side of a vertical right-angled triangle. The book contains the so-called *Zhoubi* or ► Gaitian cosmological theory in which the heavens are imagined to cover a flat earth like a tilted umbrella, and shows paths for the sun at different seasons of the year. From the positions of the stars and planets mentioned in the text, Japanese scholars established a period between 575 and 450 BCE for the observations and inferred that the book was written within the same period. Christopher Cullen recently showed that the book could well be a work of the early first century.

During the second century ► Zhang Heng (78–139) constructed an armillary sphere as well as a seismograph for making astronomical observations and for detecting the direction of earthquakes. An armillary sphere consisted of a system of rings corresponding to the great circles of the celestial sphere and a sighting tube mounted in the center. With such an instrument Chinese astronomers could measure the positions of heavenly bodies. The mounting of the Chinese armillary sphere deserves special attention. As pointed out by Needham, it has always been equatorial unlike its counterpart in Europe which was ecliptical, but only changed to equatorial in modern telescopes. The new armillary sphere made by Zhang Heng resulted in more accurate observations and better star maps.

An important role of Chinese astronomy was calendrical calculation. The emperor regarded calendar making as one of his duties associated with the mandate that he received from Heaven. The Chinese calendar took into account the apparent cycle of the sun and the cycle of the moon, both of which, as we know, cannot be expressed in an exact number of days. The astronomer responsible for constructing a lunisolar calendar had to make accurate observations of the sun, the moon, and the planets, but however accurate his observations and his calculations, his calendar would sooner or later, in just a matter of decades, get out of step with observations. Hence throughout Chinese history no less than 100 calendars had been constructed. Besides, sometimes there were also unofficial calendars adopted in certain regions in China. During the seventh century Indian calendar-making made its presence felt in China. We can read the names of a number of Indian astronomers and calendar experts who lived in Changan, the capital of Tang China.

In the early days of the Tang dynasty the calendar officially adopted was the *Lindeli* calendar constructed by the great early Tang astronomer, mathematician and diviner ► Li Chunfeng (602–670). By the early eighth century a new calendar became overdue. Eventually the old calendar was replaced by the *Dayanli* calendar constructed by the Tantric monk Yixing (683–727). Yixing's secular name was Zhang Sui. He is regarded as the most outstanding astronomer of his time for his recognition of the proper motion of the stars. In the year 721 the Tang emperor Xuanzong entrusted Yixing with the task of constructing a new calendar. To do this he constructed new astronomical instruments, including an armillary sphere moved round by wheels driven by water, and he also carried out a large scale research project to measure the length of the earth's meridian. He employed the method of difference, involving equations of the second degree, as well as the method of the remainder theorem in the *Suanzi suanjing* to calculate his new calendar.

From the late seventh century Indian Tantric monks had also come to reside in the Tang capital. Later Yixing made frequent contact with them and assisted them in the translations of some of their *sūtras* into Chinese. Yixing could have acquired from them some knowledge of astrology and mathematics, including the idea of a spherical earth and the sine table. There were then three clans of Indian calendar experts living in the Tang capital, namely the Siddhārtha clan, the Kumara clan and the Kaśyapa clan, of which the Siddhārtha clan was the most active and famous. At least two members of that clan had served as Directors of the Astronomical Bureau. The most distinguished member was Gautama Siddhārtha, who constructed an iron armillary sphere when he was director and translated the *Navagrāha* calendar into Chinese in the year 718. Most important of all, he compiled the *Da-Tang Kaiyuan zhanjing* (Prognostications Manual of the Kaiyuan Period of Tang Dynasty) between the years 718 and 726. The word *Navagrāha* means the "Nine Luminaries," namely the Sun, the Moon, Mercury, Venus, Mars, Jupiter, Saturn, and two imaginary planets *Rahu* and *Ketu*. Although this calendar was never adopted in China, it found its way from there to Korea, where it was used for a period of time.

During the Song dynasty (960–1279) astronomers made more accurate astronomical observations using new and larger armillary spheres. They constructed several such instruments, the most famous of which was that made by Su Song (1020–1101). It was an armillary sphere driven by a water-wheel using the principle of escapement. A full-scale study of Su Song's instrument is given in Joseph Needham's *Heavenly Clockwork*. Su Song's instrument was both an armillary sphere and a clock, but it was known only as an armillary sphere. Hence until it was pointed out by Needham, Price, and Wang Ling, nobody knew that the clock already existed in China when Matteo Ricci introduced the clock in the late sixteenth century.

Astronomy during the Mongol period (1271–1368) was closely connected with the name of Guo Shoujing (1231–1316), the last of the great traditional Chinese astronomers. The *Shoushili* calendar that he constructed was the most advanced and accurate calendar ever produced in traditional China. It was made possible by the precise instruments he built and the method of finite difference he used in his calculations. This was also the time when astronomers from the Arab world came to work in China. The Muslims were still active in the Astronomical Bureau when the Jesuits came toward the end of the sixteenth century. The Jesuits arrived at a time when Chinese astronomy was in a state of stagnation, when no one with the knowledge and skill of Guo Shoujing could be found. The Chinese learned pre-Copernican astronomy from them. Modern astronomy came to China only around the middle of the nineteenth century. It did not take long for Chinese astronomy to join the mainstream of modern astronomy. Just as Nakayama Shigeru said that the history of Japanese astronomy was the history of Chinese astronomy in Japan, Chinese astronomy has already become modern astronomy.

See Also

- ▶ Armillary Spheres in China
- ▶ Calendars in East Asia
- ▶ Clocks and Watches
- ▶ Eclipse Observations
- ▶ Gan De
- ▶ Guo Shoujing
- ▶ Li Chunfeng
- ▶ Lunar Mansions in Islam
- ▶ Zhang Heng

References

Ahn, D. (2002). On the transmission of the planisphere astrolabe to China in the late Ming period. *Ziran Kexueshi Yanjiu (Studies in the History of Natural Sciences), 21*, 299–319.

Ansari, S. M. R., et al. (2002). *History of oriental astronomy*. Dordrecht, The Netherlands: Kluwer.

Changhao, L., et al. (Eds.). (1981). *Zhongguo tianwenxue shi (History of Chinese astronomy)*. Beijing, China: Kexue chubanshe.

Chen, C. Y. (1996). *Early Chinese work in natural science: A re-examination of the physics of motion,* *acoustics, astronomy and scientific thoughts*. Hong Kong, China: Hong Kong University Press.

Chen, M. (2002). Zu Chongzhi's works on astronomy and calendar-making: In memorial of the 1500th anniversary of Zu's death. *Journal of Dialectics of Nature, 24*(2), 68–73.

Chu, P. (1999). Trust, instruments, and cross-cultural scientific exchanges: Chinese debate over the shape of the earth, 1600–1800. *Science in Context, 12*(3), 385–411.

Cullen, C. (1996). *Astronomy and mathematics in ancient China: The Zhou Bi Suan Jing*. Cambridge, MA: Cambridge University Press.

Cullen, C. (2002). The first complete Chinese theory of the moon: The innovations of Liu Hong c. A.D. 200. *Journal for the History of Astronomy, 33*, 21–39.

Fatoohi, L. J., & Stephenson, F. R. (1996). Accuracy of lunar eclipse observations made by Jesuit astronomers in China. *Journal for the History of Astronomy, 27*(1), 61–67.

Golvers, N., Verbiest, F., & Ferdinand Verbiest Foundation. (2003). *Ferdinand Verbiest, S.J. (1623–1688) and the Chinese heaven: The composition of the astronomical corpus, its diffusion and reception in the European Republic of Letters*. Leuven, Belgium: Leuven University Press: Ferdinand Verbiest Foundation, K.U. Leuven.

Hashimoto, K. (2004). Jesuit observations and star-mappings in Beijing as the transmission of scientific knowledge. In *History of mathematical sciences: Portugal and East Asia II, scientific practices and the Portuguese expansion in Asia (1498–1759)* (pp. 129–145). Singapore, Singapore: World Scientific.

Huang, Y. L., & Chang, C. (1996). The evolution and decline of the ancient Chinese practice of watching for the ethers. *Chinese Science, 13*, 82–106.

Hu, Z. (1999). A Chinese observing site from remote antiquity. *Journal for the History of Astronomy, 30*(3), 231–235.

Iannaccone, Isaia and Ioannes Terrentius. La Più Antica Rappresentazione Della Sfera Celeste Cinese. I. Quattro Palazzi. (1998). *Convegno Internazionale Archeoastronomia, Credenze e Religioni Nel Mondo Antico,* 95–118.

Kalinowski, M. (1996). The use of the twenty-eight "Xiu" as a day-count in early China. *Chinese Science, 13*, 55–81.

Li, D. (2002). The place of Gaitian theory in the history of astronomy in China. *Nei Menggu Shifan Daxue Xuebao (Ziran Kexue Ban) (Journal of Inner Mongolia Normal University [Natural Science Edition]), 31*(3), 281–289.

Li, D. (2005). Huihui astronomical observatory in Shangdu during the Yuan dynasty: From its beginnings to its destruction. *Nei Menggu Shifan Daxue Xuebao (Ziran Kexue Ban) (Journal of Inner Mongolia Normal University [Natural Science Edition]), 34*, 309–313.

Li, Y., & Zhang, C. Z. (1999). Accuracy of solar eclipse calculations, 1644–1785, with the Chinese "Shoushi" calendar. *Journal for the History of Astronomy, 30*, 161–167.

Liu, C. (2002). Astronomy in the Xia-Shang-Zhou chronology project. *Journal of Astronomical History and Heritage, 5*, 1–8.

Mercier, R. (2003). Solsticial observations in thirteenth century Beijing. *Sciamvs, 4*, 191–232.

Nakayama, S. (1969). *A history of Japanese astronomy*. Cambridge, MA: Harvard University Press.

Needham, J. (1959). *Science and civilisation in China* (Vol. 3). Cambridge, MA: Cambridge University Press.

Needham, J. (1986). *Heavenly clockwork: The great astronomical clocks of medieval China*. Cambridge, MA: Cambridge University Press.

Qiao, L. (1998). L'Astronomia Cinese Antica. *Giornale di astronomia, 24*(3), 37–49.

Qu, A. (2002). Revisit to the solar eclipse theory in ancientChina. *Ziran Kexueshi Yanjiu (Studies in the History of Natural Sciences), 21*, 97–114.

Qu, A. (2005). An intercalary method in Chinese mathematical astronomy. *Ziran Kexueshi Yanjiu (Studies in the History of Natural Sciences), 24*, 190–195.

Shi, Y. (2004). A comparative study of the Qing dynasty astronomical bureau and the royal observatory. *Journal of Dialectics of Nature, 26*(2), 77–82.

Shi, Y., & Lü, L. (2005). An evolving track of Chinese astronomical thoughts in the 17th and 18th centuries. *Kexue Jishu yu Bianzhengfa (Science Technology and Dialectics), 22*, 101–105.

Steele, J. M. (1998). Predictions of eclipse times recorded in Chinese history. *Journal for the History of Astronomy, 29*, 275–285.

Steele, J. M., & Stephenson, F. R. (1998). Astronomical evidence for the accuracy of clocks in Pre-Jesuit China. *Journal for the History of Astronomy, 29*, 35–48.

Taub, L. (1996). On the complexity of the relationship between astronomy and religion: Jesuit missionary-astronomers in China in the 16th and 17th centuries. In J. M. Van DerMeer (Ed.), *Facets of faith and science* (The Role of Beliefs in the Natural Sciences, Vol. 3, pp. 15–29). Lanham, MD: University Press of America.

Tseng, L.-y. (2001). Picturing heaven: Image and knowledge in Han China. Ph.D. dissertiti, Harvard University.

van Dalen, B. (2002). Islamic and Chinese astronomy under the Mongols: A little- known case of transmission. In *From China to Paris: 2000 years transmission of mathematical ideas. Proceedings of a conference held in Bellagio, Italy, May 8–12, 2000* (pp. 327–356). Stuttgart, Germany: Steiner.

van Dalen, B., Yungsik, K., & Bray, F. (1999). *Tables of planetary latitude in the 'Huihui Li' (II)*. Seoul, South Korea: Seoul National University Press.

Witek, J. W. (1996). A dialogue on astronomical phenomena and natural theology in early eighteenth century China. In *Western humanistic culture presented to*

China by Jesuit Missionaries, XVII–XVIII Centuries (pp. 309–329).
Xi, Z., & Chen, M. (2003). Twentieth century Chinese scholarship in the history of astronomy. *Guangxi Minzu Xueyuan Xuebao, 10*(1), 6–11.
Xing, G., & Shi, Y. (2005). On the solar eclipse records from the Han dynasty and their application to the analysis of the precision of the systems of calendrical astronomy of the Han dynasty. *Chinese Journal for the History of Science and Technology, 26*, 107–121.
Yang, X. (2002). Huang Baijia's position in the debate about the left-handed or right-handed rotation of the sun, moon, and five planets around the earth in ancient China. *Ziran Kexueshi Yanjiu (Studies in the History of Natural Sciences), 21*, 222–231.
Yang, S., & Zhang, H. (2001). Influence of Adam Schall's changing calendar on Yun-Qi theory in the early Qing dynasty. *Zhonghua yi shi za zhi (Beijing, China: 1980), 31*(3), 155–159.
Yao, C. (2004). Astronomy activities of the Qintianjian during the Qing dynasty. *Guangxi Minzu Xueyuan Xuebao, 10*(1), 43–46.
Yoke, H. P. (1977). *Modern scholarship on the history of Chinese astronomy*. Canberra, Australia: The Australian National University, Faculty of Asian Studies.
York, T. J. (2001). An analysis of close conjunctions recorded in ancient China. *Journal for the History of Astronomy, 32*, 337–344.
Zhang, Y. (Ed.). (1980). *Zhongguo dabaikequanshu: tianwenxue (The Great Chinese encyclopedia: Astronomy)*. Beijing, China: Zhongguo Dabaikequanshu chubanshe.
Zhang, B. (2001). *The Europeanization of astronomical instruments in the Ming and Qing China*. Shenyang, China: Liaoning jiao yu chu ban she.
Zhang, B. (2003). The introduction of European astronomical instruments and the related technology into China during the seventeenth century. *East Asian Science, Technology, and Medicine, 20*, 99–131.

Astronomy in Egypt

Gregg De Young
The American University in Cairo, Cairo, Egypt

We have few written records dealing explicitly with the heavens, and those that we possess are usually derived from the Greek astronomical tradition and therefore are very late in Egyptian history. Thus, in order to assess the astronomical knowledge of ancient Egypt, we rely on such limited pieces of evidence as "diagonal calendars" that decorate some Middle Kingdom (ca. 2150–1780 BCE) coffins, orientation of tombs and pyramids relative to the cardinal compass points, and astronomical ceilings (and their accompanying inscriptions) used in New Kingdom (ca. 1550–1085 BCE) temple or tomb decorations.

Evidence from the region of Nabta Playa indicates that systematic observations of the heavens were already well developed during the predynastic period (prior to 3100 BCE) of Egyptian history. Here, an ordered array of stones grouped in a rough circle around a central stone are reminiscent of the artificial arrangement of megaliths at Stonehenge, although the Egyptian arrangement is much older.

One of the primary incentives for study of the heavens in ancient Egypt was the necessity to establish the cultic calendar on a firm basis. This cultic calendar, growing out of less formal agricultural and ritualistic calendars, defined the beginning of the year using the heliacal rising of Sothis (modern Sirius). For administrative purposes, a civil calendar was superimposed upon the older luni-stellar cultic calendar. The determination of the administrative year was not defined by astronomical observations, however, but by counting off 365 days from the beginning of the year. Because the civil year contained exactly 365 days, it was typically out of step with the natural or solar year. The two coincided only every 1,460 astronomical years (the so-called Sothic cycle).

The determination of cultic celebrations, however, continued to be based largely on lunar phenomena. In order to correlate the two calendars, the Egyptians used the observation that there are very nearly 309 lunar cycles in 25 civil years. In general, any two successive lunar months had 59 solar days, but every 4 years, the last two months were given 60 days, a correction reminiscent of our leap year. This correlation allowed the priests to predict with fairly consistent accuracy where lunar festivals should fall within the civil calendar, obviating the necessity to observe the heavens in order to determine the time for a particular festival.

The civil year was divided into 36 "decans" of 10 days each, to which five epagomenal days were added. These decans are represented in the diagonal calendars or star clocks depicted on several Middle Kingdom coffins, presumably as a way for the deceased to know when specific spells needed to be recited during the journey to the afterlife. Such star clocks may also have been associated with nightly timekeeping in temples for religious observance. In order to predict the coming of the dawn so as to be prepared to perform essential temple rituals, each hour of the night was associated with one or more bright stars whose heliacal rising would signal the beginning of each hour of the night. Because the sun moves slightly slower than the stars in its apparent circling of the Earth, any chosen star will rise farther and farther in advance of the sun, so that it is an effective indicator of the first hour of the night only for about 10 days, after which the asterism which had originally indicated the second hour now introduced the first hour of the night.

In the New Kingdom, the focus shifted from heliacal rising of each decan star to its zenith transits – an easier phenomenon to observe. But this shift required that the decan asterisms be redefined. These observations apparently involved noting the position of stars relative to the body of an assistant (e.g., when the star is located above his right eye). Charts illustrating this method are seen in the tombs of Ramses VI, Ramses VII, and Ramses IX.

It has often been noted that pyramids, and especially the pyramids of the Giza plateau, as well as numerous tombs and temples, seem to be aligned with the cardinal compass directions. The precision of such alignments points to an astronomical determination of the cardinal directions, although we do not know exactly how this was done. The older hypothesis was that a level artificial horizon was constructed, against which the rising and setting points of a given star would be marked. Bisection of the angle between these two sightings, as measured from the center of the artificial horizon, determines true north. This technique, although possible, appears cumbersome. A somewhat simpler method would have been to erect a gnomon perpendicular to the Earth and to construct around it a circle of arbitrary radius. Mark the two points at which the shadow of the gnomon touches this circle, once before noon and once after noon. The line bisecting the angle formed between these two observations and the gnomon determines true north. We have, however, no surviving evidence to reveal which of these two procedures the ancient Egyptians used. (It is also fair to say that many temples and tombs are not so precisely oriented – many merely face the Nile, which flows roughly from south to north, without regard for local geographical variations.) Although most temples appear to be aligned east and west, two directions that are associated with solar worship, others are explicitly oriented to stars, especially Sothis.

The scanty surviving evidence suggests that the Egyptian observer of the heavens used only the simplest of observational tools, and even these may not have been used extensively prior to the New Kingdom period (ca. 1550–1085 BCE). Nocturnal observations typically involved a *merkhet* (a palm rib notched at its wider end, used in conjunction with a plumb line) to determine the zenith transit of a celestial object. Daytime observations generally involved determination of solar altitude using length of shadows. These measurements were sometimes made using a horizontal graduated bar, with a small perpendicular block at one end to cast a shadow on the horizontal bar. Herodotus reports that the Egyptians knew sundials, but surviving evidence favoring that view is scanty. The shadow clock, however, suffers from the same problems as the sundial. Both are constructed to divide the day into equal parts, although the inclination of the Earth's axis creates unequal lengths of daylight throughout the year, complicating any attempt to regulate time through astronomical observations.

When astronomical observations were not possible, the Egyptians sometimes used a water clock similar to a Greek clepsydra to determine hours. Water is allowed to escape from a container of known volume through a small orifice at the base. The interior is graduated to show the lapse of time. The ancient Egyptians apparently did not appreciate that the rate of outflow is not constant. Here, too, we find that a degree of inaccuracy or indeterminacy seems to have been accepted.

Astronomical ceilings are among the most striking pieces of evidence concerning the ancient Egyptian's knowledge of the heavens. Central to these documents are a group of figures whose composition and orientation change very little with time. These are usually considered to represent the circumpolar constellations, although all attempts to match these figures with visible star groupings, apart from the foreleg (Big Dipper, part of the constellation Ursa Major), have so far been unsuccessful. In addition to these groupings, there are often iconographic and inscriptional references to the naked-eye planets and to individual bright stars (most notably Sothis/Sirius). All of this indicates that the ancient Egyptians were careful observers of the night sky, although probably not overly concerned with reducing these observations to mathematical models of the kind found in Greece.

We know very little about practitioners of astronomy. Only in very rare instances do funerary titles indicate someone who may have observed or studied the heavens for some specific purpose beyond personal curiosity. The evidence indicates, however, that there was a continuing effort to observe and describe celestial phenomena.

References

Belmonte, J. A., & Shaltout, M. (Ed.). (2010) *In search of cosmic order: Selected essays on Egyptian archaeoastronomy*. Cairo: The American University in Cairo Press.

Böker, R. (1984). Über Namen und Identifizierung der ägyptischen Dekane. *Centaurus, 27*, 189–217.

Clagett, M. (1995). *Ancient Egyptian science, Volume II: Calendars, Clocks, and Astronomy*. Philadelphia: American Philosophical Society.

Depuydt, L. (1998). Ancient Egyptian star clocks and their theory. *Bibliotheca Orientalis, 55*, 5–40.

Franci, M. (2010). *Astronomia Egizia: Introduzione alle conoscenze astronomiche dell'antico Egitto*. Edarc: Firenza.

Isler, M. (1989). An ancient method of finding and extending direction. *Journal of the American Research Center in Egypt, 26*, 191–206.

Lesko, L. (1991). Ancient Egyptian cosmogonies and cosmology. In B. Schafer (Ed.), *Religion in ancient Egypt: Gods, myths, and personal practices* (pp. 88–122). Ithaca: Cornell University Press.

Malville, J., Schild, R., Wendorf, F., & Brenmer, R. (2008). Astronomy of Nabta Playa. In J. C. Holbrook, J. O. Urama, & R. Medupe (Eds.), *African cultural astronomy: Current archaeoastronomy and ethnoastronomy research in Africa* (pp. 131–143). Dordrecht: Springer.

Neugebauer, O., & Parker, R. A. (1960–1969). *Egyptian astronomical texts* (Vol. 4). Providence, RI: Brown University Press.

Parker, R. A. (1970–1981). Egyptian astronomy, astrology, and calendrical reckoning. In C. C. Gillispie (Ed.), *Dictionary of scientific biography* (Vol. 16, pp. 706–727). New York: Scribners.

Plumley, M. (1975). The cosmology of ancient Egypt. In C. Blacker & M. Loewe (Eds.), *Ancient cosmologies* (pp. 17–41). London: Allen and Unwin.

Symons, S. (1999). *Ancient Egyptian astronomy: Timekeeping and cosmography in the New Kingdom*. Ph.D. thesis. University of Leicester, Leicester. Available online: http://www.scribd.com/doc/164698572/Ancient-Egyptian-Astronomy-Sarah-Symons-1999-Thesis (Accessed 22 April 2014).

Wells, R. A. (1994). Re and the calendars. In A. J. Spalinger (Ed.), *Revolutions in time: Studies in ancient Egyptian calendrics* (pp. 1–37). San Antonio: Van Siclen Books.

Wells, R. A. (1996). Astronomy in Egypt. In C. Walker (Ed.), *Astronomy before the telescope* (pp. 28–41). New York: St. Martin's Press.

Astronomy in Hawaiʻi

Rubellite Kawena Kinney Johnson

There were two important tasks that drew on ancient Hawaiians' understanding of space and time. One was constructing a ritual calendar for determining the length of the day, week, month, and year; the other was navigating on the seas between island destinations.

The first, calendrics, was the responsibility of the priests, among whom were stargazers called *kilo hoku*, from *kilo* (to observe or to watch), and *hoku* (star). The same stargazers, however, observed more than stars. They knew the sun's motions and those of the moon and the planets, but the stars were the most challenging.

Let us look at this from the standpoint of the student who starts out in "class," which was a place set aside for men and boys to worship the gods. In a place where men only spoke with one another in the men's eating house, the *hale mua*, the "front" (*mua*) house in the compound of the household (*kulana kauhale*), a young boy began his training in these subjects. Since they were part of required religious training, he found himself within rock-walled enclosures, or temple (*heiau*) grounds set aside for men's worship, the *tabu pule* scheduled through seven nights, *na la kapu kauila*, totalling 56 nights in an 8-month period. The 240-day tabu period was followed by 120 days of the *makahiki* season during which taxes (*auhau*) were collected.

No one knows how astronomical subjects were taught, although some information has survived through stories and chants from the migration period of discovery and exploration, with wayfinding practice associated mainly with places visited in ancestral lands to the south. The sun's motion between the north and south and across the equator may have been the first fundamental horizon system to be learned, combined with the observations of stars nearest the rising and setting points of the sun in the morning and evening.

The sun's rising (*hiki*) gives the cardinal direction east its name: *hikina*. When above the horizon, it is *kau*, to be placed or to be hung, but it also means to set, as of the sun afloat westward, *kau lana ka la*. When the sun sets, it "enters" (*komo*) into the world below, so that cardinal direction west is called *komohana*, the "entering" place of the setting sun. When the sun has stopped on its northern journey, that point is called the sun "afloat," *kau lana ka la*. Its daily motion as it arches upward from its eastern azimuth or "pit" (*lua*) to local zenith (*nu'u*) and after noon "declines" ('*aui*) is called *ka'a*, *ka'a ka la ma lalo*, the sun moves down. When it crossed the equator, the sun was said to "trample" (*ke'ehi*) the "diaphragm" (*houpo*) of the god Kane (*ke'ehi i ka houpo o Kane*), the sun being the "eyeball" of Kane (*Kane 'onohi o ka la*). This is the basic compass, adding north for the right ('*akau*) and south for the left (*hema*) sides of the body.

The days were counted as nights of the moon, and there were two revolutions tracked, one synodic, and the other sidereal. Each "night" was clocked into quarters. The clock began at midnight, called *Kau*, or *Aumoe*, the latter meaning "time of sleep." Kau situates the clock on meridian, as at midnight and so also at noon, so the midday was also called Kau. When the sun was in the zenith (*nu'u*, *lolo*) it was called *kau ka la i ka lolo*, the "sun was over the brain (*lolo*)." This position of the sun, not only on meridian but in the zenith as well, took place twice in the year – once when the sun was going north, between May and June, and again when the sun was going south, between June and July. People today may call this "Lahaina noon," but generally the zenith sun appears at the southernmost part of the island of Hawai'i, about 19° north about May 15th (although the date is variable). All other "noons" when the sun is on meridian are called *awakea* after Sky Father, Wakea, whose name is synonymous with noon and the center of the celestial equator, called *Ka Piko o Wakea*, the "Navel of Wakea" (Sky Father). Piko means "center of the body," which has three such piko: one at the top of the skull in the soft spot, the fontanel; one at the navel, and one at the midpoint of the genital area in line with the piko in the middle of the skull. When one lies down, then the piko at the center of the horizontal body, called the '*opu*, is in contact with navel center of Mother Earth, *Ka Piko o ka Honua*. "The Navel of the Earth," or terrestrial equator, which extended beyond earth into the sky is *Ke Ala i Ka Piko o Wakea* (Path to the Navel of the Sky); *Ka Piko o Wakea* is the celestial equator.

The clock having thus two *Kau*, midnight and midday, is an indigenous concept of the "mean day," by which day and night are divided into equal parts. There were no hours, except the quartering for the night, commencing about sunset (i.e., 6:00 p.m.), called a "corner" (*kihi*), and the next "corner" at sunrise, *Kihi puka*; puka means "to emerge," as a celestial body, whether sun, moon, stars, or planets. Between the kihi corners were the *pili* quarters, meaning "close to," as in *pili 'aumoe*, about 9:00 o'clock at night, and *pili puka*, about 3:00 a.m., meaning "close to sunrise." From these data it is appears that the shape of the Hawaiian clock between the two Kihi is angular rather than circular, perhaps a rectangular shape. The day clock is spread out on both sides of noon (Kau, Awakea) by morning (*kakahiaka*), afternoon (*'auinala*, from *'aui*, "to decline," as of the sun), and evening (*ahiahi*). Day and night are *ao* (daylight) and *po* (night).

The moon was regarded as feminine, as passive light or a reflection of the goddess Hina, perceived as ruling the tides, as well as growing sea life on and around the living reef. Each night of the moon had a separate name through one synodic revolution of the moon, or that passage from the first crescent perceived in the west until it returned to that point again in 29.5–30 nights.

The new moon, or dark phase, was *Muku* (cut off or severed). Hina, the moon goddess, was thought to have gone into and through the Milky Way (*Ka Wai Ola a Kane*, "Living Waters of Kane"), in which her dying soul (*Mauli*) revived in the life-giving semen of the creator god. Her spirit was the last crescent waning moon (*Mauli*). On the night of Muku, Hina's spirit was in the Milky Way. After Hina comes through the *Wai Ola a Kane*, the first braid of her gray hair is seen at Hilo after sunset, low on the horizon, alive again. The waxing (*ho'onui*) moon begins at Hilo, moving south until first quarter at 'Ole, thus:

> These ten "nights," or 10 days, were the first *anahulu* decan week of the month and year. In this circuit of 10 days the lighted part of the moon's crescent increased as the moon continued southward. This was followed by two more anahulu decan weeks of rounding (*poepoe*) of the moon when the lit portion lost its "cusps" (*Ole*, milk teeth) until the fully lit circle, after which it began to wane or "shrink" (*'emi*) back to the dark phase of new moon (Muku).

The ritual period of tabu days during 8 months of the year was coordinated between synodic and sidereal lunations, zenith stars, and azimuths of sun and stars in the ecliptic. [The following is excerpted (and readjusted) from Johnson 2000.]

> The first ritual tabu period of the month, called a pule period, was imposed on the night of Hilo and raised on the morning of Kulua…
>
> This period of the Ku pule tabu amounted to 2 and 1/2 days, between Hilo, Hoaka, Kukahi, Kulua…
>
> During the poepoe rounding decan of the waxing moon, the tabu pule period was called the tabu of Hua, imposed on the night of Mohalu (12th night) and raised on the morning of Akua (14th night), i.e., from Mohalu, to Hua, and Akua. This added 1 and 1/2 more days to the 2 and 1/2 day Ku tabu before first-quarter moon…
>
> A tabu pule period was assigned to the god Ka (na)loa. Imposed for 1 and 1/2 days, it began on the night of 'Olepau and ended on the morning of Ka (na)loa-ku-lua, i.e., from 'Olepau to Kaloakukahi and Kaloakulua…
>
> After Kaloa-pau came the 27th night of Kane when began the tabu pule for this god on 1 and 1/2 days, from the night of Kane to the morning of Mauli, i.e., Kane, to Lono, and Mauli. While including the 28th night of god Lono, no tabu pule was set aside for the god Lono during the month.

The tabu period was in force for 240 days and relaxed for 120 days, beginning in the month of October, or the last month of the summer (Kau) season. This anticipated the shift of prevailing winds from the southwest (Kona) and the beginning of the agricultural year, *makahiki*, in November when the Pleiades star cluster (*Makali'i*) was expected to rise above the eastern horizon in the evening, opposite the sun and after the new moon in November.

David Malo, native Hawaiian scholar at Lahainaluna Seminary in the mid-nineteenth century, said:

> The makahiki period began in Ikuwa, the last month of the period called Kau, and the month corresponding to October, and continued through the first 3 months of the period Hooilo, to wit: Welehu, Makalii and Kaelo, which corresponded with November, December, and January…
>
> There were 8 months of the year in which both chiefs and commoners were wont to observe the ordinary religious ceremonies, three of them being the Hooilo months of Kaulua, Nana, and Welo, corresponding to February, March, and April; and five, the Kau months of Ikiiki, Kaaona, Hinaiaeleele, Hilinaehu, and Hilinama, which corresponded to May, June, July, August and September. (Malo, 1951, p. 141)

The moon calendar was a coordination of synodic revolutions of the moon between Hilo and

Muku of 29.5–30 days/nights of the month with sidereal lunations of 27.3 days/nights based on the transit of the meridian by a star, probably during quarter moon ('Ole nights) until the next transit.

What is the significance of the sidereal/synodic count in lunations of the moon's revolution around the earth and sun in 1 year? (1) The principle of the sidereal count is that, with respect to a star on the meridian, the moon's period of revolution around the earth is 27.3 days (Kane is the 27th night of the lunation). (2) The principle of the synodic count says that from its starting point at new moon, until it returns to that point, the moon revolves around the earth once every 29.5 days. Thus, (3) For every sidereal revolution of the moon around the earth in 27.3 days, the earth moves 1/13th of its orbit around the sun (with respect to a star on the meridian).

What was then the mode of intercalation to coordinate the sidereal with synodic lunations? We may only infer how that would have been done.

1. If we erase the 1/3rd fraction (Kane = 27 nights)
2. Then: 27 days × 13 months = 351 days = 1 sidereal year
3. We intercalate the fortnight (14 days) = 365 days = 1 tropic year
4. If we include the 1/3rd fraction, then: 13 sidereal months = 27.3 × 13 = 351.39 days
5. Intercalate 13.86 days = 365.25 days

This segment in *Kumulipo Mind* explored the relationship between the indigenous system and that borrowed from nineteenth century European calendrics after contact:

> This formula provided an iconography of time in the sacred structure of temples and ritual schedule to a numerology, such as 16 sidereal lunations is equivalent to 32 fortnights (13.5 days × 16) and 432 days, the significance of which has been explored in the discussion of the decan system and tropic. (Johnson, 2000, p. 111–112)

Perhaps by pure chance the formula appears again in the Babylonian use of base 60 in the division of time connected to the earth's rotation on its axis such that 15° equal 1 h circle of the earth's rotation, thus:

1. 1 min = 60 s
2. 60 min = 1 h
3. 1 h = 3,660 s
4. 24 h = 1 day
5. 1 day = 1,440 min
6. 1 day = 86,400 s
7. 12 h = 43,200 s
8. 6 h = 21,600 s
9. 3 h = 10,800 s
10. 1 1/2 h = 5,400 s
11. 3/4 h = 2,700 s
12. 3/8 h = 1,350 s

By this may be comprehended that the basic determination is made that the "turning" (kahuli) of the earth on its axis, or because of its rotation, creates the meridian, called *kaupoku o ka hale*, the 'ridgepole of the house' (meaning the house of God, the heiau), cutting the night/day into two halves by which celestial bodies ascend to the zenith (nu'u) and transit by descent to the horizon.

The motion, however, is the earth rotating on its axis, which could not be seen except as a change.

> O ke au i kahuli, wela ka honua
> O ke au i kahuli, lole ka lani...
> In the time of turning over and around,
> The earth became hot; the sky changed
> [Wa Akahi, Kumulipo].

> The passage of time is then measured by equalizing time on either side of the meridian, as between noon and midnight, or midnight to midnight, or noon to noon. The clock is geared to time elapsing between meridians, rather than between sunset and sunrise, or vice versa. The Hawaiians, like the Babylonians, had discovered the "mean day". By it they set their clock to keep track of the length of one day as from one midnight to the next.

The apparent movement of the sun was observed along the horizon between November and February as a slow period (actually, of the earth's orbit around the sun) and the fast sun between March and October. Perhaps the ancients had determined when the sun appeared to have crossed the celestial equator sometime in

April and again in October, or the minor axis of the ecliptic, the major axis between January and July constituting the anomalistic, rather than the tropic year (i.e., the orbit of the earth around the sun).

This was essentially the story of demigod Maui lassoing the sun to make it go more slowly during the winter months by tying down all 16 legs of the sun to a *wiliwili* tree on the western slopes of Haleakala in east Maui. The sun's motion north and south between the solstices was perceived as the motion of a spider (*ke ala a ke ku'uku'u*) as it laid down a web of the celestial grid through which the stars are tracked in their fixed courses from east to west in the night sky.

Finally, as in classic cosmologies of the Mediterranean and Eurasian systems, the sky becomes a pictorialized storyboard conveying by imagery and metaphor the positions and movements of constellations as characters from the ancestral heroic traditions of the past, so that the sky is not filled with nameless lights. The following is part of a continuing quotation excerpted from *Kumulipo Mind*:

> The 'way of the spider' is known in Hawaii as the ecliptic, Ke-ala-a-ke-ku'uku'u 'pathway of the spider' (ku'uku'u, 'to let down, as a net') who is called Tukutuku-raho-nui (spider-of-large-scrotum) 'Great Spider', Tahitian (and Tuamotuan) tutelary deity of net-weaving in the Tahaki cycle.
>
> The pathway of this spider was shown on the navigation gourd (ipu makani) diagrammed by Kaneakaho'owaha, counselor to Kamehameha I, in old Hawaii. It had several markings: the celestial equator, Ka Piko o Wakea 'The Navel of Wakea (Sky Father)'; the ecliptic, Ke ala a ke Ku'uku'u 'The Path of the Spider', which was divided into four parts:

1. The limit of the sun's path in the north on the 15th or 16th day of the month Kaulua (June, for Gemini), the summer solstice, Ke Ala Polo-hiwa a Kane "The Black Shining road of Kane"
2. The limit of the sun's path in the south on the 15th or 16th day of the month Hilinama (December, unidentified), Ke Ala Polohiwa a Kanaloa "The Black Shining Road of Kanaloa"
3. The eastern quarter, Ke Ala'ula a Kane 'The Dawning of or the 'Bright (Red) Road of Kane'
4. The western quarter, Ke Ala Ma'awe'ula a Kanaloa 'The Red-Track (as of a spider's thread, from *awe*, strand, thread; '*awe*, tentacle) of Kanaloa'

> A line was drawn in by burning in (pyrogravure) between the North Star (Polaris) and the Southern Cross, indicating the meridian. From another tradition of the navigation gourd, according to Theodore Kelsey, the night sky was graphed, in the form of a net (koko) woven over the calabash of mesh squares, a grid numbering 24–36 spaces (maka), as of a net ('upena), called na maka o 'Alihi 'the eyes of 'Alihi. Below the rim of the gourd, securing the mesh to the rim, was a red cord of 'olona twine called the 'Alihi, corresponding to the name of Tahaki's loyal cousin and helper, Karihi, who assisted Tahaki in reaching the sky world (Kelsey, in Johnson & Mahelona, 1975, pp. 150–152).
>
> The Hawaiian navigation gourd net which bears the name of Karihi as the supporting red cord, 'alihi, and the 'eyes of Karihi', na maka o 'Alihi, is a parallel to the net of Tahaki fashioned by Tukutuku-raho-nui 'Great Spider' (Tahiti) whose path was outlined between the solstices and equinoxes on the ecliptic.

Tahaki's birth, like that of Maui, was in a West Polynesian home, and the place where Hema (Sema) was 'caught by the 'A'aia' was in Kahiki-west, or Viti, meaning in the direction of Fiji. In the Ulu genealogy, Kaha'i appears in the tenth generation after Maui.

In Hawaiian myth the spider's web as the shape of the spider in the sky is a form of the supernatural hero, Kana, son of Haka-lani-leo and Hina, chief and chiefess of Hilo, island of Hawaii. Kana was the grandson of Uli, the goddess, and Ku. Uli was the sister of the sky god Wakea and Manu'a (god of the underworld). The name Manu'a belongs to Samoa.

Kana is born supernaturally as a rope which was thrown into a pig pen and forgotten. He is the 12th son. The spirit of the cast-away baby visits the grand-mother Uli, and she recovers the neglected rope, putting it into a calabash of water where it grows 40 fathoms in 40 days, or one fathom a day, but no more than 400 fathoms.

In the meantime Kana's older brother, Niheu, who is only half as tall (5 feet) as his ten brothers, is the only person able to lift the 10-fathom 1-yard-long great *ulua* fish. Niheu tells his father he is unable to rescue his mother.

Kana is sought to help Hina because of his superb stretching powers, so Kana is sent by Uli to help Niheu rescue Hina from Keoloewa of Moloka'i. Meanwhile Keoloewa orders the turtles to raise the fortress, Ha'upu, on Moloka'i, higher. Niheu tries to climb it but is distracted by the plover who plucks five hairs from his head, whereupon Niheu falls, breaking his leg. (All of Niheu's strength is in his hair, which is never cut). So Kana employs his bodies to reach Haupu fortress:

> . . .Kana was very angry, for he knew that now they would have a great deal of trouble in rescuing their mother again. Kana turned over in the mats and having thus broken the ropes, stood up. The king saw that this man was taller than his fortress. As Haupu was slowly raised higher and higher, Kana stretched his body, first his human body, then his rope body, next his *convolvulus* (morning glory) vine body, his banana (cordage) body, and last his spider web body. (Fornander, 1969, pp. II: 16–18)

In a Kaua'i variant the motif of Kana's changing the hill by stamping (on) it with his foot (*ke kapua'i a Kana*; *kapua'i*, measuring foot; (vs.) *wawae*, "foot," as of the body) is repeated. The name of the hills raised by the turtles, both on Moloka'i and Kaua'i, is Haupu:

> Kana was afraid that it would reach too high, so he stretched himself up until his body was no larger than a spider's web. When he was tall enough, he put his foot on top of the mountain and crushed it down [Another trait of his demigod is that he possessed two large, staring eyes].

In the tale of Kana the spider's web is the equivalent of the cord kept in a calabash of water. The cord measures out from the calabash, forming a 40–400 fathom rope. This may be interpreted again as the bailing gourd (*Hina-ke-ka*) filled with water and kept on the canoe.

The god of the golden plover, *kolea*, was Lono-kolea-moku, symbolized as a red stone in the heiau foundations at Cape Kumukahi, Puna, Hawaii. The rock was the first in a row of five stones, four of which were called "The Wives of Kumukahi," spaced around the cape and used to mark positions of the sun at its northern (*Hanakaulua* [Gemini]) and southern (*Kanono*, unidentified) limits.

The name Kumukahi (First Foundation) given to the easternmost point of land in the Hawaiian group is associated with the migration of Mo'ikeha from Tahiti. His younger brother, Kumukahi, got off the canoe near the place bearing his name, while Mo'ikeha continued northward. Several others jumped ship between Hawaii and Kaua'i, and Mo'ikeha pressed onward with his companion, La'amaomao, who had the wind calabash (*Ipu makani a La'amaomao*). La'amaomao would call the winds into the *ipu* when they were too strong for the canoe or summoned them forth out of the *ipu* when the sea was dead calm. Yet, when Mo'ikeha sent Kila, his youngest son, to Tahiti to get another son (or nephew), La'amaikahiki, La'amaomao was not in the returning crew doing all of the navigation for Kila.

About four to five centuries later, in the sixteenth to twentieth generation after Mo'ikeha, his mother, La'amaomao-wahine, bequeathed the wind calabash of La'amaomao to Ku-a-Paka'a:

> When La'amaomao finished talking, she opened the cover of a large gourd (ipu nui) and drew out a certain small gourd (ipu hokeo 'u'uku) which had been woven tightly with 'ie (Freycinetia) cord with a cover (po'i) on top.
>
> Then she turned to her son: "I give this gourd to you, as its name was your grandmother's name and mine also, and within it are her bones. When she was alive, all of the winds of this archipelago were her servants, beneath a marvelous power which she received, and she gathered all of the winds into this gourd, and they are still in this gourd until now, and their names were committed to her memory, those from Hawaii to Ka'ula, and when there was no wind, she would remove the cover and call the wind, and the wind would then blow, and when the cover was replaced the wind would cease, and this gourd was famous as the 'Wind Calabash of La'amaomao'." (Nakuina n.d).

The account of the wind calabash of La'amaomao finds a parallel in the Rarotongan tradition of the wind god, Raka-maomao, whereas in Samoa La'amaomao was a war god. In the tradition of Rata, the wizard Nganahoa combats the demons of the sea in a floating calabash called a "red gourd" ('*ue kura*) from which he divines their approach and continues to warn the doubting Rata. Nganahoa, a wizard who flies kites, applies to Rata to go with him on his voyaging canoe to find Vahieroa. Rata considers him useless and leaves without him, but Nganahoa follows him on a large gourd floating on the sea:

> At the time that the canoe sailed away there were only eleven men on board. The canoe sailed on until the land was out of sight, when the crew descried a large gourd floating on the surface of the sea. The crew threw Ngana'oa and his gourd overboard, and left him to his fate (as they thought).
>
> . . .The canoe proceeded on its voyage, and had sailed on for some distance when the crew noticed another gourd floating on the ocean; they at once cried out, 'There is our 'ue-kura floating on the sea.' Rata heard them and called out, 'Pick it up.' They did so, and when they opened it they were again confronted by the glistening eyes of Nganahoa. (Nakuina, 1910)

Nganahoa in this form is the bailing calabash, like Hina-ke-ka. In the Tuamotus, Nganahoa is a star represented in Rarotonga as a character prominent in the Rata story. Like Tahaki (Kaha'i), Rata (Laka), grandson of Tahaki, goes on a voyage to find his father, Vahieroa (Wahieloa).

In Hawaii, Nganahoa is the name of the phallic rock on Moloka'i, Ka Ule o Nanahoa (Penis of Nanahoa). This ule was Ul or Uun "Aldebaran" (Hyades, in Taurus) in Micronesian star names. Aldebaran was one of the "four royal stars" or "Guardians of the Sky" in Persian astronomy, 5,000 years ago, when it marked the vernal equinox (Allen, 1963, pp. 383–385).

A peculiar attribute of Nganahoa in the Rarotongan version is that when the bailing calabash was brought aboard the canoe, all that was seen inside were the staring eyes of the wizard. In the Ipu-makani-a-La'amaomao carried by Mo'ikeha on his journey, La'amaomao was, apparently, not a body on the canoe, but rather, the bones of an ancestor in the calabash by which Mo'ikeha called the winds to come out when the ocean was dead calm, calling them back when the winds were too strong.

> Aldebaran (Nganahoa, Ka Ule o Nanahoa, Ul, Uun] in Taurus has been an ancient ancestor of star-worshipping wind-watchers on deserts as well as oceans. That the gourd was encased in basketry in Hawaii is clear in the case of the wind calabash of La'amaomao, but the Unu o Lono shrine, as the Ipu o Lono god image in the hale mua men's eating house, was suspended from a net (koko), reminiscent of the net ('upena) that went across the sky in the Kaha'i story.

Often ignored but present in the tradition of the Ipu o Lono is a small note, "This image had suspended from its neck a gourd, ipu, which was perforated to receive a wooden bail" (Malo, 1950, p. 88). This means that the larger gourd of Lono, the *unu* (temple), also carried the *ka* bailing cup, gourd symbol of the goddes Hina-ke-ka, canoe-bailer form of the moon (goddess) (Johnson, 1989, p. 50).

> The Ipu-makani-a-La'amaomao wind calabash is, in part, derived from the Malay word for 'compass', *mata angin*, 'eye of the wind' (*angin*). The standard Polynesian wind compass had eight 'eyes' (*maka*) or as many as 32 wind directions ('Aitutaki, Cook Islands). Hina-ke-ka, the bailing gourd, was not the wind compass (Ipu-makani-a-La'-amaomao). It was a reflecting mirror or an instrument used as a plumb bob or water level. The Nganahoa calabash carried by Rata (Laka) was thrown out into the sea ahead of the canoe.

If Rigi was the Milky Way in the Caroline Islands (Micronesia) whose worm body became the "Eyes of the Pleiades" (Mata-riki, Makali'i) and was the companion (*hoa*) of Rigi, Aldebaran? After the Pleiades sets, Aldebaran is right behind it all of the time. When the Pleiades rise, Aldebaran is right behind them again. It was called "The Follower" (Al Dabaran), i.e., of the Pleiades, originally given to the entire group of the Hyades (Allen, 1963, pp. 383–384). This composed the letter *A* as the *alpha* in the alphabet derived from the head of the bull consisting of Aldebaran as the eye in the face and the other stars above the head constituting the horns. This eye was the Ule o Nanahoa (Nganahoa) in the wind calabash of La'amaomao (Hawai'i) that had helped Rata sail his canoe in the lands between Samoa, Tonga, and probably, Rarotonga where the tradition is prominently remembered as it is in Hawai'i.

The sky was a place to picture the characters and creatures in the heroic Polynesian past. The major figure was the culture hero and demigod

Maui-ki'iki'i-a-Kalana whose position in the stars favored the constellations of Hercules, Ophiucus beneath, and Sagittarius in the ecliptic to the south. Available to Maui in that hour circle and the adjoining one is the constellation of Scorpius, with which the hero pulled up the land of Hawai'i as a giant fish. Scorpius is pictured as the fishhook that Maui used (Ka makau nui o Maui), three stars lying from east to west above the bright star and mid-shank of the hook, Antares, first magnitude star in the fishhook constellation as it curves around Shaula (Mohalu) to Leshaa in the barb. From the city of Honolulu this "hook" rises over the crater of Diamond Head to the southeast and drags over the sky until it sets to the west. Maui in Hercules sets before the hook ascends, 180° away on the eastern horizon, or a composition of Maui's three brothers, Maui-mua, Maui-roto, and Maui-pae, who are the three stars in the Belt of Orion stretched over 10° on either side of the equator. They are pictured as sitting in a canoe as they are helping Maui to pull together the fish that Maui caught and which drifted into separate parts. They were told not to look back, and as one of the three brothers does look back, the fish comes apart again into separate islands. Otherwise they are three men in a boat in a canoe house straddling the equator. Beside the Belt of Orion in the place of his sword, the ancient Hawaiians evidently saw the same shape of a weapon, calling it Na Kao, the javelins, i.e., the Belt and Sword of Orion, or perhaps they mistook it for Na Ka o Makali'i, the bailers (i.e., bailing gourds) of Makali'i (in the Pleiades).

Another interesting facet of Scorpius is that it lies within the swirling, twisting motion of a stream or pond of water, the Milky Way, as it courses or spirals across the sky during its own moving about. It will be seen stretched across the sky as a diagonal, from northeast to southwest, and only certain stars and constellations lie in the stream, called the Wai Ola a Kane, or living waters of Kane, the creator-god. In the same stream lies a reptile or shark called 'Aikanaka, whose wife is the moon, Hina-hanai-a-ka-malama. Through the year the lizard or reptile will jackknife across the overhead skies as the swirling stream moves until it is lying from northwest to southeast. Then it lies in two separate streams across the north and across the south, and then arches around the entire visible horizon before it slips off the edge of the world and comes back again, spiraling across the sky from northeast to southwest.

This is the galaxy, and the center around which it spirals is the galactic equator, and by it the ancient priesthood also told time. The motion of breaking up of the spiral was called *Kaha'i*, *Ha'iha'i*, *Ha'imoha'i*, for another hero of the migrations, Kaha'i, who went to the skies on a rainbow to look for his missing father, Hema. Only certain stars and constellations are found in the *Wai Ola*, pictured also as a coconut tree, with branches opening to the north and the roots growing to the south. Sirius lies outside this swirl, seeming to be alone and thus called, Lono-meha, "Lone Lono." Another star that seems to shine alone and brightly to the north is Arcturus in Bootes, called Hokule'a, meaning "clear star" or "star of gladness," according to the Polynesian Voyaging Society which named the canoe after Arcturus.

Otherwise, the Milky Way was called the "spine," *Kuamo'o*, in which the following were always found: Castor and Pollux in Gemini, called the "Twins"; Mahana Kaulua, or Na Mahoe, the twin in front, Castor, Mahoe Mua, and the twin behind, Pollux; Mahoe Hope; the Hyades, Kaomaaiku or Kanukuokapuahi; the Magellanic Clouds, "butterflies," Pulelehuakea, Pulelehuaeli; stars in Lyra, Keoea, Keho'oea, and Scorpius.

In the opposite pole, Canopus was called the solitary "Lord of Space," Ali'i-o-Kona-i-ka-lewa. It occupies the pole at one time, the star Achernar at another, and then there is the Southern Cross, rising on its side in the east, then coming upright, before tilting to the west and going out of sight. Some Hawaiians see a triggerfish, *Humu*, as the *humuhumu-nukunuku-a-pua'a*, or pig-snout fish in which the pig demigod, Kamapua'a, made his journeys by sea assuming the form of a triggerfish. The snout of the fish is pointed downward and the fin upward. Others knew the Southern Cross as a "cross" Hoku Ke'a, or a batfish, one of the skates or rayfish with wings outspread, tail upward, guilty for stealing the moon and hiding her, mother of culture hero Maui-ki'iki'i-a-kalana. So Maui retrieved Hina from the clutches of the batfish by waiting for the demon fish to close all of its eight eyes in sleep before he cut all of them out of the head of the monster. Another *humu* star, meaning, to be sewn or patched together, *humu*, is Humu, or Altair in Aquila, west of Maui-ki'-iki'i-a-kalana. The pole star to the north, Polaris, is called Hokupa'a, "Fixed Star," but then all stars fixed in their tracks were called *na hoku pa'a* as against "wandering stars" or planets, the *hoku ae'a*, "wandering" or "vagabond" stars. The whole constellation of the Big Dipper was called "The Seven," Na Hiku.

Below the pole starting with Perseus is a line of stars that meets up with the asterism of the Pleiades in the head of the Bull, Taurus. These stars are called *a line*, i.e., Ka Lalani. Near the Pleiades, called "Little Eyes", Makali'i, are the Hyades, which are the opening of the fireplace, *Ka Nuku o Kapuahi*, recalling perhaps, as on the island of Mangaia in the Cook group, that a tribe of people suffered being cooked alive in an oven. Aldebaran in the eye of the Bull is called *Ka Oma Aiku*, meaning the adze of Aiku, one of the heroes of the migrations in the south, also known as Aukele-nui-Aiku, a navigator who found the home of Pele's sister in Ra'iatea and Borabora. The other "twins," Mahapili, are in Scorpius. The orbit of the stars was called the "circular road," *Ala Poai*. For the most part, so many star names retained in the nomenclature are unidentified, indicating the loss of much that the ancients had identified about the sky concerning the heroic past of their own wanderings, as they often called it, to go over the horizon ever receding.

Muku	0	"cut-off"	New moon, dark phase
Hilo	1	"braid"	Moon in the west
Hoaka	2	"tusk" (moon shad ow, boar tusk)	
Ku-kahi	3	Ku-1 "cusp" (moon going south)	
Ku-lua	4	Ku-2	
Ku-kolu	5	Ku-3	
Ku-pau	6	Ku-end	
'Ole-ku-kahi	7	'Ole-1 "eye-tooth" (moon in the south)	
'Ole-ku-lua	8	'Ole-2	No planting nights
'Ole-ku-kolu	9	'Ole-3	Moon southeast
'Ole-pau	10	'Ole-end = one *anahulu* decan week of 10 days	

(*continued*)

Huna	11	"hidden" as cusps of the moon
Mohalu	12	Shaula, in Scorpius
Hua	13	Jupiter = one-half sidereal lunation
Akua	14	God (moon in the east)
Hoku	15	Star (full moon)
Mahealani	16	16th moon (full moon)
Kulu	17	"drop" (waning moon)
La'aukukahi	18	"plant" 1 (moon going north)
La'aukulua	19	"plant" 2
La'aupau	20	"plant end" = two anahulu decan weeks
'Ole-ku-kahi	21	'Ole-1 (quarter moon, north)
'Ole-ku-lua	22	'Ole-2
'Ole-pau	23	'Ole-end
Kaloa-ku-kahi	24	Ka(na)loa 1"god of the sea" (fishing)
Kaloa-ku-lua	25	Ka(na)loa 2
Kaloa-pau	26	Ka(na)loa-end
Kane	27	Milky Way = one sidereal lunation
Lono	28	Lono (moon west of north)
Mauli	29	"spirit"
Muku	30	"cut-off" = three anahulu decan weeks
		=one synodic lunation

(1) Tabu pule of Ku	2 1/2 nights	Hilo, Hoaka, Kukahi, Kulua
(2) Tabu pule of Hua	1 1/2 nights	Mohalu, Hua, Akua
(3) Tabu pule of Kanaloa	1 1/2 nights	Olepau, Kaloakukahi, and Kaloakulua
(4) Tabu pule of Kane	1 1/2 nights	Kane, Lono, Mauli

See Also

► Stars in Arabic-Islamic Science

References

Allen, R. H. (1963). *Star names, their lore and meaning*. New York: Dover Publications.

Fornander, A. (1969). *Account of the Polynesian race*. Rutland, VT: Charles E Tuttle Publishing Co.

Johnson, R. K. *The Kumulipo mind, a global heritage* (published over the internet by MightyWords, 2000, and FatBrain, 2001; no longer available).

Johnson, R. K., & Mahelona, J. K. (1975). *Na Inoa Hoku: A catalogue of Hawaiian and pacific star names*. Honolulu, HI: Topgallant Publishing Company.

Malo, D. (1951). *Hawaiian antiquities*. Honolulu, HI: Bishop Museum.

Nakuina, M. K. (1867–1911). Moolelo Hawaii o Pakaa a me Ku-a-Pakaa, na Kahu Iwikuamoo o Keawenuiaumi, ke Alii o Hawaii, a o na Moooopuna hoi a Laamaomao, (unpublished manuscript, n.d.; translated by Rubellite K. Johnson from the original Hawaiian text).

Nakuina, M. K. (1910). The Rarotongan version of the story of Rata. *Journal of the Polynesian Society 9*.

Stimson, J. F. (1957). *Songs of the sea kings*. Salem, MA: The Anthoensen Press.

Astronomy in Japan: A Cultural History

Steven L. Renshaw
Center for Asian and Pacific Studies, University of Iowa, Iowa, USA

Japan's astronomical heritage, like so much of the culture's history, is one of enigma. Navigationally remote in ancient times and perhaps somewhat still socially remote amidst modern urbanization, it is easy for native and foreigner alike to perceive that there must be something unique and mysterious about what is "Japanese." Yet, this island country is a mixture of Eastern and Western imports, and the social, political, and pragmatic processes related to such importation have origins dating back at least two millennia. One who actually visits the country may be somewhat overwhelmed by a large number of temples, shrines, and other architectural landmarks, some dating back many centuries, all reflecting an interaction of native sociocultural systems with those derived from the Asian continent. The visitor may also be somewhat disappointed to find much of the nation's heritage engulfed by high-rise buildings and accompanying elements of industrialization, a factor which is also very much a part of modern Japan. Illumination from such industrialization is a thorn to every lover of the stars, from amateur to professional. Perhaps it is indeed the mixture of foreign imports with indigenous belief systems, a mixture more subtle than that of cultures such as the United States whose multiethnicity is so pronounced, that indeed proves to be the most unique aspect of Japan. In order to understand the deeper significance of Japan's heritage with the sky, one must often look beneath what appears on the surface.

For many in the West, astronomy in Japan is generally connected to Japanese names attached to comets, asteroids, and supernova discovered by one of her many amateur astronomers, to astronauts accompanying NASA missions, to space probes launched from Tanegashima Island, or to the building of a huge telescope on Mauna Kea sporting the name of one of the most prominent asterisms of Japanese star lore, *Subaru*. A complete review of issues related to this heritage is far beyond the bounds of a single article. We will concentrate primarily on the cultural relations with the stars that have developed over the centuries in Japan. To provide an overview as well as a basis for understanding what astronomy means to this land, we will concern ourselves with (1) the development (or perhaps nondevelopment) of astronomy as a science in Japan and (2) the significance of historical, social, and political purposes and their relation to star lore, mythology, and other aspects of cultural astronomy.

Astronomy as Science in Japan: Chinese and Western Influences

Many professional and amateur astronomers in Japan have asked, "Were ancient Japanese people not interested in the stars?” (e.g., see Yokoo, 1997). Such a question reflects the fact that compared with Western traditions, it is quite difficult to find early star mythology and records of scientific or prescientific development that compare with many other ancient cultures. Though the exact date is uncertain, writing was introduced relatively late to the Japanese islands (the system was based on Chinese characters), and thus there is very little written record of ancient views of astronomy earlier than the seventh or eighth century.

In looking at Japan’s development of astronomy, Aveni’s (1989) allusion to a kind of ethnocentrism inherent in viewing *History of Astronomy* only through the eyes of the modern West and its evolved science is echoed in reverse. The Meiji Reformation (1867–1868) with a “de-emphasis” of Buddhist traditions followed by post-World War II rejection of the most meaningful aspects of indigenous Japanese mythology left many in this country with a sense that there is and always has been little which can be considered original in astronomy emerging from Japan. On the other hand, the reader needs only to pick up any professional journal of astronomy to quickly find the names of Japanese authors who are conducting research in the science of astronomy using Western methodologies. Thus, to look at modern astronomy in Japan is not to look at any real cultural difference but instead to find an industrial country which is producing an increasing number of eminent scientists trained in Western methodologies. The importance of understanding cultural context relative to astronomical “knowledge” has been recently revived, and one cannot help but sense a certain “lack of self-esteem” among Japanese researchers who wish to pursue it.

In his *History of Japanese Astronomy*, Nakayama (1969) gives a very thorough account of the ways in which Chinese and later Western influences were imported into Japan throughout its history. Japanese astronomy was greatly conditioned and restricted by geographical, historical, and cultural barriers, and its early phases were dominated by Chinese influence and later by Western ideas. It is doubtful that any “scientific” expansion of Japanese astronomy occurred prior to close contact with China or with China via Korea. Further, while the primary purpose of calendrical study both in the West and in China was to develop precise means of time reckoning, calendar development in Japan generally focused on divination and securing the position of rulers rather than trying to develop precise theory, cosmology, or observation methods designed to explain the workings of the universe.

Nakayama’s work is written in English and parallels the two-volume work on the *History of Astronomy* in Japan written in Japanese by the esteemed scientist and historian Watanabe (1986, 1987). A view of most Western discussions of the subject will lead the reader to conclude that little has changed in perception relative to Nakayama’s assessment (e.g., see Hashimoto, 1997; North, 1995; Pannekoek, 1961; Ronan, 1996; Sugimoto & Swain, 1989). While Aveni (1993) does emphasize more ethnographic and less ethnocentric viewpoints, he also tends to place Japan within the broader context of the “rich Chinese heritage” and does not really deal with Japan’s cultural astronomical heritage.

When the English scholar, Chamberlain (1971), was assessing the general state of affairs in Japan in his *Japanese Things*, he indicated that even apart from any scientific originality, one would never find much creative lore composed in Japan relative to the stars. Viewing astronomy in Japan from only these perspectives, it is easy to get the impression that early and perhaps even later inhabitants of Japan who never “looked up” were never inspired by much in the sky, patiently and/or eagerly waited for (or perhaps at times were even antagonistic toward) enlightenment from the Asian continent or later from the West, but nevertheless developed keen observational skills once such imports were implanted.

It is certainly true that almost everything which can be viewed as scientific astronomy was imported from the Asian continent or from the West in more modern times, and if only that side is viewed, discussion of the *History of Astronomy* in Japan can basically stop here. However, to discard the culture’s relations with the sky by judging it only by its origination or development of scientific concepts dismisses what is perhaps one of the most unique case studies in how indigenous native beliefs (and accompanying views of the heavens) were integrated, seldom by forceful means (at least from the importer's side), with belief systems of other cultures (and their consequent views of the heavens). Such a pattern of coexistence has been paradoxical if not downright baffling to most Western eyes. By neglecting the sociocultural side of Japanese history, one misses the complexity of the manner in which ancient Japanese (not only rulers, astrologers, and calendar scholars but average farmers, fishermen, and other common citizens) incorporated astronomy into an extant system of belief and purpose, such providing culturally based reasons for the way astronomy did or did not develop in these islands.

Although we discuss many other examples of Japanese adaptation and development in the next section, it is worth noting particular historical events that we have explicated elsewhere (Renshaw & Ihara, 1999). Consider the large influx of Chinese learning in the Asuka (late sixth to early eighth centuries AD) and Nara (710–784 AD) periods. (An exhaustive account of these periods and the influence of continental imports are far beyond the scope of this article. The reader may find articles from Vol. I of *The Cambridge History of Japan* series including Brown (1993a, b, c), Kidder (1993), Inoue (1993), Naoki (1993), Matsumae (1993), and Sonoda (1993) to be particularly relevant to a deeper understanding of these processes.) Certainly, palaces and Buddhist temples were being laid out using Chinese-derived geomantic principles, and Chinese methods of calendar reckoning were adopted (Nakayama, 1969). However, each aspect of Chinese learning that was incorporated had to find juxtaposition with a set of beliefs or purposes that sometimes stood in direct contradiction. Juxtaposing the descendancy of the emperor as a child of the sun goddess Amaterasu with the Chinese perception of imperial rule centered on the north celestial pole required some compromise. Buddhist temples aligned in north–south directions had to fit within a terrain that had Shinto shrines aligned in less celestial fashion but more along the flow of natural sites such as prominent sacred mountains, forests, waterfalls, or distinguished outcroppings of rocks. Apart from the necessary attendant "blessing" of a particular Shinto deity on a Buddhist temple, the said deity often had a shrine built directly within the precincts of the temple grounds and was even given a form of "Buddhahood." Compromises also included such practices as substituting Shinto ritual objects for bones of the Buddha in the treasures buried beneath pagodas (see Brown, 1993c; Matsumae, 1993; Sonoda, 1993).

The picture we see from reading Krupp (1983, 1989) substantive accounts of temple layout and practice of seasonally based ritual in ancient Chinese capitals was only partially incorporated within the layouts and attendant rituals of ancient Japanese palaces and their imperial owners. Certainly, as will be seen in the review of social consciousness and purpose in the next section, rituals such as human sacrifice found no place in a belief system based on ritual purification and abhorrence of death. It is also significant to note that while China underwent several dynastic changes, some accompanied with revisions in cosmology and astronomical perception, Japan retained virtually one dynastic descendancy reaching well into the twentieth century, thus often seeing no need for "advances" taking place on the continent (Brown, 1993a, c).

When cultural perspectives are included, it seems clear that the history of Japanese astronomy is not simply the history of Chinese astronomy or even, for better or worse, a direct mirror of such. While it may be impossible to distinguish anything as having been uniquely Japanese, cultural practices from earliest to modern times bear distinct marks of a social consciousness and purpose inherent in Japan's cultural development. Too, while Chinese astronomy may not have been given its due in modern scholarship, it is also evident that all Asian cultures cannot be "lumped together" with China in order to gain a full understanding of the relation of astronomy and culture in any particular one.

Socio-Political Purposes and Their Impact on Development and Adaptation of Star Lore and Mythology

Ruggles and Saunders (1993) ask, "What do people see when they look at the sky?," and further state that the answer is as much a cultural as an astronomical one. Their perception is especially relevant to unraveling the enigma of Japan's heritage with the sky. A growing database of archaeological evidence, renewed postwar and nonreactive scholarship with regard to historical texts, and the development of interdisciplinary approaches reveal Japan as a culture that has always been guided by an indigenous social consciousness and for most of its history a rather consistent set of social and political purposes (Brown, 1993a). Such was certainly a factor in how Japanese developed myth, legend, and lore related to the stars, and it is in this area that we can find the rich sources of cultural astronomy in Japan. (A good chronology in English of Japan's general history may be found in Torao and Brown's (1991) *Chronology of Japan*. The most exhaustive history of Japan in English is the recently released Cambridge series (Hall et al., 1993). For shorter and perhaps more approachable views of Japanese history written in English, the following may be of value: Sansom's (1974) prewar but still viable 3-volume *A History of Japan* and his (1973) *Japan: A Short Cultural History*; Hall's (1971) *Japan From Prehistory to Modern Times*; Mason and Caiger's (1973) *A History of Japan*; and Morton's (1995) *Japan: Its History and Culture*.)

The ancient sense of social consciousness and purpose may best be understood by using the analogy of a lake fed by two springs. The lake represents the historical and modern sociocultural milieu of Japan, and the springs feeding it are the sources from which that milieu has been formed. The first and nearest spring is composed of a native social consciousness and a specific set of socio-political purposes that we detail later. The second spring (better viewed as many secondary springs) consists of the infusion of ideas, concepts, technologies, philosophies, and religions including a virtually continuous input from the Asian continent and in later centuries large contributions from the West.

It is important to realize that the primary spring has always been fed by the second. The flow may have been slow or even imperceptible at times, but it has always been there (Oguma, 1995). On the other hand, this primary spring (regardless of its diverse historic origins) has always been deep and has formed an archetypal base through which everything must be filtered to become "Japanese." At least within the last 1,600–1,800 years, the secondary spring has probably never had a direct route to Japan's archetypal lake; such flow has almost always passed through the primary spring.

Brown (1993c), Kidder (1993), and Matsumae (1993) have provided a cogent paradigm through which Japanese social consciousness and attendant Shinto beliefs and practices may be understood as well as socio-political purposes that guided the early formation of Japan as a unified country. From this paradigm, three primary aspects of early Japanese consciousness emerge: "linealism," "vitalism," and "optimism." Linealism emphasizes ancestral descendancy with filial duty to parents, siblings, friends, nation, etc. Vitalism emphasizes life along with the abhorrence of anything that has to do with death and stresses ritualistic (not moralistic) purity. Optimism places emphasis on being concerned, not so much with the distant past or future but rather with moving forward through seasons and cycles of life, regardless of circumstances. The socio-political purposes which played a role in Japan's early development as a nation may perhaps be best paraphrased as follows: (1) unification of often warring petty "kingdoms" (along with their local myth, legend, and lore) through (2) cooperative efforts of common people in various ways such as cultivating rice (using celestial signs and allegories for seasonal determination of planting and harvesting as well as agriculturally based festivals) in order to (3) establish a singular lineal order of imperial rule (resulting in perhaps one of the greatest national Japanese myths that of the sun goddess Amaterasu and her place as ancestral head of the imperial line). (From our earlier discussion, the reader should have a good idea of the kinds of conflicts many imported ideas created for early Japanese. Other brief examples will further clarify the point: while the infusion of Confucianism reinforced many aspects of "lineality," especially with regard to the development of bureaucratic governmental practices, the Confucian idea of a cyclical rise and fall of dynasties was never really accepted in Japan and stood directly against the idea of a singular imperial line. The fourth- and fifth-century infusions of Buddhism with beliefs, which emphasized a better life in death than in the present, directly contradicted the concept of vitalism and optimism. In addition, the Buddhistic idea of eventual decay and the Confucian idea of a "glorious past" were incongruent with virtually all aspects of Japanese consciousness and purpose.) It can easily be argued, given the political developments of the twentieth century, that while some commodities have changed and political power has not always been imperial based, these fundamental aspects of Japanese consciousness and purpose still form a prime keystone of the culture's psyche. (It is easy for the reader to get full insight into the significance of these ideas by reading the many excerpts of manuscripts from periods throughout Japan's history which are accompanied by commentary in the excellent *Sources of Japanese Tradition* compiled by Tsunoda, de Bary, and Keene (1964). The sense of Shinto consciousness and its pervasiveness in modern Japanese life is also discussed by Shigemitsu (1996).)

One of the few writers in English to deal with Japan's cultural star lore and myth is Krupp (1991, 1997). Readers may be familiar with the several accounts he provides of the fundamental Japanese myth of Amaterasu and its relation to the Japanese political history. However, while this myth, itself closely tied with the political purpose of unification, is a prime example of lore that reflects Japanese sense of consciousness and purpose, there are many other aspects of Japanese traditions and bodies of star lore which show the complex relation between indigenous native belief, pragmatic social need and purpose, and the kinds of celestial ascriptions that developed therefrom. Little of this material has found its way into English sources, and in the remainder of this article, we discuss some of the many examples of relations between Japanese values and social purpose and the stars. Specifically, we will look at (1) values applied to particular star groupings such as Oyaninai Boshi; (2) cooperative efforts such as planting, harvesting, and fishing reflected in star lore closely tied to such asterisms as Subaru and the belt stars of Orion; (3) ancient Japanese purposes as seen in star paintings of archaeological sites such as the tombs of Takamatsu Zuka and *Kitora Kofun*; (4) mixtures of Shinto belief and values seen in adaptations of continental legend and ritual such as that of the legend of Orihime and Kengyuu and its relation to the festival of Tanabata; and (5) the preeminent holiday of the year for Japanese, New Year's Day, in which the values of linealism, vitalism, and optimism come together in a celestial greeting of new beginnings.

Oyaninai Boshi: Linealism, Vitalism, and Optimism in the Stars

There are a number of celestial symbols which concern various groupings of three stars: Oyaninai Boshi including Orion's belt stars (Nojiri, 1973), three stars of the fifth moon station of the Azure Dragon of Spring which includes Alpha Scorpio flanked by Sigma and Tau, and three stars discerned in the constellation Aquila including Alpha flanked by Beta and Gamma Aquila (Uchida, 1973). (Here and in later sections, we discuss the Chinese-derived *Sei Shuku* or "moon stations" along with the animals of cardinal directions. Though used extensively in Japan from earliest Chinese infusions, a discussion of their complexity is more appropriate in a work on Chinese astronomy. The reader is urged to look at sources such as Needham (1959), Ho (1985), or Nivison (1989).) All have to do with seeing the image of two parents standing or being supported on either side by their child in the middle. Such symbols of filial duty are numerous in Japanese star lore and reflect the strong sense of lineality later reinforced by Confucian ethics. Further, particular attention is placed on this value relative not only to parents but to friends as well. An example of a sense of Japanese identity is seen in Kenji Miyazawa's more modern "lore," the *Milky Way Railroad* (Sigrist & Stroud, 1995). (*Douwa Shu; Ginga Tetsudou no Yoru* (A Collection of Tales; Night of the Milky Way Railroad) was originally started in 1924, adapted for some years, and finally published posthumously in 1951 (Miyazawa, 1951). It remains one of the most popular stories in Japan, loved by children and adults.)

Another legend incorporating the aforementioned sense of Japanese consciousness includes the belt stars and M42 region of Orion. According to Uchida (1973), one day, two sisters were walking down the road, the younger dutifully following her older sister and shouldering a tub of water. Being chased by an ogre, they found a rope leading to the heavens and began to climb. Though the sisters escaped the ogre, the younger sister sadly had her foot bitten off. These days, we see the bamboo pole (the three belt stars called Take no Fushi in this story) with which she continues to carry water as she follows her sister (the moon) around the sky. Her remaining foot (M42 region) peeks from the folds of her kimono. Western readers may find the end of this legend disturbing or even somewhat cruel. However, all the fundamental values of Japanese consciousness are found in this story: linealism in the form of filial duty, vitalism in strength and courage, and optimism in a will to "go on" within one's present condition to an immediate brighter future.

The anecdotal nature of such star lore and legend takes on a completely different meaning when viewed within the context of ancient Japanese social consciousness and purpose. Again, while it would be futile to argue that such lore developed independent of external sources, it is also clear that its Japanese development reflects a unique cultural identity.

Cooperative Activity: Pragmatic Signs in the Stars

As in many cultures, the three belt stars of Orion (called *Mitsu Boshi*), the Hyades (*Ame Furi Boshi* or rain stars), and the Pleiades (*Subaru*) played a prime role as symbols of fertility and timepieces relative to seasonal change, specifically planting and harvesting during the rice cultivation period (1982; Hirose, 1972; Nojiri, 1973, Uchida, 1973). Their earlier and later heliacal setting in spring as well as heliacal and later rising in fall encapsulate that season and in more ancient times provided symbols related to festivals such as Spring *Higan* and *Ura Bon*. Spring Higan is celebrated within a period of 7 days surrounding the spring equinox. At this time, as any casual observer in latitudes similar to Japan will note, the Pleiades, Hyades, and Orion, all begin to set earlier and earlier each evening. For early Japanese, this setting was allegorical to planting of rice seedlings (Subaru or the Pleiades appearing as united seedlings), the rainy season (Hyades or Ame Furi Boshi seen as rain stars), and cultivation (one of the earliest symbols seen in the three belt stars of Orion was that of *karasuki* or plow). Ura Bon is celebrated in the fall when ancestral *kami* (deity) visits and is sent on their way in thanks for bountiful harvests. In more ancient times, when this festival was celebrated on the lunar calendar-based 14th–16th days of the 7th month (late August or early September in the Gregorian calendar), these three prominent star patterns were indeed seen to transit the zenith as the full moon set and dawn arrived, a signal that ancestral spirits had indeed departed for yet another "season" (Miyata, 1996). The appearance of Subaru rising in the evening at this time of the year seems to have had significance not only in its relation to the end of the rice harvest but to the coming of winter.

The mythology found in the *Kojiki* (Records of Ancient Matters; see Chamberlain, 1981; Philippi, 1968) and the *Nihongi* (Chronicles of Japan; see Aston 1972) places much importance on the deity (sun goddess) Amaterasu, who "conquered" lesser deities (local states) and was considered the progenitor of the imperial line. Interestingly, one of the earliest and most significant aspects of Subaru was related to the myth of Amaterasu. Apparently taken from the phrase *mi Sumaru no Tama*, the name *Sumaru* was used to describe this asterism referring to the string of the

August jewels known to have been hung on the *sakaki* tree while deities danced to lure Amaterasu from the cave (Nojiri, 1973). Allegorically, just as the sun (Amaterasu) was seen to depart for the winter, jewels (Subaru or Sumaru) were seen to appear in the sky, jewels which could be seen throughout the winter months and serve as a reminder for early Japanese that at some time the sun would indeed return with her spring warmth and another planting season could begin.

Lore related to Subaru is extensive, but its prime importance can be seen in the fact that it not only played a role in what would become a central myth for unification of the country but also a timepiece for the pragmatic need of farmers and fishermen who played a role in such unification efforts. For common people, struggle for unification was of secondary importance. What was of prime concern was that they know good and bad times for planting, harvesting, or setting lines for fishing. While the three star patterns we have mentioned were of significance because of their heliacal rising and setting, the three belt stars of Orion, due to their prominence, apparent equal spacing, and perceived change in position as they traced their way across the winter sky, were of particular pragmatic use to early and later Japanese citizens.

When viewed in early evening, the perceived angle of the three belt stars, seen rising in the east, moving across the sky, and setting in the west at different times of the year, provided the base for particularly interesting lore in which farmers used Orion as an agricultural symbol (Hara, 1975; Nojiri, 1988; Uchida, 1973). The three belt stars are variously called *Awainya Boshi* (Millet Stars), *Komeinya Boshi* (Rice Stars), or *Awaine Boshi* (Millet and Rice Stars). All these names relate to seeing *Mitsu Boshi* as a fulcrum, balancing the yield of rice or millet crops as they move across the heavens. The star *Alnilam* (*Epsilon Ori*) is seen as the center of this fulcrum. *Mintaka* (*Delta Ori*) being higher or lower than the center indicates the yield of millet; *Alnitak* (*Zeta Ori*) represents the yield of rice. In latitudes of Japan, *Mitsu Boshi* rises in an apparent vertical position. As the three stars move across the sky in the fall, they appear at an angle that gives rice a strong weight on the balance; this is the time to harvest rice and plant millet. As this constellation is seen setting in the West in late spring, Zeta Ori begins to dip lower and lower; this is the time to harvest millet and plant rice.

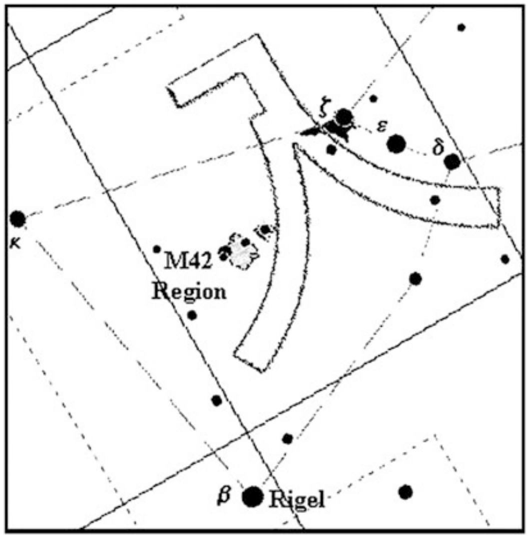
Especially in the cultivation of rice, several symbols of agriculture have been seen in the relation of the three belt stars to the M42 region. One of the oldest object references associated with this configuration uses the term *karasuki* to describe the three belt stars as prongs of a plow with the M42 region being the handle used to pull it in the field. As mentioned earlier, this symbol is especially meaningful related to the evening appearance of the three stars in the time of early spring.

As a further example of adaptation of imports to suit unique and indigenous Japanese needs, it is interesting to look at some of the Chinese interpretations of star groupings such as Subaru or the three stars of Orion's belt and the differences in names applied by each culture. By the seventh century (perhaps earlier), the Chinese "cosmology" which gave rise to the concepts of 28 *Sei Shuku* or lunar stations encircling the celestial globe had found its place in Japan (Nakayama, 1969; Watanabe, 1987). The constellation of Orion contains two such *Sei Shuku*: the 20th which includes the small *Meissa* (*Lamda*, *Phi Ori*) and the 21st which embodies a much larger section of Orion and is most distinguished by the belt stars (*Mitsu Boshi*). Chinese characters were used by later Japanese writers to represent these configurations; however, the original Chinese term for the 21st *Sei Shuku* was simply *Shin* (three) while earliest records of Japanese nomenclature use *karasuki* or plow (Ozaki et al., 1993; Shinmura, 1994). Early Japanese gave little significance to the 20th station. Though continental influence can certainly not be dismissed as a major factor in Japan's agricultural development especially with regard to tools, it would appear that seeing this agricultural symbol in Orion may indeed have been in use before introduction of writing and other imports of more advanced Chinese culture into Japan.

Following massive infusions of culture from China and Korea, Japanese emperors practiced the custom of "plowing the first furrow" around the lunar New Year. However, Japanese lore associating the three stars with a plow seems to have preceded and perhaps only been augmented by the introduction of this Chinese-based ritual. See Krupp (1983, 1989) for a description in English of this and other cultivation-related ceremonies that were practiced by the emperor in China. As they were recognized in Japan, some became part of the imperial ceremony, but many never found a place either because they did not fit within the imperial "purposes" mentioned earlier or because they were in direct conflict with native *Shinto* belief (e.g., ritual sacrifice).) "Astronomy" as practiced in China during Japan's early formation as a nation had depended for some time on somewhat more precise estimates of a lunar calendar for fixing dates (Ho, 1985; Nakayama, 1969). Because of its pragmatic use as an agricultural sign (though nonprecise), especially its prominent evening setting at what later was called Spring *Doyou* (the period of 18 days prior to the sectional term "Summer Begins," the official time for preparation to begin planting rice), *karasuki* may have been original with early Japanese farmers. At any rate, its setting has certainly survived as a symbol of planting in most rice-producing parts of Japan.

Another symbol for planting indeed reflects Chinese influence, and this is clearly seen in the incorporation of *kanji* or Chinese characters. This symbol, again related to the setting of Orion in the west during the beginning of the rice cultivation season, was yet another reinforcement for use of the belt stars and M42 region as a sign for planting. Uchida (1973) indicates that Japanese in some agricultural areas see the kanji for "entry" in the configuration and call it *Hoshi no Iri* (Entry of Stars). As fishermen saw stars set into the sea, Japanese farmers saw stars set into the western landscape. This symbol of Iri was merely another sign that it was time to plant (enter) rice seeds into the earth (Fig. 1).

Agricultural associations discussed so far have generally been related to the setting of *Mitsu*



Astronomy in Japan: A Cultural History, Fig. 1 The *kanji* for *Iri* or Entry superimposed on the belt stars and M42 region of Orion (Computer graphic by Steven L. Renshaw)

Boshi during early stages of annual rice cultivation. As mentioned, the rising of the three belt stars in the east was also an agricultural symbol and was allied with the end of the period of rice cultivation. Hara (1975) records that in many rice-farming areas, the stars were called *Haza no Ma*, a term that refers to a three-pole stand that is used in the field to dry rice. In the early phases of autumn, when Orion is no longer seen at sunset but rather rising earlier and earlier each night, farmers looked to the belt stars and saw them as a symbol that "only *Hasa* are left in the field," the harvest of rice being over.

While the combination of a lunar calendar and later adoption of a Gregorian calendar in post-Meiji era in Japan led to more precise methods for determining times for planting and harvesting, many old farmers in rural agrarian areas still use methods that are centuries if not millennia old. According to Uchida (1973), the following timepiece is still recited in such areas: "When *Mitsu Boshi* are one fathom high, it's time to go to bed; when *Mitsu Boshi* are in the middle, it's the middle of winter; and when *Mitsu Boshi* lay, it's time to wake up." This refers to the vertical alignment of the three belt stars as they rise in early fall, the angular position in the middle of the southern sky in winter and the horizontal visual alignment in the west in spring. These metaphors are related to, respectively, fall harvest, winter rest, and spring planting.

Star lore related to fishing is somewhat more rare than that which is related to crop cultivation. It was primarily through cooperation of local farmers along with their local ancestral *kami* in the production of rice that early Japanese rulers were able to fulfill their purpose of unifying the country. Still, incorporating the legends of families of fishermen was an important part of this unification, and a mix of agrarian and fishing lore is found (see Nojiri, 1982, 1987).

In some fishing areas, the three belt stars are called *Kanatsuki*, which is a name given to a spear with three prongs used in fishing (Nojiri, 1973; Uchida, 1973). We can note some similarity in pronunciation of *karasuki* (plow) and *Kanatsuki*. As a sign, *Kanatsuki* was used as a timepiece for favorable catches. When prospects for such seemed to be particularly good in the fall, old fishermen were often heard to say "Let's wait for *Kanatsuki*" before going out for the evening's catch.

Perhaps one of the most significant relations to "fishing" found with *Mitsu Boshi* relates to their designation by some fishermen as Sumiyoshi Boshi. Sumiyoshi were the three deities mentioned in the *Kojiki* as being created from the ocean and being particularly favorable to seafarers (Nojiri, 1988). Incorporation of these deities in the *Kojiki* and *Nihongi* was no doubt designed to find favorable reaction from the *be* or local families of fishermen. However, their use in legends which also included allusions to agricultural symbols makes them a significant aspect of the way in which Japanese developed celestial allegories.

Obviously, ancient Japanese were not blankly "staring at their rice fields" while the heavens "revolved" overhead. Creative and pragmatic use of star patterns played a central role in the day to day life of common citizens. Using the example of the belt stars of Orion, we have briefly discussed some of the more significant associations used in cooperative activity.

Adaptation of Asian Cosmology for Power and Centrality: *Takamatsu Zuka* and *Kitora Kofun*

Some archaeological sites may provide cogent information relative to the early interaction of Japanese values and purpose with imported cosmology. One of the major archaeological discoveries was made in the early 1970s (Hirose, 1972) in Asuka village, Nara prefecture. From an Edo era painting showing this mound with a tall pine tree atop, this tomb was called *Takamatsu Zuka Kofun* (Tall Pine Burial Tomb; Fig. 2).

Dating indicates that the tomb was built in the latter part of the seventh or early part of the eighth century. As was and is the case with most burials in China, Korea, and Japan, the tomb was aligned with celestial north. Paintings of animals related to the four cardinal directions were found on the walls, and careful inspection of the ceiling revealed a chart including the 28 *Sei Shuku* (lunar stations). Only a few scholars knew of the tomb's existence in the Edo era (1603–1867), and most believed it was that of the Emperor Monmu (emperor from 697 to 707). Modern excavation revealed no inscription, and Monmu's tomb was later determined to be to the east. Similar tombs have been found in both China and Korea, and the construction period was also one in which scholars from Korea had been invited to the imperial court.

What is significant about *Takamatsu Zuka Kofun* is the fact that it clearly shows the influence of Chinese and Korean cosmology on Japan in the Asuka era (late sixth to early eighth centuries). In 1998, another such tomb, located about 1 km to the South of *Takamatsu Zuka Kofun* on Mount Abe and named *Kitora Kofun* (after the Kitaura area of Asuka village), was explored. The tomb was not actually entered but probed with subminiature cameras. Preliminary dating placed its construction within the same Asuka period as *Takamatsu Zuka Kofun*. While there are some remarkable similarities, there are also some anomalous differences in the paintings of the two tombs.

In *Kitora Kofun*, the paintings of the animals of cardinal directions appear to be in somewhat

Astronomy in Japan: A Cultural History, Fig. 2 *Takamatsu Zuka Kofun* is aligned with celestial north. This view from due south shows the bamboo-covered mound of the tomb. The doors are to chambers of relatively recent origin; inside are housed temperature maintenance and dehumidifying equipment used to protect the small tomb's delicate paintings. The tomb is not opened to the public (Photo by Steven L. Renshaw)

better condition than those of *Takamatsu Zuka Kofun* (in which some paintings appear to have been defaced in ancient times). The animals do seem to have been painted in a freer style than those that are found in the tomb to the north. There also appear to be more stars in the Kitora tomb paintings of the *Sei Shuku*. Unlike *Takamatsu Zuka Kofun*, the celestial equator and ecliptic as well as "the heavenly river" or Milky Way appear distinct. Like *Takamatsu Zuka Kofun*, the tomb appears to have been plundered of any "treasure" it may have held. The south wall of *Takamatsu Zuka Kofun* was obliterated by entry in ancient times thus eliminating the painting of the Red Bird of Summer.

With regard to astronomical content, there are other significant differences. First, the paintings of *Sei Shuku* in *Kitora Kofun* appear to be based on Chinese/Korean charts of a much earlier period than that of *Takamatsu Zuka Kofun*. Second, the point of the crossing of the ecliptic with the celestial equator can be seen in *Kitora Kofun* and appears to be near a point in Aries closer to Taurus and corresponding with a position several centuries earlier than the Asuka era or the tomb's construction (the vernal equinox was shifting into Pisces by the end of the seventh century). Third, since enough stars are seen in *Kitora Kofun* to determine just which ones could and could not be seen on the horizon, a relatively good estimate of observer latitude can be made. Fourth, the painting of the "White Tiger of the West" is reversed from that of *Takamatsu Zuka Kofun* and tombs with similar paintings found in China. In *Kitora Kofun*, the tiger is painted facing north. This point is especially interesting. When looking at the west wall of *Takamatsu Zuka Kofun* (note the photograph of the White Tiger in the Chinese tomb of similar dating in Krupp's *Echoes of the Ancient Skies* 1983, p. 112), the tiger is seen to face south, and this indeed corresponds with the placement of the figure of this animal among the stars. (Editor's note: see a detailed discussion of *Kitora Kofun* in this encyclopedia.)

These tombs provide us with a view of how Chinese/Korean astronomical thought found its way to Japan and how such thought was incorporated into the social purposes of Japan's rulers. It seems evident that it is not the accuracy of the cosmology reflected in the tombs' paintings but rather the almost wholesale adoption of Chinese perceptions to further strengthen the centrality of imperial rule that was most important, especially in the case of *Kitora Kofun*. Japanese rulers wished to give themselves the same legitimacy that Chinese rulers had; incorporation of symbols and astronomical methods in order to accomplish this did not necessitate complete awareness of the underlying principles, but rather their mere presence. As mentioned earlier, such was the case with the introduction of Buddhism as well as other aspects of Chinese thinking. One can still see this kind of use of foreign import without substantive understanding in the almost playful use of foreign language in what sometimes appears to be gibberish in slogans and advertising of modern Japan. Use of foreign icons brings esteem, regardless of whether or not they are understood. Again, it must be stated that the central beliefs, ritual ceremonies, and social purposes of Japan appear to have remained and do remain somewhat constant regardless of import, such imports merely being incorporated within this larger "spring."

Adapting Chinese Lore to Native Beliefs and Purposes: Orihime, Kengyuu, and Tanabata

When we look at the adaptation of myth and legend imported from other cultures, we also find the obvious sense of indigenous Japanese values and socio-political purposes infused over time. Perhaps one of the best examples of this is the legend of Orihime and Kengyuu (Nojiri, 1973). This story and associated festival were probably imported from China in the Heian era (794–1185). The story involves the stars of Vega and Altair, and the reader should consult Krupp (1991) for an explanation of the story in its Chinese form. Essentially the same in character, there are some noticeable adaptations made based on the unique social and pragmatic needs of Japanese culture. In Japan, the star Vega is often called Orihime Boshi (Weaving Princess Star), and Altair is often called Kengyuu Boshi or Hiko Boshi (Puller of Cows Star). To give the reader one Japanese version of the legend, we will paraphrase Hara (1975).

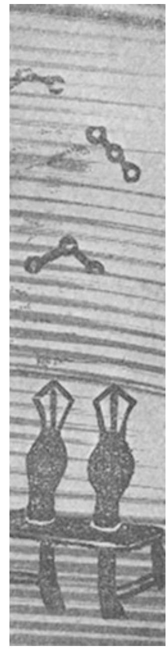
One day, the emperor's daughter, Orihime, was sitting beside the Milky Way. She had been weaving because her father, the emperor, "wished it" (he loved the beautiful clothes that she made). On this day, she was very sad because she realized that she had been so busy that she did not have time to fall in love. Her father, Tentei, the ruler of the heavens, felt sorry for her and arranged a marriage with Kengyuu (who lived across the river, the Milky Way). Their marriage was one of sweetness and happiness from the start, and everyday thereafter, they grew happier and happier. But Tentei became very angry, because in spending so much time in her happy marriage, Orihime was neglecting her weaving. Tentei decided to separate the couple, so he placed them back in their original places, separated by the Milky Way. On only one night of the year would he allow them to meet, the 7th day of the 7th month. Every year on that day, from the mouth of the river (the Milky Way), the boatman (of the moon) comes to ferry Orihime over to her beloved Kengyuu. But if Orihime has not done her weaving to the best of her skills and ability, Tentei may make it rain. When it rains, the boatman will not come (because the river is flooded). However, in such a case, *Kasasagi* (a group of magpies) may still fly to the Milky Way to make a bridge for Orihime to cross.

Related to this legend, ancient Japanese celebrated the festival of *Tanabata* on the 7th day of the 7th month each year (lunar calendar). The 7th day of the 7th month generally falls in August or September in the Gregorian calendar. At this time of the year, the constellations of Lyra and Aquila are prominent in the evening sky with their major stars (Vega and Altair) separated by the Milky Way. The 7th day of the 7th month also finds a waxing crescent moon (boat) reaching its first quarter. If it is not raining, both *Orihime Boshi* (Vega) and *Kengyuu* (Altair) are quite conspicuous at the time of the *Tanabata* festival.

Tanabata may be translated as "weaving with the loom (*bata*) placed on the shelf (*tana*)," and the festival celebrates improvement of technical skill and ability. As in China, ancient Japanese added specific values to their wishes that Orihime should hone her skills and work hard so that she could meet Kengyuu. In modern celebrations of *Tanabata*, people throughout Japan write wishes (generally for themselves or relatives) to the *kami* Orihime on colorful strips of paper. On the evening of Tanabata, they tie these paper wishes to freshly cut bamboo. Wishes may be for increased skills in work or school but may also be for anything that reflects a person's dreams and hopes for the future. Summer vegetables such as eggplant and cucumbers are prepared, and horse or cow figures made out of straw and water oats are decorated.

While the myth probably held seasonal significance in its Chinese origins, specifically the celebration of the end of the rainy season (reflected in a desire that it not rain), it found a variety of interpretations related to seasonality in its Japanese form. Particularly in relation to agricultural development in Japan, "wishes" related to celebrations of *Tanabata* ranged from desire for dry weather to desire for wet weather depending on the particular geographic region and whether a crop was to be planted or harvested at this time.

Following Shinto practice and ancient values, the concept of purification (generally including use of water) before the Bon Festival (centered on the 15th day of the 7th month) was also added to the *Tanabata* festival. Before the legend was brought from China, a ritualistic festival had been held to welcome the water kami at this time of the year; infusion of the legend of Orihime and Kengyuu added a motif of the ritual celebration of the marriage of a weaving lady and the water god (Okada & Akune, 1993). In eastern parts of Japan, an associated ritual called Nebuta was celebrated. On the early morning of Tanabata, bamboo would be set afloat in the river, and people would brush their bodies with leaves from "silk" trees. By doing so, they were said to take their sleepiness (*nebuta*) away, another form of purification and preparation for Bon (Yoshinari, 1996). The close relation of Tanabata to the indigenous Bon Festival has obviously led to a number of adaptations of the imported Chinese mythology. In short, one makes the coming of the Bon Festival sacred by excluding impure spirits from the body at the first quarter moon, thus being pure for the coming of Bon at full moon. It is interesting that in some regions of Japan, *Tanabata* is accompanied by a taboo forbidding swimming or bathing in a river. Noting the relation with the celestial "river" or Milky Way, the taboo is based on the idea that a *Kappa* or water deity resides in the river and one should not make the pure water dirty by entering the water deity's home.



Astronomy in Japan: A Cultural History, Fig. 3 Decorated strip of *Tanabata* bamboo from the *Tottori* region of Japan. Note the representation of *Hiko Boshi* (Altair and two-flanked stars in Aquila) at the top and *Orihime Boshi* (Vega flanked by two stars in Lyra) near the middle (From Nojiri, Houei Nihon Seimei Jiten of Star Names in Japan, 1973, p. 60. Used with kind permission of the publisher)

When it was first imported, *Tanabata* was celebrated only by imperial court officials. It was considered a graceful event, full of the simple elegance so associated with the Heian era of Japan. Lanterns were lighted, and poems were written on mulberry leaves still holding their dew (Nojiri, 1973). Of course, as the custom spread to local areas, towns became covered with bamboo at *Tanabata*, and the festival took on more of the values inherent in Japanese consciousness and purpose (Fig. 3).

The process of adapting this imported legend and developing indigenous practices evolved in complex ways over the centuries, and we have touched on but a bit of this complexity. In modern times, the festival is generally celebrated on a solar July 7th, a date that is generally still within the rainy season. Sadly, the festival has lost much of its seasonal significance with modern industrialization. Of course, the vitalistic ethic of improved work and skill is still valued, regardless of whether or not the day of celebration is attuned astronomically.

Prevalence of the Sun: Akemashite Omedetou Gozaimasu

No discussion of Japan's heritage with the sky can avoid the prime significance of the sun. Symbolism related to the sun is heavily incorporated in Japanese myth and is still seen in its flag. Being the most eastern of East Asian nations and indeed being seen as the land which the sun first greets in the morning, the phrase "Land of the Rising Sun" developed special meaning for Japanese from ancient times. Along with the significance of Amaterasu as sun goddess, there are other ways in which the sun has become a central part of Japanese consciousness. The celebration of the New Year represents yet another way in which indigenous values are mixed with Chinese imports to provide a unique cultural perspective on the significance of vitalism and optimism.

While Christmas is celebrated in Japan to some degree, it is not considered a national holiday, and the attendant Western religious aspects of that day are certainly missing. New Year's Day is by far the more significant holiday. Before the Meiji Restoration, the New Year was celebrated according to the Chinese lunar calendar. In modern times, though the lunar calendar still has influence on scheduling of festivals and celebrations, the Gregorian calendar change is celebrated by most people as the "official" New Year.

In the days before the New Year begins, people busily prepare by cleaning the house and cooking food to welcome the kami of new life. At this time, the post office is flooded by New Year's cards which each person sends to friends, relatives, and associates. Rail and air terminals are jammed with people trying to get back to their hometowns to spend the New Year's "night" and "daybreak" with family members.

Japanese express wishes for the New Year by saying "Akemashite Omedetou Gozaimasu." Only one kanji (Chinese character) is found in this phrase (within the first word). This kanji is a combination of the characters for sun and moon and, among other meanings, entails the sun and the moon getting together and becoming "bright." It represents "changing" and "opening," in a sense, "dawning" (Fig. 4).

明

Astronomy in Japan: A Cultural History, Fig. 4 The *kanji* for *Ake*. Symbols for the sun and moon are placed together in this character to represent "bright" or "beginning" (Computer graphic by Steven L. Renshaw)

In ancient lore (under the lunar calendar), the New Year was seen in relation to change in both the sun and moon as well as the symbol of their luminance. The meaning of the phrase "Akemashite Omedetou Gozaimasu" reflects the values of linealism, vitalism, and optimism. Perhaps it is expressed in English most appropriately as follows: "The year is changing; darkness gives way to light; new life begins; Congratulations!" Following tradition, many Japanese on New Year's morning brave the cold to find places with unobstructed views of the eastern horizon and eagerly await the rising sun, the break of day, the symbol of new life. Incorporating the ideas of much ancient mythology, the sun is seen to be making its journey back to the north, and the vernal equinox is eagerly awaited.

As in other aspects of Japanese astronomy that we have discussed, Chinese imports and traditions were incorporated from early times. The New Year of 2008 was special in that it began another 12-year cycle of the Chinese calendar (based on positions of Jupiter with its 12-year orbit and consequent position about the ecliptic; Uchida, 1981). The tradition of using Chinese-based animal names for the 12 directions and associated years is popularly maintained in Japan. In 2008, things turned around once more to the direction of *ne* (mouse), the north, to the direction of the star Polaris, sometimes called *Ne* no *Hoshi* (mouse star) but also called *Shin Boshi*, the "Heart" star, the "soul of the Heavens." 2008 began the clockwise cycle again which from ancient Chinese geomancy means moving from N to NNE (2009, *ushi* or cow), to ENE (2010, tora or tiger), to E (2011, *u* or rabbit), and so forth.

The mixture of Chinese geomancy and symbolism with indigenous social values is clearly seen in the Japanese celebration of the New Year. Yet the quiet tolling of temple bells on New

Year's Eve brings a certain calm and solitude unseen in most any other culture. It is in this very symbolic act that centuries of Japanese history and tradition, for better or worse, can be seen and truly appreciated.

Hopes for the Future Built on a Rich But Hidden Past

Most of Japan's recorded history reflects a culture continually influenced by imports, even when on the surface, the country appeared to be isolated. At the same time, a cultural consciousness combined with quite distinct social and political purposes has always been a source through which most any idea, foreign or domestic, had to be filtered.

Though we can still see much of the ancient heritage of Japanese astronomy in layouts, structures, mythology, and ethnographic lore, it is often difficult to find too many Japanese citizens aware of this sphere which incorporates a complex interaction of ancient values and purposes with celestial symbols. Feeling that the culture has adopted almost every modern concept that East or West has to offer, many Japanese themselves are unaware of the richness of their ethnoastronomic heritage. As in the West, many young Japanese are more likely to know the name of Pleiades rather than Subaru and associate the latter with an automobile company rather than the celestial symbol which meant so much to their ancestors. While Tanabata is still observed and the legend of Orihime and Kengyuu still finds its way into modern songs and prose, few people are concerned about the festival's shift away from its seasonal association. In many ways, however, Japan's embracing of the West and virtual denigration of its past reflects a process which has been a part of the culture's way of handling infusion from its earliest times. Still, when the "face" is lifted, one still finds an enduring set of values and purposes that appear to predate written history.

In discussing some modern approaches to archaeoastronomy, Aveni (1989) has alluded to the inclination to disassociate science from the social and historical context in which it was developed. He points out how such isolation lacks the notion of process or change and in a sense leads to a "predetermined goal of seeking ourselves out in the tattered pages and crumbling walls of other peoples' history (p. 8)." Aveni further mentions the danger of relying solely on written records and emphasizes using additional evidence in the form of archaeology and architectural icons to understand a nation's cultural astronomy. In taking a narrow view of astronomy as it developed into modern Western science, Aveni contends that we pursue what is interesting to us instead of what was important to the people we study.

The specific irony of Aveni's observations relative to the study of astronomy in Japan may rest in the view taken by many Japanese themselves. In a sense, the view is that we (Japanese) seek others' selves (Western science in particular) within the tattered walls of our own culture and come up sadly lacking. To further paraphrase, we (Japanese) tend to pursue what is of modern interest (to the West in particular) instead of what was actually important to our own ancestors throughout history. These perhaps enigmatic Japanese views are the result of a long and complex history involving interaction of native belief and consciousness with a perception that while unique, the native culture is somehow inferior to those imports it filters. Such lack of "cultural self-esteem" has led to a number of enigmatic events in Japanese history, not merely the denigration of its own astronomical heritage.

In looking at the overall influence of Japanese value, past and present, it may be worth noting that modern astronomical practice, while totally within the rubric of Western science, reflects a long heritage of curiosity combined with concern for future generations. A good example of this may be found in the diary of a young Kochi resident rediscovered in the 1980s. In 1664, while astronomers in Europe were trying to learn more about the motion and nature of comets, Matasaburou, a young boy age 12, began to observe what would later be known as Comet C/1664 W1. Encouraged by his teacher, Jian, he diligently observed the comet for over 4 months, wrote his impressions, and drew the changing shape of the comet in his diary. Despite the lack of astronomical knowledge, Matasaburou showed remarkable curiosity about the true nature of the *houki boshi* (brush star) and an abundant skepticism of the prevailing view among townspeople that the comet signaled doom. While his drawings do not have the flamboyance of those of Hevelius and others observing the comet in Europe, his diary shows every attempt to precisely plot the location and shape of the comet as it crossed the celestial sphere nightly. Matasaburou passed on to his own pupils the joy of discovery, and it is no doubt due to this that copies of his diary have survived the centuries. Such diligence is still seen in the work of amateur and professional astronomer alike. One cannot help but be reminded of the tireless efforts of professionals and amateurs who venture out on every clear night to observe and try to discover yet another celestial wonder.

Future astronomers, archaeoastronomers, and ethnoastronomers in Japan will no doubt come from an increasing number of young Japanese who have grown up in the intellectually free environment of modern Japan. Those not raised within the culture may find the door to Japan's astronomical past opening wider if there is a will to engage in exploration of consciousness and purpose still so evident beneath the surface of Japan's modern society. However, much work lies ahead in uncovering the vast richness of Japanese astronomy in history, and the future is probably most "optimistic" for those young Japanese scholars who find the riches of their heritage and culture inspiration and justification enough to seek knowledge about their nation's long pilgrimage with the sky.

References

Aston, W. G. (Trans.) (1972). *Nihongi: Chronicles of Japan from the earliest times to A.D. 697* (Tuttle, Ed.). Tokyo: Charles E. Tuttle.

Aveni, A. F. (1989). Introduction: Whither archaeoastronomy? In A. F. Aveni (Ed.), *World archaeoastronomy* (pp. 3–12). Cambridge: Cambridge University Press.

Aveni, A. F. (Ed.). (1993). *Ancient astronomers*. Montreal: St. Remy Press.

Brown, D. M. (1993a). Introduction. In D. M. Brown (Ed.), *The Cambridge history of Japan* (Ancient Japan, Vol. 1, pp. 1–47). Cambridge: Cambridge University Press.

Brown, D. M. (1993b). The Yamato kingdom. In D. M. Brown (Ed.), *The Cambridge history of Japan* (Ancient Japan, Vol. 1, pp. 108–162). Cambridge: Cambridge University Press.

Brown, D. M. (1993c). The early evolution of historical consciousness. In D. M. Brown (Ed.), *The Cambridge history of Japan* (Ancient Japan, Vol. 1, pp. 504–548). Cambridge: Cambridge University Press.

Chamberlain, B. H. (1971). In Tuttle (Ed.), *Japanese things*. Tokyo: Charles E. Tuttle.

Chamberlain, B. H. (Ed.). (1981). *The Kojiki: Records of ancient matters* (Tuttleth ed.). Tokyo: Charles E. Tuttle.

Hall, J. W. (1971). *Japan from prehistory to modern times*. Tokyo: Charles E. Tuttle.

Hall, J. W., Jansen, M. B., Kanai, M., Twitchett, D., et al. (Eds.). (1993). *The Cambridge history of Japan* (Vol. 6). Cambridge: Cambridge University Press.

Hara, M. (1975). *Seiza no Shinwa* (Mythology of the constellations). Tokyo: Kouseisha (in Japanese).

Hashimoto, T. (1997). Astronomy in Japan. In J. Lankford (Ed.), *History of astronomy: An encyclopedia* (pp. 283–7). New York: Garland Publishing.

Hirose, H. (1972). *Nihonjin no Tenmonkan* (The Japanese astronomical view). Tokyo: NHK Books (in Japanese).

Ho, P. Y. (1985). *Li, Qi, and Shu: An introduction to science and civilization in China*. Hong Kong: Hong Kong University Press.

Inoue, M. (1993). The century of reform. In D. M. Brown (Ed.), *Ancient Japan* (Vol. 1, pp. 163–220). Cambridge: Cambridge University Press.

Kidder, J. E. (1993). The earliest societies in Japan. In D. M. Brown (Ed.), *The Cambridge history of Japan* (Ancient Japan, Vol. 1, pp. 48–107). Cambridge: Cambridge University Press.

Krupp, E. C. (1983). *Echoes of the ancient skies: The astronomy of lost civilizations*. Oxford: Oxford University Press.

Krupp, E. C. (1989). The cosmic temples of old Beijing. In A. F. Aveni (Ed.), *World archaeoastronomy* (pp. 65–75). Cambridge: Cambridge University Press.

Krupp, E. C. (1991). *Beyond the blue horizon: Myths and legends of the sun, moon, stars, and planets*. New York: Oxford University Press.

Krupp, E. C. (1997). *Skywatchers, shamans, and kings: Astronomy and the archaeology of power*. New York: Wiley.

Mason, R. H. P., & Caiger, J. G. (1973). *A history of Japan*. Tokyo: Charles E. Tuttle.

Matsumae, T. (1993). Early Kami worship. In D. M. Brown (Ed.), *The Cambridge history of Japan* (Ancient Japan, Vol. 1, pp. 317–358). Cambridge: Cambridge University Press.

Miyata, N. (1996). *Minzokugaku heno Shoutai* (An invitation to folk study). Tokyo: Chikuma Shinsho (in Japanese).

Miyazawa, K. (1951). *Douwa Shu; Ginga Tetsudou no Yoru* (A collection of tales; night of the milky-way railroad). Tokyo: Iwanami Shoten (in Japanese).
Morton, W. S. (1995). *Japan: Its history and culture*. New York: McGraw-Hill.
Nakayama, S. (1969). *A history of Japanese astronomy*. Cambridge: Harvard University Press.
Naoki, K. (1993). The Nara state. In D. M. Brown (Ed.), *The Cambridge history of Japan* (Ancient Japan, Vol. 1, pp. 221–267). Cambridge: Cambridge University Press.
Needham, J. (1959). *Science and civilisation in china* (Mathematics and the sciences of the heavens and the earth, Vol. 3). Cambridge: Cambridge University Press.
Nivison, D. S. (1989). The origin of the Chinese lunar lodge system. In A. F. Aveni (Ed.), *World archaeoastronomy* (pp. 203–218). Cambridge: Cambridge University Press.
Nojiri, H. (1973). *Nihon Seimei Jiten* (Dictionary of star names in Japan). Tokyo: Tokyo Do Shuppan (in Japanese).
Nojiri, H. (1982). *Nihon no Seimei* (Japanese star names). In H. Nojiri (Ed.), *Seiza* (Constellations) (pp. 223–236). Tokyo: Koseisha Koseikaku (in Japanese).
Nojiri, H. (1987). *Seiza Meguri* (Tour of the constellations). Tokyo: Seibundou Shinkousha (in Japanese).
Nojiri, H. (1988). *Hoshi no Shinwa Densetsu Shusei (Collection of mythology and star legends)*. Tokyo: Koseisha Koseikaku (in Japanese).
North, J. (1995). *Astronomy and cosmology*. New York: W. W. Norton.
Oguma, E. (1995). *Tanitsu Minzoku Shinwa no Kigen* (The myth of the homogeneous nation). Tokyo: Shinyousha (in Japanese).
Okada, Y., & Akune, S. (1993). *Gendai Koyomi Yomikaki Jiten* (Modern calendar dictionary). Tokyo: Kashiwa Shoubou (in Japanese).
Ozaki, U., et al. (Eds.). (1993). *Dai Ji Gen* (Great origins of words). Tokyo: Kadokawa Shoten (in Japanese).
Pannekoek, A. (1961). *A history of astronomy*. New York: Dover Publication.
Philippi, D. L. (Ed.). (1968). *The Kojiki: Records of ancient matters*. Tokyo: University of Tokyo Press.
Renshaw, S. L., & Ihara, S. (1999). Archaeoastronomy and astronomy in culture in Japan: Paving the way to interdisciplinary study. *Archaeoastronomy, 14*, 59–88.
Ronan, C. (1996). Astronomy in China, Korea, and Japan. In C. Walker (Ed.), *Astronomy before the telescope* (pp. 245–268). New York: St. Martin's Press.
Ruggles, C. L., & Saunders, N. J. (1993). The study of cultural astronomy. In C. L. Ruggles & N. J. Saunders (Eds.), *Astronomies and cultures* (pp. 1–33). Niwot, CO: University Press of Colorado.
Sansom, G. B. (1973). *Japan: A short cultural history*. Tokyo: Charles E. Tuttle.
Sansom, G. B. (1974). *A history of Japan*. Tokyo: Charles E. Tuttle.
Shigemitsu, Y. (1996). *Japan as an East Asian nation: Religion and morality*. Kawasaki: Global Culture Center.
Shinmura, L. (Ed.). (1994). *Koujien* (Japanese etymological dictionary). Tokyo: Iwanami Shoten (in Japanese).
Sigrist, J., & Stroud, D. M. (Eds.). (1995). *Kenji Miyazawa's the milky-way railroad*. Tokyo: Stone Bridge Press.
Sonoda, K. (1993). Early Buddha worship. In D. M. Brown (Ed.), *The Cambridge history of Japan* (Ancient Japan, Vol. 1). Cambridge: Cambridge University Press.
Sugimoto, M., & Swain, D. L. (1989). *Science and culture in traditional Japan*. Tokyo: Charles E. Tuttle.
Torao, T., & Brown, D. M. (1991). *Chronology of Japan*. Tokyo: Business Intercommunications.
Tsunoda, R., de Bary, W. T., & Keene, D. (1964). Compilers. In R. Tsunoda, W. T. de Bary, & D. Keene (Eds.), *Sources of Japanese tradition* (Vol. 2). New York: Columbia University Press.
Uchida, T. (1973). *Hoshi no Hougen to Minzoku* (Dialects of the stars and cultures). Tokyo: Iwasaki Bijutsu (in Japanese).
Uchida, M. (1981). *Koyomi to Tenmon Ima Mukashi* (Calendar and astronomy; past and present). Tokyo: Maruzen (in Japanese).
Watanabe, T. (1986). *Kinsei Nihon Tenmon Gakushi; Vol. I: Tsuu Shi (A view of Japanese history of astronomy in modern times; Vol. II: General history)*. Tokyo: Koseisha Kosaikaku (in Japanese).
Watanabe, T. (1987). *Kinsei Nihon Tenmon Gakushi; Vol. II: Kansatsu Gijutsu Shi (A view of Japanese history of astronomy in modern times; Vol. II: Techniques of observation)*. Tokyo: Koseisha Kosaikaku (in Japanese).
Yokoo, H. (1997). Kodai Nihonjin wa Hoshi ni Kyoumi ga nakattaka (Were ancient Japanese not interested in stars?). *The Heavens, 870*, 14–15 (in Japanese).
Yoshinari, N. (1996). *Zokushin no Cosmology* (Cosmology of folk beliefs). Tokyo: Hakusui Sha (in Japanese).

Astronomy in Mainland Southeast Asia

Yukio Ōhashi

Southeast Asia is divided into two parts, mainland Southeast Asia and insular Southeast Asia (also called the Indo-Malay Archipelago). Mainland Southeast Asia is further divided into two parts. One is Vietnam, where Chinese influence is greater than Indian influence, and the other includes Burma, Cambodia, Laos, and Thailand, where Indian influence is greater. The Malay Peninsula is a part of mainland Southeast Asia geographically, but is culturally closer to insular Southeast Asia.

Astronomy in Burma, Cambodia, Laos, Thailand, and Yunnan

Traditional Calendars in Burma, Cambodia, Laos, Thailand, and Yunnan

The traditional calendars of Burma, Cambodia, Laos, and Thailand in Southeast Asia, and those of the Tai (or Dai in the Pinyin system of Chinese transliteration) people in Sipsong-panna (or Xishuang-banna in Pinyin) in the Yunnan province of China have similar characteristics. (For the calendars in mainland Southeast Asia, except for Vietnam, see Eade (1989, 1995). For the Burmese calendar, see Irwin (1909), de Silva (1914), and Htoon-Chan (1918). For the Cambodian calendar, see Faraut (1910). For the Lao calendar, see Phetsarath (1940) and Dupertuis (1981). And also, for the Dai calendar in Yunnan in China, Zhang and Chen (1981) may be consulted. It may also be mentioned here that de Casparis (1978) may be consulted for calendars in insular Southeast Asia.) They are basically based on the Indian (Hindu) calendrical system, which is a luni-solar calendar, with certain simplifications. The Indian influence is seen, for example, in the fact that the length of a year used in most of these calendars is 365.25875 days. This is similar to the sidereal year (not tropical year) of the Ārdharātrika school, one of the schools of Hindu astronomy. Dikshit, an authority on Hindu astronomy in the second half of the nineteenth century, pointed out that the length of a year used in an astronomical work procured by a French envoy from the Ayutthaya dynasty of Siam (present Thailand) is the same as that of the *Sūrya-siddhānta* quoted in the *Pañca-siddhāntikā* of ► Varāhamihira (sixth century AD) (Dikshit, 1981, p. 378). This *Sūrya-siddhānta* belongs to the Ārdharātrika school.

Besides the Indian influence, there is also Chinese influence in this area, notably the animal names of the 12-year cycle.

The main differences between Indian (Hindu) traditional astronomy and the calendars in mainland Southeast Asia (except for Vietnam) are as follows. (The traditional calendar of Vietnam is based on the Chinese system, which I shall discuss in the next section.)

1. In the Hindu traditional calendar, an intercalary month is inserted when two successive new moons occur during which the sun remains in the same zodiacal sign. In mainland Southeast Asian calendars, the 19-year cycle is usually used for intercalation during which seven intercalary months, which consist of 30 days, are inserted after the fixed month of a year. Actually, the 19-year cycle is not harmonious with the sidereal year which is used in Hindu and mainland Southeast Asian calendars, and I suspect that this 19-year cycle might have been introduced from China.
2. In the Hindu traditional calendar, 1 month is divided into 30 *tithi*s, which are the periods during which the longitudinal difference between the sun and moon changes by 12°, and the number of the *tithi* at the beginning of a day (usually sunrise) becomes the name of the day. So, the number of days in a month is automatically determined. In mainland Southeast Asian calendars, 29-day months and 30-day months are usually distributed alternately at definite months of a year, and 11 intercalary days are distributed in 57 years at the fixed month of a year. Actually this method is slightly inexact.

One thing may be added here. Among Tai (or Thai) people, lunar months are named by serial number, and there are some variations of this method. This method is similar to the Chinese method, but is absent in the Hindu traditional calendar. The method used by Dai people in Sipsong-panna in Yunnan province (in China) is quite similar to an ancient variation of a Chinese method.

I suggest the following tentative hypothesis. The 19-year cycle intercalation and the method of month reckoning using serial numbers were introduced from China, and were modified after the introduction of the Indian calendar (Ārdharātrika school). (For details, see Ōhashi, 2002). It may also be mentioned here that the calendar used in the inscriptions of Champa, which was a kingdom that existed in present central and south Vietnam until the seventeenth century AD, was also based on the Indian calendar.

Controversy Regarding the Dai Calendar in Yunnan, China

There was a controversy between Dong Yantang and Zhang Yong, both of whom are Chinese scholars, in the first half of the twentieth century regarding the origin of the Dai peoples' calendar in the Yunnan province of China. In 1938, Dong Yantang published a paper on the origin of the Dai calendar (Dong, 1938). In this paper, Dong Yantang argued that the Dai calendar was based on the Qin calendar of ancient China.

In 1939, Zhang Yong wrote a paper on the Dai calendar (Zhang, 1939). Zhang Yong criticized Dong Yantang's paper, and concluded that the Dai calendar was based on the Indian calendar. Zhang Yong pointed out some reasons. For example, the Dai calendar uses half months just like the Indian calendar, and the Dai calendar divides a year into three seasons just like the Indian calendar. These reasons are justified. Zhang Yong mentioned other reasons also, and tried to show that the Dai calendar was completely based on Indian calendar without Chinese influence.

I think that the Dai calendar is basically based on Indian calendars, but there may be some Chinese influence also, as I mentioned in the previous section.

Historical Development of the Traditional Calendars in Yunnan and Burma

According to Zhang Gongjin and Chen Jiujin (Zhang and Chen 1981), the texts entitled *Suding* and *Suliya* were followed by the Dai people for making calendars before AD 1931, but the text entitled *Xitan* has been followed since AD 1931 or so. Zhang and Chen also say that the *Suding* and *Suliya* do not follow the 19-year cycle of intercalation strictly, but the *Xitan* follows the 19-year cycle of intercalation. The calendrical luni-solar year of the *Xitan* practically keeps pace with the tropical year, although the solar new year's day is calculated by the sidereal year as before. I compared their astronomical constants with Indian constants, and found that the *Suding* and *Suliya* follow the Ārdharātrika school, while the *Xitan* follows the Saura school (Ōhashi, 2002).

According to Irwin (1909), the *Makaranta* (there are two methods of epoch: AD 638 and AD 1436), which probably follows the "original *Surya Siddhanta*" (i.e., Ārdharātrika school), was followed in Burma originally. Afterwards the *Thandeikta* (epoch: AD 1738), which chiefly follows the "present *Surya Siddhanta*" (i.e., Saura school), was used. Irwin writes that the *Thandeikta* is said to have been composed in about AD 1738 or AD 1838, and that the present *Sūryasiddhānta* was introduced into Amarapura, Burma, in AD 1786, and translated into Burmese after about 50 years. Irwin also states that the 19-year cycle of intercalation was followed in the *Makaranta*, but was not strictly followed in the *Thandeikta*. We should note that the Burmese *Makaranta* is probably different from the well-known Indian Sanskrit astronomical table *Makarandasāraṇī* (AD 1478) of ► Makaranda, which follows the Saura school.

Here, the treatment of the 19-year cycle of intercalation is just the opposite of the Dai calendar (Yunnan, China) and Burmese calendar. More detail about the calendar reform in these regions should be investigated.

Traditional Astronomy and Modern Astronomy in Thailand

In the mid-fourteenth century AD, Lithai (King Ruang) of the Sukhothai dynasty wrote the *Traiphum* (Three Worlds) (Reynolds & Reynolds, 1982). This is a celebrated text of traditional Thai cosmology, which is based on Buddhist cosmology. Some information about traditional astronomy and the calendar is also found there.

In 1685, King Narai of the Ayutthaya dynasty observed a lunar eclipse with a telescope with the Jesuits sent by the French King (See Tachard, 1688/1981, pp. 230–246; Choisy, 1993, p. 215). King Narai requested mathematicians from France, and planned to build observatories at Louvo (now Lop Buri) and Siam (now Ayutthaya). This event may be considered the beginning of modern astronomy in Thailand.

In 1687, a French envoy, Simon de la Loubère, visited the Ayutthaya dynasty and procured an astronomical work entitled *Souriat*. This work was later analysed by a celebrated astronomer, Jean Dominique Cassini (See Loubère, 1693/1969, pp. 64–67 and 186–199; Bailly, 1787). This is the earliest information of India-based astronomy reaching Europe. Dikshit pointed out that the length of a year used there is the same as that of the *Sūryasiddhānta* quoted in the *Pañcasiddhāntikā* of ► Varāhamihira (sixth century AD) (Dikshit, 1981, p. 378).

In the nineteenth century, King Mongkut (Rama IV) (r. 1851–1868) studied European astronomy as well as Thai traditional astronomy. He ordered his own observatory near Phetburi. He predicted the total solar eclipse of 1868. According to the *Dynastic Chronicle*, the King calculated the eclipse "by using the old astrological texts of Siamese and Mon, as well as many old American and English texts." According to Thongchai, the Mon text used by the King is the *Saram*, one of the two Mon treatises for planetary calculation known in Siam; the other text more conventionally used by astrologers at that time was *Suriyayat*. (See Thiphaakorawong, vol. 2 1966 of 1965–1974, pp. 532–539; Cook, 1992; Thongchai, 1994, chapter 2). This was a symbolic event in the course of the introduction of modern astronomy into Thailand.

There are several inscriptions with calendrical data in Thailand, which are also important sources of Thai astronomy (Eade, 1996). There was an independent kingdom, Lanna, in North Thailand from the end of the thirteenth century to the beginning of the twentieth century. The people of Lanna had their own astronomy, which was based on Indian astronomy. (See Soonthornthum, 1998; for the Northern Thai calendar, see Davis, 1976).

Burmese Constellations

Burma has a special system of constellations, and there are three beautiful star maps drawn on the ceilings of corridors of the Kyauktawgyi Pagoda at Amarapura (near Mandalay, Burma) (Fig. 1a–d are the star maps photographed by the author in 1984).

King Pagan (r. 1846–1852) built the Kyauktawgyi Pagoda in 1847 on the model of the Ananda Temple at Pagan (Lu Pe Win, 1960, p. 5). There is a pioneer study of Burmese constellations by Francis Buchanan (1799) (also see Nishiyama, 1997). Although Burmese constellations include Indian constellations, there are many Burmese unique constellations, which are very important for investigating the original Burmese contribution.

Astronomy in Vietnam

There are four main countries where Classical Chinese was used as the official language of traditional learning: China, Korea, Japan, and Vietnam. In this section, I will discuss some aspects of Vietnamese astronomy based on the sources I consulted. When a Vietnamese or East Asian person is referred to in this section, the surname is written first as is the custom in these regions, unless commented upon otherwise.

Previous Researches

In 1934, Mikami Yoshio, a pioneer of the study of the history of Eastern ► mathematics in Japan, wrote a paper on a mathematical work of Vietnam. This is a study of a Vietnamese mathematical work entitled *Chi-minh toan-phap*, written in classical Chinese, which was brought to Japan by Matsumoto Nobuhiro, an authority on Vietnamese study in Japan.

In 1940, Yung Chang (as transliterated in his own paper where Chang is the surname, or Zhang Yong in modern Pinyin transliteration) (1911–1939), a Chinese scholar, wrote a paper on the Vietnamese calendar. This is a pioneer study of the Vietnamese calendar, and I was much impressed by this work. In the 1960s,

Astronomy in Mainland Southeast Asia, Fig. 1 (continued)

Astronomy in Mainland Southeast Asia, Fig. 1 Star maps drawn on the ceilings of corridors of the Kyauktawgyi Pagoda at Amarapura

Huard and Durand wrote popular articles on the history of Vietnamese science (Huard & Durand, 1961/1965; Durand & Huard, 1964/1966). In 1964, Ho Peng-Yoke wrote a paper on the records of natural phenomena, including astronomical phenomena, recorded in a historical work of Vietnam. It is necessary to continue this kind of work, comparing the records with other East Asian records, and checking them with modern calculations.

In 1979, a monograph on the history of science in Vietnam was published in Vietnamese in Hanoi (Vien Su hoc, 1979). This book includes 12 papers, including a paper on the history of Vietnamese mathematics written by Ta Ngoc Lien. As far as I know, this book is the most detailed work on the history of science and technology in Vietnam. In 1991, Han Qi, a Chinese scholar, wrote an overview of the history of astronomy and mathematics in Vietnam (Han, 1991). [Ed. note: See Han Qi's article on Jesuits and Knowledge Exchange in China in this volume].

In 1999, the ninth International Conference on the History of Science in East Asia was held at Singapore. In this conference, there was a session on "New Topics in the History of Science in East Asia-Preliminary Research on Vietnamese Scientific Tradition." In this session, Chu Tuyet Lan and Nguyen Xuan Dien from the Institute of Sino-Nom Studies, Hanoi, introduced Vietnamese works on science, medicine and technology (Nguyen, 2002), and Alexei Volkov read a paper on the *Toan-phap dai-thanh* of Luong The Vinh, a Vietnamese mathematical work. I think that this conference marked a kind of breakthrough for the study of the history of Vietnamese astronomy and mathematics.

In 2000, I visited the Institute of Sino-Nom Studies in Hanoi, and consulted some Vietnamese astronomical works with the help of Ms. Chu Tuyet Lan and Mr. Nguyen Xuan Dien. When I visited Vietnam, I found a small book on 13 Vietnamese scientists, both premodern and modern, written in Vietnamese (Le, 1999). This is a popular book for youths.

In 2002, Alexei Volkov published a paper on the *Toan-phap dai-thanh*. I think that this is a monumental paper on the history of mathematics in Vietnam. Also in 2002, a convenient bibliography of classical literature of Vietnam was published in Taiwan. Several astronomical and mathematical works are listed there (Liu, Wang & Chen, 2002, part 1, pp. 452–459).

Vietnamese Astronomy

Rough History of Vietnamese Calendars

1. Acceptance of Chinese calendars, notably the *Shoushi* calendar

   The *Yuanshi*, the official history of the Yuan dynasty of China, says that a Chinese calendar was given to the Vietnamese king (Tran dynasty) in 1265 (*Yuanshi*, vol. 209, Annan, the second year of Zhiyuan). At that time, the *Shoushi* calendar, the celebrated calendar of the Yuan dynasty, had not been made, and the *Daming* calendar of the previous Jin dynasty was still used in China.

   The *Dai-Viet su-ky toan-thu*, an official history of Vietnam written in Classical Chinese, says that the *Shoushi* calendar was given to a Vietnamese king (Tran dynasty) from the Chinese Emperor in 1324. (*Dai Viet Su Ky Toan Thu*: 220, vol. 6, 42 b in the original block print). From the above sources, we can suppose that Chinese calendars were accepted in Vietnam until the early fourteenth century.

2. *Hiep-ky* calendar

   The *Dai-Viet su-ky toan-thu* states that the *Shoushi* calendar was changed into the *Hiep-ky* calendar in 1339 (Tran dynasty) (*Dai-Viet su-ky toan-thu*: 229, vol. 7, 9 b-10 a in the original block print). This record possibly means that the name of the calendar was changed, and does not necessarily mean that the method of calculation was changed. The *Mingshi*, the official history of the Ming dynasty of China, says that the *Datong* calendar of China was given to the Vietnamese king (Tran dynasty) in 1369, the next year of the establishment of the Ming dynasty (*Mingshi*, vol. 321, Annan, the second year of Hongwu). It may be that the *Datong* calendar, which is a revised version of the *Shoushi* calendar, was accepted in Vietnam at that time.

3. *Thuan-thien* calendar

   The *Dai-Viet su-ky toan-thu* tells that the *Hiep-ky* calendar was abolished, and the *Thuan-thien* calendar was adopted in 1401 (Ho dynasty) (*Dai-Viet su-ky toan-thu*: 267, (vol. 8, 39a in the original block print). The difference between these two calendars is not recorded.

4. Acceptance of the Chinese *Datong* calendar

   Vietnam was directly ruled by the Ming dynasty of China from 1413 to 1428, and the *Datong* calendar must have been used. The Le dynasty was founded in 1428 in Vietnam, but there is no record that the calendar was changed.

   The *Mingshi* states that the *Datong* calendar was given to the Mac, who ruled Vietnam for certain period, in 1540 (*Mingshi*, vol. 321, Annan, the 19th year of Jiajing). In 1829, Nguyen Huu-than wrote in his *Y-trai toan-phap nhat-dac-luc* that the *Datong* calendar had been used until the *Hiep-ky* calendar (Vietnamese adoption of the Chinese *Shixian* calendar) was adopted in 1813 (Zhang, 1940, p. 34.).

5. *Hiep-ky* calendar (=*Shixian* calendar)

   According to Nguyen Huu-than, as we have seen above, the *Shixian* calendar of the Qing dynasty of China was adopted in Vietnam as the *Hiep-ky* calendar in 1813 (Nguyen dynasty). This *Hiep-ky* calendar should not be confused with its previous namesake. Zhang Yong compared Vietnamese chronological tables with Chinese calendar, and pointed out that the *Shixian* calendar was actually used in Vietnam from 1813 to 1840.

6. Consideration of the longitudinal difference

   Zhang Yong pointed out that the Vietnamese *Hiep-ky* calendar has differed from the Chinese *Shixian* calendar since 1841. This must be due to the consideration of the longitudinal difference between Vietnam and China.

Calendar Reformation Under Minh-manh

In order to reform the calendar, astronomical observations were made under the emperor Minh-manh (r. 1820–1840) of the Nguyen dynasty. There are some source materials about this reformation.

The *Dai-Nam hoi-dien su-le* (1855) is a comprehensive official record of the system of government of the Nguyen dynasty. It has a section on the Kham-thien-giam (National Astronomical Observatory). According to this section, it was declared in 1837 that the prime meridian for Vietnam passed through its capital (Hue), whose latitude was determined to be 16°22′30″, and longitude measured from the Western prime meridian to be 105° (*Dai-Nam hoi-dien su-le*, vol. 259, 13a–b). The actual position of Hue is 16°27′N, and 107°33′E (from Greenwich). So, the above-mentioned Western prime meridian must be Paris (2°20′E from Greenwich).

There is another interesting work entitled *Thien-van-khao* (Study of Astronomy), which is volume 1 of the *Su-hoc bi-khao* of Dang Van-phu. This text records longitude and latitude (from Hue) of several places determined in 1837. According to this text, the longitude seems to have been determined by the observation of lunar eclipses using local time. From the above sources, we know that Vietnamese astronomers made efforts to make the calendar more suitable for Vietnam.

Another interesting work is the *Quoc-trieu thien-van-chi*. This is a chronological compilation of the records of heavenly phenomena from 1569 to 1888.

The traditional astronomies in several regions of mainland Southeast Asia are very interesting, but their detailed study is our future task. Several original sources are still in manuscript form or extremely rare. Fortunately, some people are now going to study this subject, and I hope that more results can be reported in the near future.

In the case of Vietnamese astronomy, it is necessary to compare it with Chinese astronomy, and in the case of Burmese, Cambodian, Lao, and Thai astronomies, it is necessary to compare them with Indian astronomy. Thorough study of the regional differences and their relationships with regional cultures are needed. I hope some readers of this article contribute to this subject in the future.

References

Primary Sources

Dai Viet Su Ky Toan Thu. (1998). Vol. 4 (reprint of the original block print). Hanoi: Nha Xuat Ban Khoa Hoc Xa Hoi (Social Science Publishers).

Dai-Nam hoi-dien su-le, v. 259, block print. “VHv 1570/42” preserved in the Institute of Sino-Nom Studies, Hanoi.

Quoc-trieu thien-van-chi, photocopy “VHc 01610” of manuscript “VHv 370” preserved in the Institute of Sino-Nom Studies, Hanoi.

Thien-van-khao (Study of Astronomy) (Vol. 1 of the Su-hoc bi-khao) of Dang Van-phu, photocopy “VHc 02030” of manuscript “A 1490” preserved in the Institute of Sino-Nom Studies, Hanoi.

Secondary Sources

Bailly. (1787). *Traité de l'astronomie indienne et orientale*. Paris: Debure l'âiné.

Buchanan, Francis. (1799). On the religion and literature of the Burmas. *Asiatick Researches* 6 (or, in a reprint of AD 1809s edition (New Delhi: Cosmo Publications, 1979, in my hand). 163–308).

Choisy, Abbé de. (1993). *Journal of a Voyage to Siam 1685–1686* (Journal du voyage de Siam fait en 1685. & 1686. Paris: S. Mabre-Cramoisy, 1687), Trans. Michael Smithies. Kuala Lumpur: Oxford University Press.

Chunyin, Liu, Wang Xiaodun, and Chen Yi eds. (2002). *Yuenan Han-Nan wenxian mulu tiyao*. (A concise bibliography of Chinese and nom literature in Vietnam, in Chinese), 2 parts, Taipei: Zhongyang yanjiuyuan, Zhongguo wen-zhe yanjiusuo.

Cook, N. (1992). A tale of two city pillars: Mongkut and Thai astrology on the eve of modernization. In W. Gehan & E. C. Chapman (Eds.), *Patterns and illusions, Thai history and thought* (pp. 279–312). Canberra, Australia: Richard Davis Fund and Department of Anthropology, Research School of Pacific Studies, The Australian National University. Singapore.

Davis, R. (1976). The Northern Thai calendar and its uses. *Anthropos, 71*, 3–32.

de Casparis, J. G. (1978). *Indonesian chronology (Handbuch der Orientalistik, III.1.1)*. Leiden, Netherlands: E.J. Brill.

de Silva, T. P. (1914). Burmese astronomy. *The Journal of the Burma Research Society, 4*, 23–43. 107-18, and 171-207.

Dikshit, Sankar Balakrishna. (English Translation of) Bharatiya Jyotish Sastra (History of Indian astronomy). Trans. R. V. Vaidya. Part II. *History of astronomy during the Siddhantic and modern periods*. Delhi: The Controller of Publications (Government of India). 1981. [This book was originally written in Marathi. Pune: Hari Narayana Gokhale Syane Pune ethe Aryamushana Chapakhanyanta Chapuna Prasiddha kela, 1896.]

Dong, Y. (1938). Boyi lifa kaoyuan. (On the origin of the Tai calendar, in Chinese). *Xinan bianjiang, 3*, 55–71.

Dupertuis, S. (1981). Le Calcul du Calendrier laotien. *Peninsule, 2*, 25–113.

Durand, M., and P., Huard. 1966. The spread of modern science in Viet Nam. *Science in the twentieth century*.

Ed. Rene Taton (Trans. A. J. Pomerans) (French original: La Science Contemporaine II, 1964, Presses Universitaires de France). London: Thames and Hudson, 594–596.

Eade, J. C. (1989). *Southeast Asian ephemeris, solar and planetary positions, A.D. 638–2000*. Ithaca, NY: Southeast Asia Program, Cornell University.

Eade, J. C. (1995). *The calendrical systems of Mainland South-East Asia, (Handbuch der Orientalistik, III.9)*. Leiden, Netherlands: E.J. Brill.

Eade, J. C. (1996). *The Thai historical record, a computer analysis*. Tokyo: The Centre for East Asian Cultural Studies for Unesco, The Toyo Bunko.

Faraut, F. G. (1910). *Astronomie cambodienne*. Saigon, Vietnam: F.-H. Shneider.

Han, Q. (1991). Zhong-Yue lishi-shang tianwen-xue yu shuxue de jiaoliu. (The ancient Sino-Vietnamese astronomical and mathematical relations, in Chinese with english summary). *Zhongguo keji shiliao (China Historical Materials of Science and Technology), 12*(2), 3–8.

Ho, P. Y. (1964). Natural phenomena recorded in the Dai-Viet Su-ky Toan-thu, an early Annamese historical source. *Journal of the American Oriental Society, 84*, 127–149.

Htoon-Chan. (1918). *The Arakanese calendar* (3rd ed.). Rangoon, Burma (Myanmar): The Rangoon Times Press.

Huard, P., and M., Durand. (1965). The beginnings of science in Viet Nam. *Science in the nineteenth century*. Ed. Rene Taton (Trans. A.J. Pomerans) (French original: La Science Contemporaine, 1961, Presses Universitaires de France), London: Thames and Hudson, London. 579–584.

Irwin, A. M. B. (1909). *The Burmese and Arakanese calendars*. Rangoon, Burma (Myanmar): Hanthawaddy Printing Works.

Le, M. Q. (1999). *Danh nhan khoa hoc Viet Nam. (Famous Vietnamese scientists, in Vietnamese)*. Ho Chi Minh City, Vietnam: Nha xuat ban Tre (Youth publishers).

Loubère, de la, Simon. (1969). *A new historical relation of the Kingdom of Siam*. Trans. A.P. (from the French). London: T. Horne, 1693. Kuala Lumpur: Oxford University Press.

Lu Pe Win, U. (1960). *Historic sites and monuments of Mandalay and Environs*. Burma, Republic of the Union of Myanmar: Ministry of Culture.

Mikami, Y. (1934). Annan no ichi sansho ni tsuite. (On a mathematical work of Annam, in Japanese. *Gakko Sugaku, 14*, 3–11.

Nguyen, Dien Xuan. Ancient Vietnamese manuscripts and printed books related to science, medicine and technology (inventory, classification and preliminary assessment). *Historical perspectives on East Asian science, technology and medicine* (Proceedings of the 9th ICHSEA). Ed. Chan, Alan K. L., Gregory K. Clancey and Hui-Chieh Loy. Singapore: Singapore University Press and World Scientific, n.d. (actually published in 2002). 547–554.

Nishiyama, M. (1997). In I.-S. Nha & F. R. Stephenson (Eds.), *Myanmar (Burmese) constellations on old Myanmar sky charts. Oriental astronomy from Guo Shoujing to King Sejong* (pp. 289–302). Seoul, South Korea: Yonsei University Press.

Ōhashi, Yukio. Originality and dependence of traditional astronomies in the East. *Historical perspectives on East Asian science, technology and medicine* (Proceedings of the 9th ICHSEA). Ed. K. L. Alan Chan, Gregory K. Clancey, and Hui-Chieh Loy. Singapore: Singapore University Press and World Scientific, n.d. (actually published in 2002). 394–405.

Phetsarath, P. (1940). Calendrier laotien. *Bulletin Des Amis Du Laos, 4*, 107–140.

Reynolds, Frank E., and Mani B. Reynolds and Trans. (1982). Three worlds according to King Ruang. Berkeley: University of California.

Soonthornthum, Boonrucksar. Astronomy in Old Lanna's culture. *Proceedings of the Third International Conference on Oriental Astronomy*. Fukuoka, Japan 27–30 Oct 1998. Ed. Masanori Hirai. Fukuoka: Fukuoka University of Education, n.d.

Tachard, G. (1981). *(A relation of the) Voyage to Siam*. London: J. Robinson and A. Churchil. Bangkok: White Orchid Press.

Thiphaakorawong, Cawphraja. The dynastic chronicles, Bangkok Era, the fourth reign, B.E. 2394–2411 (A.D. 1851–1868). 5 vols. Trans. Chadin (Kanjanavanit) Flood (from Thai). Tokyo: The Centre for East Asian Cultural Studies, The Toyo Bunko, 1965–1974.

Thongchai Winichakul. *Siam Mapped*. Honolulu: University of Hawai'i Press, 1994. Chiang Mai: Silkworm Books, 1995. (Thongchai is the author's first name. Thai people are usually referred to by their first names, as the author himself wrote in this book, and only "Thongchai" is mentioned on the spine of the Honolulu edition.)

Vien Su hoc ed. (Institute of History) (Ed.). (1979). *Tim hieu khoa hoc ky thuat trong lich su Viet Nam. (Study of science and technology in Vietnamese history) (in Vietnamese)*. Hanoi, Vietnam: Nha xuat ban Khoa hoc xa hoi (Social science publishers).

Volkov, A., et al. (2002). On the origins of the Toan phap dai thanh(great compendium of mathematical methods). In Y. Dold-Samplonius (Ed.), *From China to Paris: 2000 years transmission of mathematical ideas* (pp. 369–410). Stuttgart, Germany: Franz Steiner Verlag.

Zhang, Y. (1939). Boyi foli jie (On the Buddhist calendar of Tai people, in Chinese). *Kexue, 23*(9), 518–528.

Zhang, Gongjin and Jiujin Chen. Daili yanjiu. (1981). (A study of the Dai calendar, in Chinese). *Zhongguotianwen-xueshi wenji* (Collected Papers of the History of Astronomy in China). Vol. 2. Beijing: Kexue chubanshe. 174–284.

Zhang, Yong. (=Chang, Yung). (1940). Yue-li shuorun-kao. (Sur la concordance des dates néoméniques du calendrier annamite et du calendrier chinois de 1759 a 1886, in Chinese with French abstract), Xinan yanjiu 1. 25–35.

Astronomy in Medieval India

S. M. Razaullah Ansari
Aligarh Muslim University, Aligarh, UP, India

Introduction to Islamic Astronomy

Muslims are obliged to discharge three major religious duties (*arkān*), which could be planned quite accurately using mathematical sciences, particularly astronomy (King, 1993). They are (1) Islamic prayer times that are defined according to the rules of astronomical time reckoning (*'Ilm al-Mīqāt*), (2) calculating the direction of *Ka'ba* (*Qibla*) – the rectangular-shaped room at the center of the Grand Mosque in Mecca – to which Muslims face while praying, and (3) the sighting of the lunar crescent (*Hilāl*) at sunset, by which begins the first day of every month of the Islamic calendar. Evidently this sighting depends on the position of the Sun and Moon and also their positions with respect to the local horizon. Consequently, in the first few centuries of the spread of Islam (eighth to ninth century), Muslims began an intensive and extensive reception of the natural and even social sciences. A multitude of scientific works from Babylon, India, Iran, and Greece were translated into Arabic. This transmission had an official sanction as well. Beginning with the reigns of Umayyad Caliph 'Abd al-Malik ibn Marwān (ca. 700) and his successor son Hishām (724–743) and particularly during the reigns of the Abbasid Caliphs al-Manṣūr (754–775), Hārūn al-Rashīd (786–809), and al-Mā'mūn (813–833), the transmission of foreign or ancient sciences achieved its climax. At this time, Sasanian, Indian, and finally Greek astronomy and mathematics were assimilated and led to the writings of great scholars. Some of these are al-Khwārizmī, al-Farghānī, and al-Battānī (ninth to tenth centuries); Ibn Sīnā, Ibn al-Haytham, and al-Bīrūnī (eleventh century); and Naṣīruddīn al-Ṭūsī (thirteenth century), to name just the most important ones. For example, al-Ṭūsī was the director of the Marāgha observatory, and he initiated the so-called *Hay'a* tradition by developing a non-Ptolemaic theoretical model of planetary motion. For details see Saliba (1994).

India was ruled by the sultans of Central Asia and their descendants during the Sultanate period (1191–1526). The Indian Mughal period (1526–1857) began with the dynastic rule of Ẓahīruddīn Bābur (reigned 1526–1530), followed by his son Humāyūn (r. 1530–1556) and Akbar (r. 1556–1605) whose grandson Shāhjahān (r. 1627–1658) is famous for building the Tāj Maḥal at Agra. During the Indian medieval period, both sultans and particularly Mughal emperors were very keen to patronize the scholars from Central and West Asia. Those scholars (*Ulamā*, *Fuḍalā*), including also mathematicians and astronomers, thronged the courts of sultans, emperors, and even local rulers and nobles (*Umarā*). They brought with them various scientific (mathematical and astronomical) texts, such as the writings of Abu'l Rayḥān al-Bīrūnī (d. 1048), Naṣīrudīn Ṭūsī (d. 1274) of Marāgha, Sulṭān Ulugh Bég (d. 1449) of Samarqand, and Bahāuddīn al-'Āmilī (d. 1622). Mughal Emperor Bābur (prior to his conquest of India) had forged an alliance with the Shāh Ismā'īl-I of Persia and his son Emperor Humāyūn, who had bonded a friendship with Shāh Tahmāsp bin Ismā'īl (d.1576). Consequently, even during the following reigns of Mughal emperors, Akbar, Jahāngīr, and Shāhjahān, the cordial relationship with Iranian Safavid rulers, namely, Shāh 'Abbās-I (d.1629) and Shāh 'Abbās-II (d. 1666), strengthened further (Riazul Islam, 1970). An interesting anecdote is that Shāh 'Abbās-I sent to Jahāngīr on his request as gift the *original* astrolabe of Sultan Ulugh Bég – the founder of the astronomical observatory at Samarqand in 1420. The Shah of Iran kept for himself only its copy (Riazul Islam, 1970). Evidently in such a politico-cultural milieu, several Iranian/Central Asian scholars and scientists flocked to the courts of medieval Indian sultans and emperors who patronized them liberally. In this context, one may understand the origin of the exact sciences, e.g., astronomy and mathematics, which were transmitted to the Indian subcontinent during the medieval period and which were developed further by indigenous

Indian scholars (for a survey on Islamic astronomy and its transmission into India, see Ansari (1995), Appendix I).

A specific feature of Islamic astronomy was the emphasis on observational astronomy. Even in the early Abbasid period (750–850), astronomical observatories were established, in which practical astronomy was carried out quite diligently. The earliest observatories, the Shammāsīya and Qāsīyūn observatories, both founded by Caliph al-Mā'mūn (d. 833), resulted in an observatory movement which culminated in the establishment of the Marāgha observatory in 1259 (Director, Naṣīruddīn al-Ṭūsī), the Samarqand observatory in 1420 (founded by Sulṭān Ulugh Bég, for whom see van Dalen (2007b)), and the Istanbul observatory in 1575–1577 (Director, Taqī al-Dīn Muḥammad) (see for details Sayili (1960) Chapters II, VI, and VIII). An important task at those observatories (*Raṣad Gāh/Khāne*) was the compilation of *Zīj* (plural *Zījāt*), which are astronomical-mathematical tables or handbooks to be used for determining the position of the Sun, Moon, and various planets. All Zījes, in Arabic, Persian, Hebrew, and Turkish, contain tables for functions of spherical astronomy and of trigonometrical functions. The compilers deal briefly also with the following topics: solar and lunar parallax and their eclipses, lunar visibility, gazetteers, star catalogues, and tables of ascendants for astrological purpose. To overview the Zīj literature, cf. the pioneering survey by Kennedy (1956), an updated interim report by King and Samso (2001), and the comprehensive Zīj survey of about more than 200 Zījes by van Dalen (2007a). For Zijes compiled in India, see also Ansari (2014), forthcoming.

Zijes of the Sultanate Period

Zīj-i Nāṣirī (ZN)

We know now that this was the first Indian Zīj of the period written by Maḥmūd ibn 'Umar al-Rāzī, who dedicated it to Nāṣiruddīn Maḥmūd bin Sultan Shamsuddīn Iltutmish (r. 1246–1265 in Delhi), hence its title, abbreviated hereafter as *ZN*. Storey (1972, pp. 74–75) informed about only one manuscript then extant in the Ḥusayn Agha Nakhjawānī Library (Tabriz), which does not seem to exist now. For its brief history, cf. Ansari (2008, pp. 62–63). Fortunately I have been able to find another complete manuscript of this *Zīj*, in the Āyat Allāh Najafī Mar'ashī Library (Qum), Ms. 9176, comprising 165 ff., copied close to the time of the author (see Ḥusaynī & Mar'ashī, 1994, p. 293). Note that Emperor Akbar's chronicler Abū'l Faḍl 'Allāmī mentioned *ZN* in the list of 86 Zījes given in his book: *Ā'īn-i Akbarī* (*Institutes of Akbar*). It means that it was available in India even in the sixteenth century. In the first *rukn* ("pillar") on fol.111a, 65 fixed stars (*Thawābit*) are catalogued for the year 615 Yazdigird (AD 1246) with their longitudes and latitudes. In one of his numerical examples (fol.10b), the given date is Thursday 22 Sha'bān AH 641 (4 Feb. AD 1244). The author's base meridian is Delhi. In fact, his numerical examples lie mostly between AD 1235 and 1245, during which time Maḥmūd ibn 'Umar evidently had been compiling his *Zīj*. In other words this first Indian *Zīj* was compiled even before *Zīj-i Ilkhānī* (AD 1271) of Naṣīrudīn Ṭūsī at Marāgha observatory.

ZN consists actually of two *rukn*, the first of which contains tabulated material for detailed calculations of heavenly bodies in 66 chapters (120 ff). The second *rukn* (paginated afresh) deals with the theory or general principles of astronomy, illustrated by direct calculation without recourse to tables; it consists of 60 chapters (44 folios). The topics are chronology; functions of trigonometry and spherical astronomy; planetary positions, conjunctions, and eclipses; astrology; and geographical tables. According to a detailed comparative study by Dalen (2004, p. 831), the mean motions in ZN were calculated with very high accuracy, and these tables agree with *Zīj al-'Alā'ī* compiled in Arabic by al-Fahhād, who is mentioned by Maḥmūd ibn 'Umar in his list of 14 astronomers, whose Zījes he studied particularly (fol. 1b-2a of ZN). 'Abd al-Karīm al-Fahhād al-Shīrwānī (ca. 1180) originally wrote this Zīj in Arabic. It is nonextant presently. It was translated into Persian by

Shamsuddīn al-Bukhārī (Tabriz, 1295/1296), whose Greek disciple Gregory Chioniades prepared in ca. 1305 in Constantinople (now Istanbul) its recension in Byzantine Greek, which is fortunately extant. David Pingree published its text with an English translation and commentary, cf. van Dalen (2004, p. 826). In fact *Zīj al-ʻAlāʼī* was mentioned by Abū'l Faḍl ʻAllāmī in the list of 86 Zījes given in his book: *Āʼīn-i Akbarī*, i.e., it was extant in the sixteenth century in India. However, Abū'l Faḍl named the compiler as Fakhruddīn Abu'l Ḥasan ʻAlī bin Karīm al-Shīrwānī, also known as al-Fahhād.

Zīj-i Jāmī ʻMaḥmūd Shāh Khiljī (ZJ)

This Zīj is dedicated to Sultan Maḥmūd Shāh Khiljī (r. 1435–1469) of Mālwa province. This anonymous *Zīj* was written during 1448–462 because of the interruptions of the author's travels from Cairo to Bīdar in India. An incomplete but unique manuscript copy is extant in the Bodleian Library (Oxford), Ms. Greaves 6, with 104 folios (Persian Mss. No. 1522 in the *Catalogue* by Ethé), scribed by Mawlānā Fiṭr in AH 878 (AD 1473). The Persian text of the manuscript is not complete, for it ends with the first chapter. The second chapter and the epilogue are missing. The colophon is written at the end of the first chapter. John Greaves (1602–1652), Savilian Professor of Astronomy (1643–1648) at Oxford, translated into Latin an excerpt – first section (*faṣl*) of the first chapter of the Persian text – in his *Astronomica quaedam* (London, 1650). Cf. de Young (2004), for all details about John Greves and his work.

This *Zīj* comprises a prolégoména (*Muqaddama*), two chapters, and an epilogue (*Khātimah*). The *Muqaddama* is further divided into 36 sections (*faṣl*), in which the author deals with arithmetic, astronomical mathematics, calendars, and astrolabes. Thereafter sections contain astronomical material: treating the Sun and Moon planets and calculating their ephemerides (*Taqwīm*).

Observatory at Balāghāt

During the rule of the Khiljī's sultans (1288–1321), practical astronomy became quite popular because of its astrological usage. The historian Ḍiyauddīn Barnī reported in his famous *History of Firoz Shah* (*Sīrat-i Fīrūz Shāhī*) that:

> In Delhi the science of astrology [ʻ*Ilm-i Nujûm*] was very much in vogue and it was supported by the nobility and scholarly circles. . . .No locality was without an astrologer [*Munajjim*]. . .. The astrologers of ʻAllāʼī era [i.e., of ʻAllāʼuddīn Khiljī and his descendants] were great experts and specialists of the astrological calculations and also in the astronomical observations [*raṣadbandî*]. (Ghori & Khan, 1969, p. 28) quotes Barnī's text, p. 162.

Fīrūz Shāh Bahmanī (r. 1397–1422), the eighth sultan of the Bahmani dynasty of Deccan, was reported to have been quite an expert in several sciences, particularly in natural philosophy, logic, mathematics, and astronomy. He used to lecture 3 days a week on standard treatises of mathematics and astronomy: recension of "Principle of Euclid Geometry" (*Taḥrīr Usūl Uqlidis*) by Naṣīruddīn Ṭūsī (d. 1274) and on a commentary of his "Memoirs on Astronomy" (*Tadhkira fī ʻIlm al-Haʼya*). However, the sultan's interest in astronomy culminated in commissioning the first observatory on Indian soil at Bālāghāt – the summit of the pass near the Indian town of Daulatābad. The construction started in 1407 AD, i.e., before Ulugh Beg's observatory at Samarqand in 1420 AD. However, it remained incomplete due to the sudden death of the Director-Designate Ḥakīm Ḥasan Jīlānī (Farishtah/Briggs, Vol. II, p. 27).

Zijes of the Mughal Period

Zīj-Ulugh Bég (ZUB)

As mentioned above (section "Introduction to Islamic Astronomy"), the original astrolabe of Sultan Ulugh Bég's observatory at Samarqand was a gift from the Shāh ʻAbbās I of Iran to the Mughal Emperor Jahāngīr s/o Akbar. Another noteworthy gift by the Shah was a large ruby inscribed with the name of Ulugh Bég, which was presented to the then crown prince Shāhjahān by the Iranian ambassador in about 1620–1621 (Riazul Islam, 1970, p. 80). Sultan Ulugh Bég's madrasa and observatory, founded in Samarqand in 1417 and 1420, respectively, were known in Mughal India. Emperor Babur visited the observatory and described it in his Memoirs (*Bābur Nāmah*). The director of the madrasa, Ṣalāḥuddīn Mūsā Qāḍī Zādeh al-Rūmī's writings are extant today in Indian manuscript collections (Ansari, 1995, Appendix, p. 292). However, the main proponent of the astronomical tables compiled at Samarqand, ZUB, was Mīr Fatḥullāh Shīrazī (d. 1589), a pupil of Ghiyāthuddīn al-Manṣūr Shīrāzī (d. 1506) who wrote a tract on the "Rectification (*Taṣḥīḥ)* of Zīj-i Ulugh Beg." Mīr Fatḥullāh, who also drew the horoscope of Akbar and has been known as the inventor of Akbar's Ilāhī calendar, had been commissioned by the emperor to get *ZUB* translated into Sanskrit by a team of Muslim and Hindu astronomers (Abū'l Faḍl/Blochmann (Tr.), Part I, p. 110). A unique manuscript of the Sanskrit translation is extant in Maharaja Man Singh II City Palace Library (Jaipur). The importance of *ZUB* lies in the fact that all its tabulated material is based on actual observations. Cf. van Dalen (2007a, pp. 97–100).

According to my own survey, more than 50 copies of *ZUB* are available in manuscript collections/libraries of India and Pakistan (Ansari, 1995, p. 293). This is surely the indicator of the spread of *ZUB*. It is therefore not surprising that Zījes compiled in Mughal India were based more or less on ZUB, in style and even in content. I enumerate them in the following.

Mulla Chānd's Commentary on ZUB

Mullā Chānd ibn Bahā'uddīn was the astrologer-astronomer at Emperor Humāyūn's and later also at Akbar's courts. He is known to have drawn horoscopes of Akbar (b. 25 Oct. 1542 AD) and of Jahāngīr (b. 30 Aug. 1569); see the reproduction in Abū'l Faḍl's *Akbarnāma*, Vol. 1 (pp. 56–57) and Vol. 2 (pp. 506–507), respectively. On Akbar's horoscopes and their historical significance, see Orthmann (2005). I thank her for presenting me a copy of her publication.

A unique copy of his commentary, rather a simplified version (*Tasḥīl*) of *ZUB*, is extant in the Man Singh Museum Library (Jaipur), Ms. No. 6 (Arabic and Persian). This manuscript copy bears the seal of one 'Abd al-Khāliq ("a slave of Shāh Jahān"), dated AH 1038/AD 1628–1629. This *Tashīl* by Mullā Chānd is mentioned by Farīduddīn in his *Zīj-i Shāh Jahānī* and also by Raja Jai Singh in *Zīj-i Muḥammad Shāhī*. Mullā Chānd has more or less followed the style of *ZUB* in the text of his commentary. He has inserted a chapter or two here and there for making the contents easily understandable. At the end of each *maqāla*, he added tables, which are updated versions of the corresponding tables of the *ZUB*, because of the passage of time of about 150 years between the compilation of the original *ZUB* and *Tashīl*. Cf. Ghori (1985, pp. 33–34).

Zījes Compiled by Farīduddīn Munajjim

Farīduddīn Mas'ūd bin Ḥāfiẓ Ibraḥīm Dehlavī, known also as Farīduddīn Munajjim (astronomer), attended the famous madrasa of Shāh Niẓām of Nārnol and was also a pupil of Fatḥullāh Shīrāzī from whom he learned rational sciences (*'Ulūm-i 'Aqliya*) including astronomy and astrology. His elder brother Ṭayyab Muhandis was also a famous mathematician, who wrote on calendars and made an astrolabe for Mirzā 'Abdul Raḥīm Khān-i Khānān (d. 1627), Emperor Akbar's Chief of Army Staff (*Sipāh Sālār*), and who became renowned as a scholar and translator of Babur's Memoirs (*Tūzak-i Bābarī*) from Turkish into Persian in 1590. Farīduddīn became well known when he prepared the horoscope of the son (b. 1613) of Sultan Ibrāhīm 'Ādil Shāh II (ruler of Bījāpūr, r. 1580–1627), the manuscript of which is extant in Berlin. Farīd began his career in the service of Khān-i Khānān and remained with him till about 1615. Three of his astronomical writings are known today: a manual on astronomical calculations, *Sirājul Istikhrāj* written in AH 1006/AD 1598, and *Zīj-i Raḥīmī* written in 1617. In 1598 he joined the service of Khān-i Khānān. The title is a chronogram, but adding only the numerical values of its dotted letters: ***j*** (3) + ***t*** (400) + ***kh*** (600) + ***j*** (3) = 1006, according to *abjad* notation. Both these works are dedicated to his patron Khān-i Khānān. The third is *Zīj-i Shāhjahānī*, compiled about 1629 and dedicated to Emperor Shāhjahān. I confine myself here only to these two Zījes.

Zīj-i Raḥīmī (ZR)

The unique copy of *ZR* is extant in the Central Library of the Holy Shrine of Raḍawī, Ms. No. 5554 with 441 folios (cf. Fikrat's *Catalogue*, p. 299), but the manuscript is incomplete. It ends after the few tables of the planet Saturn, with no colophon evidently. As Farīd tabulates the equation of time (*Ta'dīl al-Ayyām)* for the Sun and Moon for the year 1026 AH/1617 AD (ff. 152b, 153a), he might have been compiling *ZR* around that year.

ZR is modeled on *ZUB*; it comprises an introduction (*muqaddimah*) and four discourses (*maqālas*). Farīduddīn eulogizes "the nearest of his times, the most trustworthy and accurate *Zīj-i Raṣadī* compiled by Mirzā Ulugh Beg" (fol. 2b, line 7–9). Farīd distinguishes here two kinds of Zījes: *Zīj-i Raṣadī* based on theoretical principles and practical observations of the positions of stars and their motions in longitude and latitude. On the other hand, *Zīj-i Ḥisābī* is one of those Zījes which are corrected by calculating the discrepancies and changes occurring during the course of time in the mean motions of Sun, Moon and planets. In fact, ZR contains a section on each calendar/era as usual in Zījes, viz., Hijrī, Philip, Persian (Yazdigird), Malikī, Chinese (*Qatā*), and Chinese-Uighur. It consists also of detailed tables of trigonometrical functions (ff. 21–39), tables for solar declination (*mayl awwal*) and second declination (*mayl thānī*), and for right and oblique ascensions. The last ones are for the latitudes of Samarqand, the Indian capital town Akbarābād (modern Agra), and for Lahore. Farīduddīn included also in his Zīj a geographical gazetteer of 325 cities. Cf. Ansari (2013, section 3.2).

Zīj-i Shāhjahānī (ZShJ)

It was completed in AH 1039/AD 1629, but the epoch year is AH 1041/AD 1631–1632. Farīduddīn compiled this Zīj in collaboration with his brother Ṭayyab and under the supervision of Yamīn al-Dawlah Āṣaf Khān. As the title indicates the Zīj is dedicated to Shāhjahān. The complete title is *Kārnāmah-i Ṣāḥib Qirān-i Thānī, Zīj-i Shāhjahānī* (Great Work of the Lord of Second Conjunction, Shāhjahān's Zīj). This ceremonious title owes its origin to the fact that Venus and Jupiter were in conjunction (*Qiran*) at the time of Shāhjahān's birth on 5 Jan. 1592 in Lahore. R. C. Kapoor (Bangalore) has checked this statement by calculating for 00:00 UT the elliptical longitudes of Venus and Jupiter at the time of birth of Shāhjahān. They are 8 s 15°.1290 and 8 s 3°.4112, respectively, i.e., both in the same zodiac sign Scorpio. I thank Kapoor for this assistance. Exactly the same conjunction occurred at the birth of Amīr Tīmūr, the great great grand forefather of Shāhjahān. Therefore Tīmūr and Shāhjahān were entitled as "Lord (*Ṣaḥib*) of the first and second conjunctions (*Qiran*)." Actually this is an astrologically auspicious conjunction. 'Abdul Ḥamīd Lāhorī, the emperor's chronicler in his *Pāḍshāh Nāmāh*, reported that "in view of its many benefits and [containing] numerous principles and rules, [the Emperor] ordered that it should be translated into the language of Hindustan by Indian astronomers in consultation with Persian astronomers for the sake of public utility" (Ṭāhir/'Ināyat Khān, *Mulakhkhaṣ* p. 82). In fact Pandit Nityānanda, the Hindu court astronomer of Shāhjahān, translated the *ZShJ* into Sanskrit in 1630. Four copies of this text with the title *Siddhāntasindhu* are extant in the Maharajah Man Singh Museum and Royal Collection in Jaipur.

The *ZShJ* consists of the same chapters as in *ZUB*, i.e., one introduction and four discourses (*maqālas*). Each *maqāla* is divided into many chapters (*bāb*); a chapter is further divided into sections (*qism or faṣl*). The introduction is similar to Farīduddīn's *ZR*, defining and explaining *Zīj-i Raṣadī* and *Zīj-i Ḥisābī*. The chapter on calendar/eras comprises the usual Hijrī, Rūmī, Yazdigird, Malikī, and Chinese-Uighur, but with the addition of the Indian calendar, *Shākha Sālbāhan* (*Śālivāhana Śakha* in Sanskrit). The tables of *ZShJ* are not confined to the basic tables but contain auxiliary tables for simplification, as in *ZR* or in any commentary. For technical details cf. van Dalen (2007a), p.148.

Zīj-i Muḥammad Shāhī (ZMS)

Sawā'i Jai Singh (1688–1743), raja of Amber (modern Rajhastan), was an erudite scholar of

Sanskrit literature and particularly of astronomy. He wished to implement his program of improving ancient and medieval Indian astronomy. To that end he is known to found a number of observatories with masonry instruments. These astronomical observatories were built in five Indian cities, namely, Delhi (1721–1724), Jaipur (1728–1735), Banaras (~1730), Ujjain (~1730), and Mathura (year unknown), so that observations of the same phenomenon could be carried out from many locations. As he was extremely receptive to astronomical ideas of different cultural areas, he established a school of translations at Jaipur for translation of Islamic astronomical treatises into Sanskrit (Sarma, 1998) and later also European scientific texts, especially Philippe de La Hire's *astronomical tables* and Homann's *Atlas*. Johann Baptist Homann's *Grosser Atlas über die Ganze Welt* (Nürenberg 1725), acquired in 1730, is preserved in the Sawai Man Singh Museum (Jaipur). This Atlas is important, since it contains charts for the planetary systems of Copernicus, Tycho Brahe, and Riccioli. These were brought to Sawā'i Jai Singh by his delegation of Indian astronomers sent to the Portuguese King, which was headed by Jesuit Emmanuel de Figueredo; the delegation returned in Nov. 1730. What immortalized Jai Singh's name throughout the world of astronomy was in fact the *Zīj-i Muḥammad Shāhī*. In fact Emperor Muhammad Shāh (r. 1719–1748) on the advice of his astrologer, Mubashshir Khān, directed Sawai Jai Singh to get a modern (*Jadīd*) Zīj compiled, so that the actual title is *Zīj-i Jadid Muḥammad Shāhī*. Various sections in ZMS are based solely on *Zīj-i Ulugh Bég*. The tables and texts concern the Sun, Moon, and planetary mean motions adapted from de La Hire's tables. See details in Mercier (1984), van Dalen (2000), and Pingree (2002). ZMS became quite popular among the Persian-knowing Indian scholars (14 mss. extant in India), also in Iran (32 mss.) and Central Asia (13 mss.), where it almost replaced the *Zīj-i Ulugh Bég*. The earliest extant manuscript copy to date is in Tashkent and is scribed by Ḥuḍūr llāhī Kāshmīrī, dated 1775.

Sawai Jai Singh mentioned in one chapter of ZMS that he had a telescope constructed in his kingdom and used it for observing the crescent of Venus, satellites of Jupiter, rings of Saturn, and sunspots. Ansari (1985a) has discussed the diagrams of these observations, which appear on the margin of a couple of manuscripts of ZMS. However for want of micrometer and cross-wire attachments, he could not use them as devices for accurate measurements (Ansari, 1985b, pp. 364–369).

According to a number of Persian sources, Mirzā Khayrullāh Khān (d. 1747), director of Jai Singh's observatory at Delhi, was the actual compiler of ZMS, who was supervised by Jai Singh. Muḥammad ʻAlī s/o Khayrullāh Khān, who scribed a copy of ZMS (Ms. 2144, fol. 105A, in the National Library, Tehran), confirmed his father's authorship of ZMS. Another evidence is from Iranian commentator, Muḥammad ʻAlī alias Mubashshir Khān, who came to India to study under Khayrullāh Khān the text of ZMS and its method of calculations. His commentary on ZMS is extant in the National Library, Tehran (Ms. No. 6447, scribed in 1884). See details in Ansari (2007/2014).

Zīj-i Bahādurkhānī (ZBKh)

This Zīj in Persian was composed in 1838 by Abul Qāsim alias Ghulām Ḥusain Jaunpūrī, on the order of the Rāja Khān Bahādur Khān, the raja of Tikārī (in south of Bihar), to whom it was dedicated. This Zīj was written in India between 1855 and 1858 and lithographed at the Cadre (*Kādar*) Press, Banaras (modern Varanasi). The printed copy is extant in the Salar Jung Museum Library (Hyderabad). It consists of 906 pages of about quarto size. A good copy of *Zīj-i Bahādurkhānī* is also extant in the Andhra Pradesh Oriental Manuscripts Library (Hyderabad). A recent facsimile reprint of ZBKh was published in 2009 by Islamic Azad University (*Dānishgāh-i Āzād Islāmī*), Tehran, with a preface by Farid Ghassemlou. ZBKh is actually a reworking of ZMS based on Ghulām Ḥusain's own observations, in which especially the new elements of European astronomical knowledge were included and explained.

Zīj-i Sa'īdī by Muḥammad Amīn (ZS)

The author Muḥammad Amīn Mas'ūdī bin Muḥammad Nasīm al-Ḥanafī with the *nom de plume* Kāshī came from the Indian city of Bareilly. To date only this much is known about him. The Zīj is dedicated presumably to his patron Sa'īd. A unique copy of this Zīj is extant in the Wellcome Library (London), scribed in AH 1244/AD 1828 (at colophon fol. 51b), with author's name as Muḥammad Amīn Mas'ūdī. However, his full name on fol.1a, line 7-8, is as mentioned above but without Amiīn. The manuscript was discovered by van Dalen (2007a, p. 150). I thank him for a copy of this manuscript.

ZS consists of an introduction with three discourses (*maqāla)* and an epilogue. In the section on the calendar, he treats Hijri, Yazdigird, Jalālī, Byzantine (*Rūmī*), the Chinese (*Khaṭā*), and Turkish eras. Muḥammad Amīn has drawn actually on *Zīj-i Ulugh Bég*, which is his basic source even for the calculation of ephemerides of the Sun, Moon, planets, etc. His sections are quite short. While calculating the position of the constellation Cassiopeia, he mentions using ZMS and the year 737 Jalāli/AD 1815 (fol. 26a). His source for the astrological material is Ptolemy, Māshā'allāh (d. ca. 815), and Ya'qūb al-Kindī (d. 870) (fol. 48a). The section on gazetteer (ff. 17–18) contains entries of 311 localities, out of which 70 are Indian cities and interestingly the last entry is London.

Zīj-i Maẓhari (ZM)

The author is Maẓharuddīn Muḥammad Qārī bin Bahā'uddīn 'Alī (sixteenth century) Shīrāzī. The manuscript of this Zīj belonged to the Urdu Promotion Board (*Anjuman Taraqqi-i Urdu*), Karachi. It was originally in the collection of Mawlawī 'Abdul Ḥaq (Hyderabad), who presented it to the Urdu Promotion Board. It is now in the National Museum (Karachi). Monzavi (Cat. Ms. No. 493, pp. 278–279) has given some historical information about the author. However, this is the first time that the contents are being described here. I thank Mr. Rashid Ashraf (Karachi) for procuring for me the copy of this unique manuscript. It is dated AH 987/AD 1579 (fly leaf/f. 1a). It has 33 ff. The first two pages are missing, since the manuscript begins abruptly with the sixth section (*faṣl*) of the contents. Altogether there are 12 sections (*faṣl*). The last is on fixed stars, which is not present in this manuscript.

A

The first part of *ZM* is on usual astronomical calculations according to *Zij-i Ulugh Bég* (mentioned specifically on f. 4b), as an aid to the second part on astrology which is concerned with determining various astrological parameters. The epilogue (*khātma*) begins with the "invisible and inauspicious [actually pseudo-planet] *Kaid* (f. 32a) and calculation of its ephemerides in the year 929 Yazdigird/AD 1560" (f. 33a), determination of planetary exaltation (*sharaf*), and dejection or depression (*hubūṭ*). Our author's source for this part is mainly Ptolemy's *Tetrabiblos*. Some examples to illustrate the rules are dated 1558, 1560, and 1565. I thank Mr. Rashid Ashraf (Karachi) to arrange for me a copy of this unique manuscript.

Astrolabe Makers in India

In the Sultanate period, Sultan Fīrūz Shāh Tu*gh*laq (r. 1351–1388) was famous as an expert on astrolabes. Astrolabes used for both Northern and Southern celestial hemispheres are attributed to him. Fīrūz Shāh possessed five astrolabes constructed under his guidance. They were one each in brass and silver, in gold and silver, in brass only, and two in silver. A large Northern-Southern astrolabe in gold and silver was named *Asturlāb-i Fīrūz Shāhī*, which was completed by AH 771/AD 1370–1371. In the text of *Sīrat-i Fīrūz Shāhī*, positions of constellations for the period 1370–1520 equivalent to 136 lunar years are also tabulated. This table was engraved on the back of Fīrūz's astrolabe. Moreover, the coordinates of 18 fixed stars are marked on the *rete* corresponding to 11 March 1370 (Sarma, 1998, pp. 9–10). However, Fīrūz Shāh's most significant achievement was actually "the dissemination of the science of astrolabe in India among the Jainas and Hindus" (Sarma, 1998, p. 12). The Sultan's court astronomer, the Jaina scholar Mahendra Sūrī, composed the first ever treatise on the astrolabe in Sanskrit: *Yantrarāja* (the King

Astronomy in Medieval India, Table 1 Astrolabes by Alāhadād's descendants

Number of specimens	Astrolabe maker	(Period of activity)	Current location	Year of manufacture
3	Mullā 'Īsā s/o Alāhadād		Two in Chicago; one in Cambridge (UK)	1601, 1604
6	Qā'im Muḥammad s/o 'Īsā		Calcutta	1624
			Patna	1626
			Baghdad	1631
			Oxford	1634
32	Ḍiyā'uddīn s/o Qā'im	(1645–1680)	In India: two formerly in Aligarh	1653, 1663
			Hyderabad, Patna	
			Three in Jaipur observatory	
37	Muḥammad Muqīm, s/o 'Īsā	(fl. 1609–1659)	In India: two in Delhi	1624
			Calcutta, Hyderabad. In Pakistan: Lahore, Karachi	1637
12	Ḥāmid s/o Muqīm	(1628–1691)	One in Hyderabad	1658
			One in Allahabad	1677
5	Jamāluddīn s/o Muqīm	(1666–1691)	None in India	

Note: The specimens are mostly in museums. Sarma (formerly at Aligarh Muslim University and now in Düsseldorf) is compiling a worldwide *Catalogue of Astrolabes made in India* by (see "Ghulam Hussain Jaunpûrî") Indian astrolabe makers. I thank him for putting at my disposal his data before his monumental publication

of Instruments) written about 1370. The importance of this text is indicated by the fact that there are extant 100 manuscript copies (Ohashi, 1997, p. 211 et seq. and Sarma, 1999, 2000).

Lahore School of Astrolabe Makers

The founder of the Lahore school of astrolabe makers was the famous Ustād Alāhadād Asṭurlābī Humāyūnī (flourished ca. 1567) who had been invited to Lahore by Mughal Emperor Humāyūn; the emperor was himself an expert on the astrolabe; main reference to this section is Sarma (1994) and Ansari (2011). One of Alāhadād's two surviving astrolabes is in Salar Jung Museum (Hyderabad) dated 1567 with a diameter of the *mater* (main body) of 199 mm, containing five latitude plates (tympans) and with a gazetteer (geographical coordinates) of 96 cities. The second astrolabe is extant in the Museum of History of Science (Oxford). It is not dated, and its diameter is 256 mm with six disks and a gazetteer of 157 cities. In the following, I tabulate the work of the descendants of Alāhadād.

According to S. R. Sarma (*personal communication*, dated 11 May 2010), "there are extant nearly 120 astrolabes signed by the various members of the Lahore family, and several more which are not signed but can be attributed to the family on stylistic grounds." The Lahore school of Alāhadād also made celestial globes; 23 are extant today (Sarma, 1994, p. 219). For astrolabes with Sanskrit legends made in medieval India, cf. Sarma (1999) and Ansari (2011) (Table 1).

Conclusion

My effort has been to delineate the efforts of promoting in Medieval India the Islamic astronomy as developed in the Middle East and Central Asia. The practical astronomy – compiling Zījes, establishing observatories and a school of astrolabe makers – developed because the individual astronomers and madrasas were patronized by sultans, emperors, local rulers, and nobles. Even modern European astronomy of the eighteenth to nineteenth century was well received; cf. Ansari (2002) in which a few sources in Persian have been discussed. The political upheaval due to the colonization of India by European powers during the eighteenth to nineteenth centuries led to the withdrawal of patronization, marginalizing the madrasas, the institutions of higher education, which were the lifeline for the development of mathematics and astronomy, thereby smothering the scientific renaissance initiated by Raja Sawa'i Jai Singh in the eighteenth century. The compulsory replacement of Arabic and Persian by English as medium of instructions cut off the continuity of India's education and scientific development during the Raj. Thanks to independence, that situation was reversed. Modern India is now playing its role in the world to develop astronomy and space science quite actively.

References

Abū'l Faḍl 'Allāmī (16th c./1927). *Ā'īn-i Akbarī* (Institutes of Akbar), translated into English by H. Blochmann, *Bibliotheka Indica*, No. 6. Reprint, Calcutta. I refer it as Abū'l Faḍl/Blochmann.

Abū'l Faḍl 'Allāmī (16th c./1972). *The Akbar Nāmah*, translated into English by H. Beveridge, in 3 vols. Reprinted at Delhi. Persian text originally published in Calcutta, 1877.

al-Bīrūnī, Abū Rayḥān Muḥamamd (1029). *Kitāb al-Tafhīm li Awā'il Ṣinā'a al-Tanjīm*. (*The book of instruction in the elements of the art of astronomy*), translated from Arabic into English by R. Ramsay Wright. London: Luzac & Co. 1934. (Reprinted and published by Fuat Sezgin, in *Islamic Mathematics and Astronomy Series*. Vol. 29. Institute for the History of Arabic-Islamic Science, Frankfurt am Main, 1998).

Ansari, S. M. R. (1985a). The observatories movement in India during the 17th-18th centuries. *Vistas in Astronomy, 28*, 379–385. First diagrammatic proof of Jai Singh's use of the telescope.

Ansari, S. M. R. (1985b). Introduction of modern astronomy in India during 18th-19th centuries. *Indian Journal of History of Science, 20*, 363–402, esp. 364–369.

Ansari, S. M. R. (1995a). On the transmission of Arabic-Islamic astronomy to medieval India. *Archives Internationales d'Histoire des Sciences, 45*(135), 273–297.

Ansari, S. M. R. (1995/1996). Ghulām Ḥusain Jaunpurī and His Zīj-i Bahādurkhānī. *Studies in History of Medicine and Science*, *14*(1–2), 181–188, New Series (New Delhi).

Ansari, S. M. R. (2002), "European astronomy in Indo–Persian writings", in History of Oriental Astronomy, edited by S. M. R. Ansari. Dordrecht, Kluwer Academic Publisher, pp. 133–144.

Ansari, S.M. R. (2007/2014). On Raja Sawai Jai Singh. In T. Hockey (Editor-in-chief), *The biographical encyclopaedia of astronomers* (Vol. I, pp. 585–586). New York, NY: Springer. The revised and updated version for publication in the second edition of BEA is in press, expected in 2014.

Ansari, S. M. R. (2008). Promotion of exact sciences during the 14th-15th centuries. In M. Bilquis (Ed.), *Persian literature produced during the sultanate period* (pp. 60–72). Aligarh, UP: Department of Persian, Aligarh Muslim University.

Ansari, S. M. R. (2011). A survey of Arabic-Persian sources on the astrolabe extant in India and on the Indian astrolabe-makers. In T. Nakamura, W. Orchiston, M. Sôma, R. Strom (Eds.), *Mapping the oriental sky. Proceedings of the Seventh International Conference on Oriental Astronomy*, held on 6–10 Sept 2010 (pp. 99–108). Tokyo: National Astronomical Observatory of Japan.

Ansari, S. M. R. (2013). The compilation of Zijes in India (in Persian). In M. R. Nasiri (Ed.), *Encyclopaedia of Persian language and literature in the subcontinent* (Vol. III, pp. 533–536). Tehran: The Academy of Persian Language and Literature. An updated version in English will be published in the *Indian Journal of History of Science*, Jubilee Volume (2015).

de Young, G. (2004). John Greaves' *Astronomica quaedam*: Orientalism and ptolemaic cosmography in seventeenth century England. *Indian Journal of History of Science, 39*(4), 467–510.

Farishtah, Muḥammad Qāsim Hindū *Sh*āh (1966, 1971). *Tārīkh-i Farishtah* (in Persian), Nawal Kishore Publisher, Lucknow AH1281/AD1864. English translation by John Briggs, *The history of the rise of the Mahomedan power in India*. Indian Edition, Calcutta. Vol. I–III (1966), Vol. IV (1971). Reprint of the first edition (London, 1829). I refer it as Farishtah/Briggs.

Fikrat, Muḥammad Āṣaf (1991). Alphabetical catalogue of manuscripts of the Central Library of *Āstān-i Quds Raḍawī*. Mashhad, Publication Division of the Library of Holy Shrine, No. 12, p. 299.

Ghori, S. A. K. (1985). Development of *Zīj*-Literature in India. *Indian Journal of History of Science, 20*, 21–48.

Ghori, S. A. Khan (1969). Perspective of the revival of rationalism (*'aqliyāt)* in India, in Urdu, *Majalla'-i 'Ulūm-i Islāmiya,* Aligarh, June-December, pp. 1–63.

Gillispie, C.C. (1969–1990). *Dictionary of scientific biographies*. New York, NY: Charles Scribner, a multivolume work with two supplementary volumes, abbreviated in the text by Gillispie, *DSB*.

Ḥusaynī, Aḥmad, & Mar'ashī, Maḥmūd (1994). *Catalogue of the Āyat Allāh al-'Uẓmā Najafī Mar'ashī Public Library*. Qum, Iran, *23*, p. 293.

Kennedy, E. S. (1956). A survey of Islamic astronomical tables. *Transactions of the American Philosophical Society, New Series, 46*, 123–177.

King, D. A. (1993). *Astronomy in the service of Islam* (Collected studies series, CS416). Hampshire: Variorum. 333 pages.

King, D., & Samso, J. (2001). Astronomical handbooks and tables from the Islamic World (750–1900): An

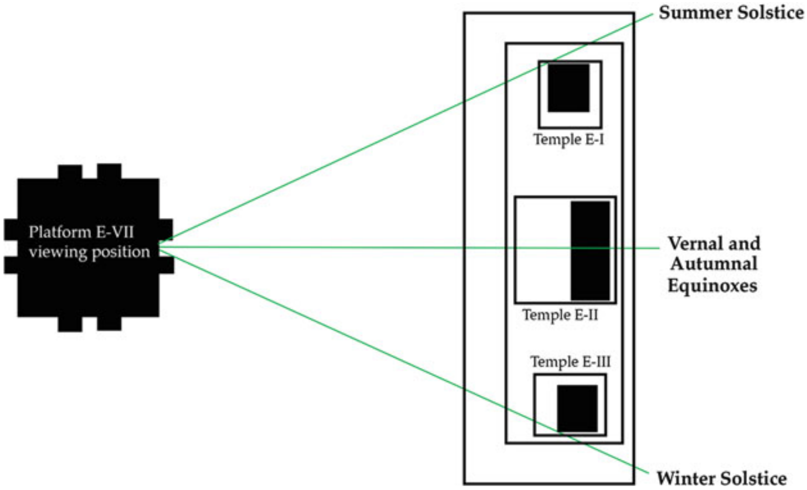
interim report (with a contribution by B.R. Goldstein). *Suhayl (Barcelona), 2*, 9–105.
Mercier, R. (1984). The astronomical tables of Rajah Jai Singh Sawā'i. *Indian Journal of History of Science, 19*, 143–171.
Monzavi, A. (1983). *A comprehensive catalogue of Persian manuscripts in Pakistan* (Vol. I). Islamabad: Iran Pakistan Institute of Persian Studies.
Moreas, G. M. (1951–1952). Astronomical missions to the court of Jaipur, 1730–1743. *Journal of the Bombay Branch of the Royal Asiatic Society, 27*, 61–65, 85.
Muḥammad Amīn Mas'ūdī (1815). *Zīj-i Sa'īdī*. Ms. WMS Persian No. 254, scribed in 1841. London: The Wellcome Library of the Wellcome Institute of the History of Medicine. I thank Benno van Dalen for presenting me a copy.
Ohashi, Y. (1997). Early history of astrolabe in India. *Indian Journal of History of Science, 32*(3), 199–295.
Orthmann, E. (2005). Circular motions: Private pleasure and public prognostication in the nativities of the Mughal Emperor Akbar. In O. Günther, H. D. Rutkin, & K. von Stuckrad (Eds.), *Horoscopes and public spheres: Essays on the history of astrology* (pp. 101–114). Berlin/New York, NY: Walter de Gruyter.
Pingree, D. (2002). Philippe de La Hire at the court of Jayasimha. In S. M. R. Ansari (Ed.), *History of oriental astronomy* (pp. 123–131). Dordrecht: Kluwer.
Riazul Islam, I. (1970). *Indo-Persian relations: A study of the political and diplomatic relations between the Mughul Empire and Iran*. Tehran: Iran Cultural Foundation, printed at Lahore.
Saliba, G. (1994). *A history of Arabic astronomy (Planetary theories during the Golden Age of Islam)*. New York, NY: New York University Press.
Sarma, S. R. (1994). The Lahore family of Astrolabists and their ouvrage. *Studies in History of Medicine and Science, XIII*(2), 205–224, New Series (New Delhi).
Sarma, S. R. (1998). Translation of scientific texts into Sanskrit under Swai Jai Singh. *Sri Venkateswara University Oriental Journal, XLI*(1–2), 68–87.
Sarma, S. R. (1999). Yantrarāja: The astrolabe in Sanskrit. *Indian Journal of History of Science, 34*(2), 145–158.
Sarma, S. R. (2000). Sultan, Sūrī and the astrolabe. *Indian Journal of History of Science, 35*(2), 129–147.
Sayili, A. (1960). *The Observatory in Islam. Publications of the Turkish historical society, series VII*, no. 38. Ankara: Turk Tarih Kurumu Basimevi (The Turkish Historical Society), 473 pp.
Storey C. A. (1972). Persian Literature. A Bio-bibliographical Survey Vol. II Part 1. London Luzac & Co. reprinted. First printed in 1958.
Ṭāhir Khān alias 'Ināyat Khān, Mīrzā Muḥammad (17th c.) (2009). *Mulakhkhaṣ-i Shāhjahān Nāmah*. An abridgment partly of *Pāḍshāh Nāmāh* by 'Abdul Ḥamīd Lāhorī (d. 1655). Critically edited by Jameelur Rehman (Delhi University), with an introduction and annotations. New Delhi: Centre for Persian Research, Iran Cultural House.
van Dalen, B. (2000). Origin of the mean motion tables of Jai Singh. *Indian Journal of History of Science, 35*, 41–66.
van Dalen, B. (2004). The *Zīj-i Nāṣirī* by Maḥmūd ibn 'Umar. The earliest Indian-Islamic astronomical handbook with tables and its relation to the '*Alā'ī Zīj*. In C. Burnett et al. (Eds.), *Studies in the history of the exact sciences in honour of David Pingree* (pp. 825–862). Leiden: Brill.
van Dalen, B. (2007a). A new survey of Islamic astronomical handbooks, with description of more than 200 Arabic and Persian Zījes. Preliminary Draft. To be published in the *Proceedings of the American Philosophical Society*, Philadelphia, PA.
van Dalen, B. (2007b). Ulugh Beg: Muḥammad Ṭaraghāy ibn Shāhrukh ibn Tīmūr. In T. Hockey (Ed.), *The biographical encyclopedia of astronomers* (Vol. II, pp. 1157–1159). New York, NY: Springer.

Astronomy in Mesoamerica

Michael J. Grofe
American River College, Sacramento, CA, USA

Astronomy in Mesoamerica developed in apparent isolation from the cultural traditions outside of the Americas and its unique advancement provides an important comparison with parallel developments of astronomical science elsewhere in the world. Containing hundreds of distinct ethnic groups and indigenous languages, the Mesoamerican culture area extends south from central Mexico into Belize, Guatemala, Honduras, El Salvador, and Nicaragua. While highly diverse, many of the cultures and language groups in this region share innovations such as intensive maize agriculture, stratified urban development, megalithic architecture, and an elaborate calendrical system consisting of a unique, repeating cycle of 260 days and a cycle of 365 days that estimates the length of the year. Together, these cycles combine to form the 52-year Calendar Round, historically shared by more than 50 linguistic groups in Mesoamerica.

It is clear that the development of writing in Mesoamerica was deeply interwoven with calendrical and astronomical observations that were



Astronomy in Mesoamerica, Fig. 1 Uaxactun E-Group, ideally commemorating rising azimuth positions of the solstices, and the equinoxes (Drawing by author)

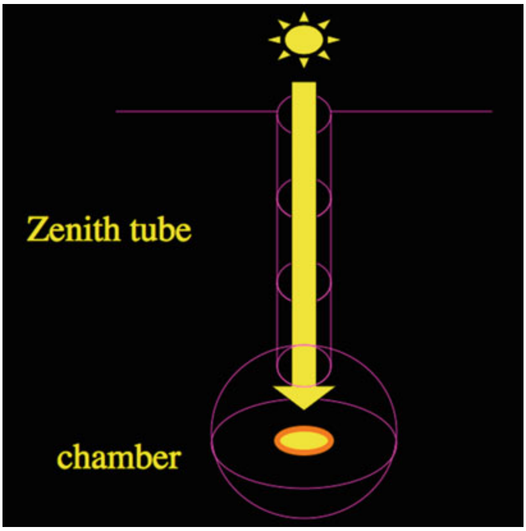
themselves inseparable from religious, divinatory, and political interests. Having persisted for perhaps 2,000 years, much of this intellectual legacy did not survive the initial invasion of the Spanish and the subsequent decimation of indigenous populations as a result of violence, disease, and centuries of political and religious persecution. Indigenous writing systems were effectively extinguished, and many written records did not survive. However, recognizable astronomical traditions have endured in many communities.

What is currently known about Mesoamerican astronomy has been reconstructed from architectural alignments, surviving written texts, and the persistence of astronomical and calendrical knowledge among contemporary indigenous groups. While it remains difficult to reconstruct and reinterpret the full extent of Mesoamerican astronomy from fragmentary sources, the existence of explicit written sources as well as implied astronomical alignments and ethnographic evidence has led to a more solid consensus among researchers, while there still remain specific areas of controversy.

It is generally agreed that Mesoamerican architectural alignments commemorate repeating celestial observations of horizon-based azimuth positions. Most obvious and familiar among these are those that suggest references to the rising and setting positions of the sun on the solstices and equinoxes. Multiple so-called “E-Group” building configurations in the Maya lowlands, such as those first identified in Uaxactun (Fig. 1), generally commemorate solstitial alignments, though the actual precision of these alignments is questionable and they may have served additional astronomical, calendrical, and ritual functions (Aimers & Rice, 2006). While the equinoctial alignments of E-Groups appear to be much less certain, a functional east-west sight line does appear at the northern Maya site of Dzibilchaltun.

Unique to the tropics, the phenomenon of the two solar zenith passages appears to have provided Mesoamericans with a precise means to calculate the length of the tropical year and to predict the seasonal rains that follow the zeniths through the migrating intertropical convergence zone. The early ethnographic record demonstrates that the observation of the solar zenith was widespread in Mesoamerica, and these days were attended with religious celebrations that were a concern to the Spanish crown (Aveni, 2001, p. 42). Contemporary Ch’orti farmers continue to predict the solar zeniths through observing the rising and setting azimuths of the sun on the 2 days when the sun reaches the zenith, and these positions actually replace the cardinal directions of east and west. According to anthropologist Raphael Girard, the Ch’orti also observe the relative positions of the Pleiades, Orion’s belt, and the Southern Cross in order to predict the occurrence of the two zeniths.

At different latitudes in the tropics, the two solar zeniths occur on different dates separated by



Astronomy in Mesoamerica, Fig. 2 Idealized zenith tube, commemorating the two solar zenith passages (Drawing by author)

variable intervals that are equidistant from the solstices. Several scholars, including Zelia Nuttall, Vincent Malmström, and Raphael Girard, have suggested that the unusual 260-day calendar found only in Mesoamerica arose in Preclassic sites to commemorate the long interval between the two zenith passages at 14.8° North latitude, namely, on August 12–13 and on April 30 to May 1. If so, it then would have spread northward throughout Mesoamerica into latitudes where the two zeniths would be at very different intervals. This astronomical explanation differs from the more widely held indigenous belief that the interval arose as a means to calculate the length of human gestation. Nevertheless, these proposals may not be mutually exclusive.

Vertical tubes that would be useful for observing solar zeniths are evident in several sites throughout Mesoamerica, including Monte Alban, Xochicalco, and Chichen Itza. These consist of subterranean chambers located beneath vertical tubes that connect to a narrow oculus (Fig. 2). At the moment of the solar zeniths, dramatic beams of light shine vertically through the oculus and into the chamber below. Though none of the surviving zenith tubes are located at 14.8° N, another similar structure in Teotihuacan with a wider oculus appears to commemorate not the local zeniths but the fixed cycle of 260 days between August 13 and May 1. In fact, as Malmström points out, the entire layout of the city of Teotihuacan, including the Temple of the Sun, is oriented toward sunset on August 13 and May 1, again implicating this fixed cycle, and we find similar architectural alignments and hierophanies to this fixed cycle throughout Mesoamerica.

The zenith tube located in Building P in Monte Alban is curiously associated with a direct line of sight to Building J (Fig. 3), an arrow-shaped building that is offset from the layout of the city. While some have proposed that the back side of the arrow intended to align with the rising of Capella in association with the zenith in the second century BC, the arrow actually points quite precisely to the base of the Milky Way in the southwest when it reached its vertical position at dawn at the time of the May zenith in the Preclassic. As such, this recognition of the vertical Milky Way parallels known contemporary observations among the Ch'orti and Tzotzil.

We also learn from Girard that the Ch'orti commemorate the solar nadir or anti-zenith in February, while Barbara Tedlock reports that K'iche' astronomers determine that the solar nadirs correspond to the time of year when the full moon reaches the zenith. The Ch'orti, who live precisely in the zone where the two zeniths are 260 days apart, do maintain a fixed cycle of 260 days that follows the agricultural year, though this begins on the February solar nadir and ends on the solar nadir in late October. Similarly, in a survey of 23 Late Preclassic and Classic structures in Campeche, Mexico, Ivan Sprajc (2009) has determined consistent alignments to sunrise on February 12 and October 30 that clearly delimit the agricultural year at multiple latitudes.

As Alonso Mendez, Edwin Barnhart, Christopher Powell, and Carol Karasik demonstrate, the Temple of the Sun in Palenque contains multiple alignments to hierophanies on the solar nadirs, the solar zeniths, and the summer solstice. Architectural alignments to local zeniths and nadirs are likewise evident in both the Caracol (Fig. 4) and the Castillo (Fig. 5) at Chichen Itza. While popular interpretations of the hierophany of the

A

Astronomy in Mesoamerica, Fig. 3 Arrow-shaped Building J in Monte Albán, Oaxaca. Dramatically offset from site layout. "Monte Albán archeological site, Oaxaca." Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons – http://commons.wikimedia.org/wiki/File:Monte_Alb%C3%A1n_archeological_site,_Oaxaca.jpg#mediaviewer/File:Monte_Alb%C3%A1n_archeological_site,_Oaxaca.jpg

Astronomy in Mesoamerica, Fig. 4 Caracol at Chichen Itza (Photograph by author)

shadow of the descending feathered serpents on the Castillo have assumed that this structure intended to commemorate the equinoxes, Susan Milbrath (1988) demonstrates that the east-west axis is more precisely aligned to the local zenith passages and solar nadirs. At the same time, the vertically descending serpents with their rattles pointing toward the zenith (Fig. 6) immediately recall the Pleiades, known to contemporary Yucatec observers as *tzab*, a rattlesnake's rattle. The Pleiades crossed the zenith at the latitude of Chichen Itza at the time of the construction of the Castillo, and it would have been heliacally rising at the time of the local zenith in late May, which announced the arrival of the rains. Indeed, contemporary Maya farmers continue to use the disappearance and reappearance of the Pleiades to time the planting of maize. In its descent, the feathered serpent of the Castillo evokes similar diving gods, which Nuttall believes to be representative of both the zenith and the time of planting.

Astronomy in Mesoamerica, Fig. 5 Castillo at Chichen Itza, showing serpents descending on either side of the stairway (Photograph by author)

Astronomy in Mesoamerica, Fig. 6 Rattle of descending serpent pointing toward zenith, Temple of the Jaguars, Chichen Itza (Photograph by author)

The Caracol in Chichen Itza was constructed in the shape of a round turret, and buildings like this are known to be associated with Ehecatl-Quetzalcoatl, an Avatar of Venus. Along with its alignment to zeniths, the Caracol shows significant alignments with the northern and southern extremes of Venus, and similar Venus alignments have been proposed for Temple 22 in Copán (Closs, Aveni, & Crowley 1984). As Sprajc demonstrates, the House of the Governor at Uxmal contains numerous iconographic references to Venus, while it also aligns to the setting positions of Venus at its northerly extreme. While not a yearly phenomenon, this northerly extreme would correspond with the onset of the rainy season, and the symbolic association between Venus and fertility is evident.

Unfortunately, without clear associations to text references, the intentionality of architectural alignments is difficult to verify. Therefore, astronomical references in the written record are particularly significant, and these are most explicit in Maya hieroglyphic records. Recognizable Venus glyphs appear in the Preclassic Maya site of San Bartolo in iconographic association with named deities (Fig. 7), while two important text references to Venus appear in the early La Mojarra Stela, a non-Maya monument written in the Isthmian script and dated to the second century AD (Kaufman & Justeson, 2001).

Surprisingly few hieroglyphic text references to Venus appear in the Classic period inscriptions. Copán Temple 11 records a Venus event similar to those found in the Postclassic Dresden Codex Venus Table, while multiple scholars have proposed that various other historical dates intended to commemorate the appearances of Venus at various points in its cycle, among

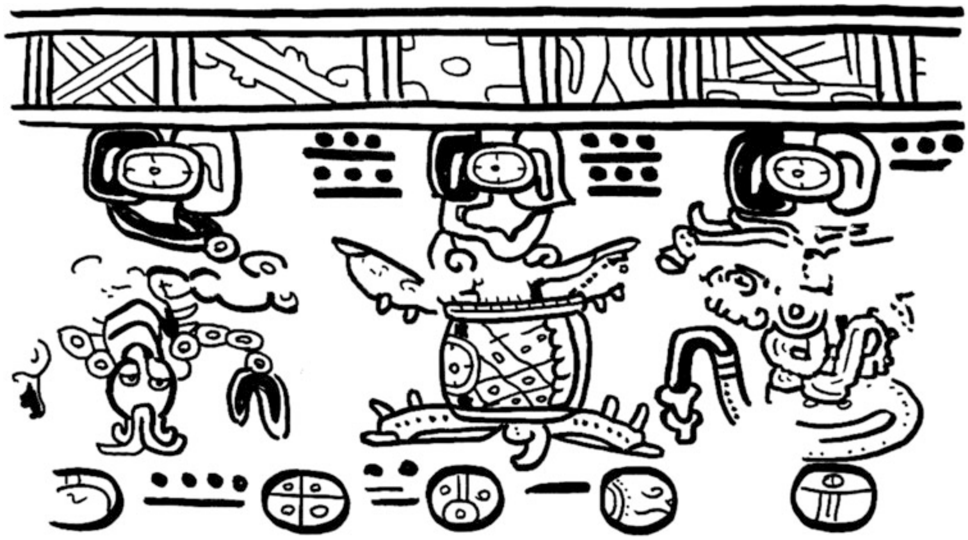
Astronomy in Mesoamerica, Fig. 7 San Bartolo Mural, showing Venus glyph in *upper left*, second from last, along with Venus deity in bloodletting scene. Photograph licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons – http://commons.wikimedia.org/wiki/File:SBmural.jpg#mediaviewer/File:SBmural.jpg

other astronomical rationales. Such arguments were quite popular in the earlier days of the decipherment, since the emphasis on astronomical interpretations was popularized by their prevalence in the few extant Maya hieroglyphic codices, the calendrical and astronomical significance of which was deciphered long before the historical content of the inscriptions was recognized. As a reaction to this overemphasis on astronomy, subsequent historical interpretations have often chosen to overlook problematic astronomical references.

There are only four surviving Maya screenfold books, all of which contain astronomical information, including widely acknowledged references to constellations, lunar synodic cycles, eclipses, and planetary cycles. The Paris Codex contains an apparent "zodiac" of 13 distinct constellations shown in association with eclipse glyphs, including a scorpion that is curiously in the same position as Scorpius (Fig. 8). However, it is debated whether these figures represent a true zodiac, given that a turtle constellation may represent Orion, which is south of the ecliptic. The Dresden Codex contains the most extensive astronomical information, including a Venus Table (Fig. 9) consisting of a canonical 584-day synodic cycle divided into 5 cycles of 584 days, equivalent to 8 cycles of the 365-day year, effectively returning the heliacal rise of Venus to the same time of year. This table is recycled for 104 years, which then commensurates with the 260-day cycle, and calendrical data associated with the table demonstrate that additional corrections would enable variously proposed calculations of the heliacal rise of Venus over much longer periods of time. Various other tables in the Dresden Codex suggest other planetary cycles. Tables of 780 days in the Dresden Codex suggest the synodic cycle of Mars, while Anthony Aveni and Harvey and Victoria Bricker have proposed that another table in the Dresden Codex was used to calculate the sidereal cycle of Mars.

We find similar Venus almanacs in the codices from Central Mexico, such as those from the Borgia group, though none quite as explicit as that found in the Dresden Codex. Nevertheless, several scholars, including Victoria Bricker and Susan Milbrath, have variously attempted to correlate the tables and the imagery in the Borgia Codex with specific astronomical events, such as historical eclipses, appearances of Venus, and seasonal configurations of stars. While it is difficult to verify the astronomical intention of these narrative scenes without explicit dates, we do find such unambiguous dates in association with Maya inscriptions. However, even fixing these more explicit dates in time remains somewhat problematic and controversial, let alone interpreting the intent of their associated inscriptions.

In addition to the Calendar Round found throughout Mesoamerica, a chronological system known as the Long Count first appeared in the



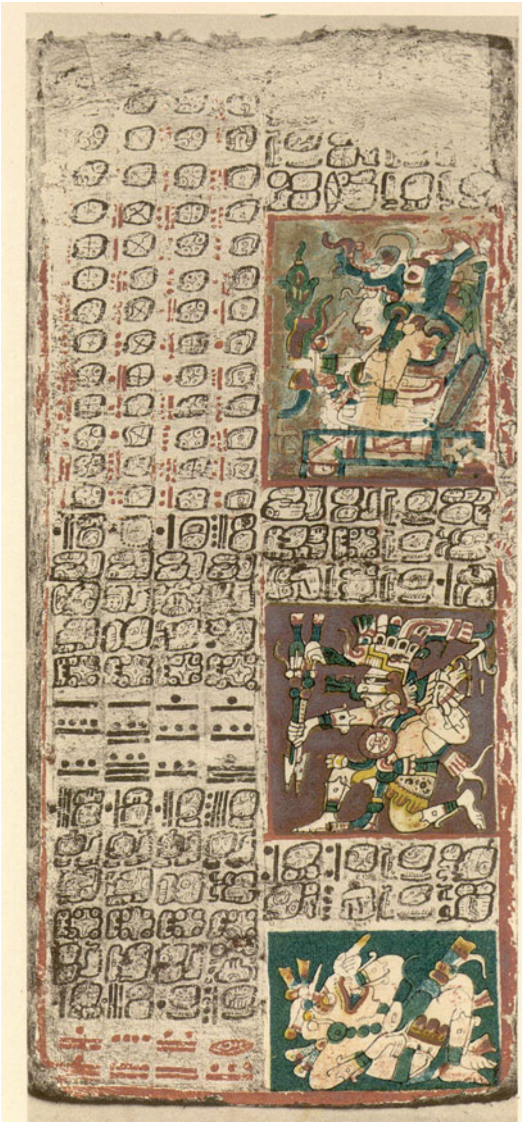
Astronomy in Mesoamerica, Fig. 8 The Paris Codex "Zodiac." Scorpion at the *left*; turtle in the *center*; rattlesnake at the *right*. Each devours (or stings) the glyph for a solar eclipse beneath a Sky Band, representing the ecliptic (Drawing by author after FAMSI photograph)

Preclassic and spread throughout the Maya area where it was ubiquitously used on monuments throughout the Classic period. This largely vigesimal positional system functioned as a precise count of days and 360-day periods reckoned from a back-calculated base date over 3,000 years prior to the first evidence of the use of this system. In this respect, the Long Count resembles the Julian Day Number (JDN) system used by contemporary astronomers to count the number of days elapsed from January 1, 4713 BC. As such, the Long Count was extremely useful as a means by which to calculate and record astronomical observations over long periods of time.

Long Count dates are typically given together with the 260-day cycle as well as the 365-day cycle (Fig. 10), and these interwoven cycles were remarkably continuous and unadjusted, though some examples of slightly offset Calendar Rounds do occur. However, it is more difficult to assess whether the Long Count itself was ever corrected or shifted from its original count, and many scholars have assumed that it remained unbroken. Various attempts to correlate the Long Count with the Julian and Gregorian calendars have often used assumed astronomical references to support their correlations, yet these approaches have proven to be problematic if only one their assumptions is incorrect.

Utilizing several ethnohistorical references to Calendar Round and K'atun positions – along with contemporary and historical 260-day counts maintained by living Maya calendar keepers – John Goodman, Juan Martínez Hernández, and Eric Thompson provided the original proposals which have resulted in the two most widely used correlations that match the Era base date of the Long Count with two different Julian Day Numbers (584283 and 584285). These are collectively known as the GMT correlation constants, and there is still disagreement among scholars regarding which is more accurate, though astronomical data strongly supports both. Given some of the unresolved discrepancies, some scholars maintain that neither correlation is correct, calling into question any proposed astronomical references that result from these correlations.

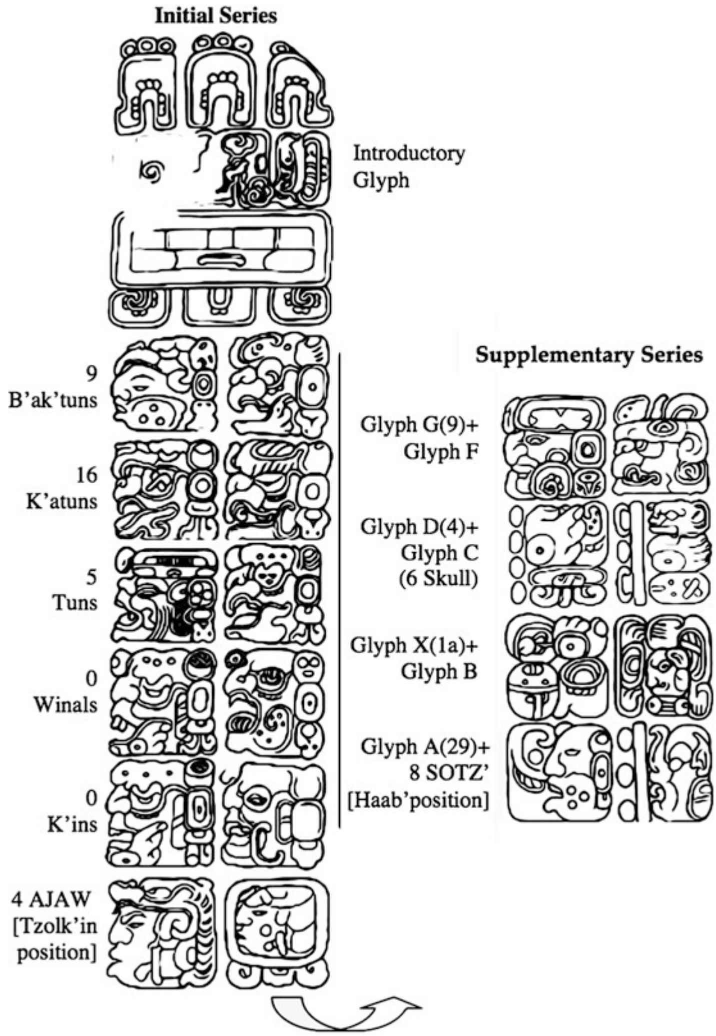
Goodman first noted that the Long Count Initial Series dates are often given together with what he named the Supplementary Series, and John Teeple first demonstrated that Glyphs D and E of this series record the age of the moon as measured from various points near the



Astronomy in Mesoamerica, Fig. 9 Dresden Codex Venus Table. Dresden Codex, page 49. Photograph Licensed under Public domain via Wikimedia Commons – http://commons.wikimedia.org/wiki/File:Dresden_codex,_page_2.jpg#mediaviewer/File:Dresden_codex,_page_2.jpg

new moon, while Glyph A designates a lunar month of either 29 or 30 days in length – the alternation of which closely corresponds with the true synodic lunar month of 29.53059 days. As a whole, lunar data from the Supplementary Series strongly supports *both* of the GMT correlations while it does not appear to favor either one, since it is unclear exactly on which day Maya observers were recording the first day of the new moon. Significantly, the lunar data from the Classic period inscriptions is consistent with that from the Lunar Table found in the Dresden Codex, and one run of this table corresponds with 11,960 days, which is equivalent to 46 cycles of 260 days and 46 synodic lunar months of 29.5308642 days. Teeple found that this exact same value for the synodic lunar cycle was used in Classic period Palenque to back-calculate lunar data for precise mythological dates found in the Cross Group. Indeed, a recently discovered series of painted texts from a wall in Xultun provides clear evidence for an earlier precedent for the Dresden Lunar Table in the Classic period.

The Dresden Lunar Table also significantly includes important eclipse data that closely corresponds with the eclipse year when using either of the two GMT correlation constants, and Harvey and Victoria Bricker (1983) have shown that the table could be used to determine repeating eclipse "warning stations," whether or not actual historical eclipses were visible. Surprisingly, overt references to eclipses are extremely rare throughout the Classic period inscriptions, with the exception of one recognizable reference on Poco Uinic Stela 3. First noticed by Teeple, this reference shows a solar eclipse glyph similar to those found in the codices, and it is associated with the Long Count date 9.17.19.13.16. A near total eclipse is known to have occurred just after noon at Poco Uinic on JDN 2009802, which corresponds with July 16, 790 AD. Therefore, Simon Martin and Joel Skidmore (2012) conclude that the correct correlation should place the Era base on JDN 584286, one day forward from one of the GMT correlations. However, Vincent Malmström (1999) maintains that the 584285 GMT correlation can be reconciled with the Poco Uinic eclipse, given that the Maya day began and ended at sunset. Therefore, the Long Count may actually overlap two Julian days, which begin and end at noon Greenwich Mean Time or sunrise in the Maya area. The Poco Uinic eclipse lends some support to the 584285 GMT correlation, while it would not support the competing 584283 correlation. Given that the



Astronomy in Mesoamerica, Fig. 10 Maya Initial Series from Quirigua Stela J. Long Count, 260-day Tzolk'in and 365-day Haab, along with Supplementary Series, showing lunar information (Drawing after Matthew Looper in Grofe (2011a))

260-day count preserved by the Highland Maya supports the latter, it is apparent that a shift of the 260-day cycle may have occurred at some time in the Postclassic, after the Long Count fell out of use.

Establishing the validity of the Long Count correlation holds great promise in that it provides the ability to observe specific, historical astronomical patterns and potential intentions in association with hieroglyphic texts and architectural alignments. Given that the 584285 GMT correlation places the Era base of the Long Count on August 13, 3114 BC Gregorian (September 8, Julian), both Robert Merrill and Vincent Malmström proposed that the Long Count Era base corresponds to the August 13 zenith passage at 14.8° N latitude where the two zeniths are precisely 260 days apart. Such a precise correspondence not only implies an intentional and highly accurate calculation of the tropical year but also suggests the means by which such a calculation could have been performed using the solar zenith. If the originators of the Long Count did in fact make such a calculation, it would follow that, at the time of the earliest attested Long Count date from Chiapa de Corzo in 36 BC, Mesoamericans had already achieved a measurement of the tropical year that was unsurpassed until Johannes Kepler in 1627. For some, such a bold assertion may be difficult to accept without additional supporting evidence. Therefore, it is all the more important to investigate this question further with a great deal of scrutiny.

Based on evidence from Copán Stela A, Teeple deduced that the drift of the 365-day Haab from alignment with the tropical year would have provided for a highly accurate tropical year of 365.2419355 days, derived from the equation of 1,403,990 days = 3,844 tropical years and slightly more accurate than the Gregorian year of 365.2425 days. Using this so-called determinant theory, Teeple and Thompson identified various values for the tropical year in different sites at different times. However, this theory lost favor when it was later determined that the dates used refer to historical events in the lives of Maya rulers. Nevertheless, the intentional association of such historical events with astronomical underpinnings should not be overlooked.

Indeed, Maya inscriptions in the Classic and Postclassic contain many long-distance numbers that link specific historical events with contrived, back-calculated mythological events that suggest astronomical measurements. Several of these dates imply tropical year calculations that apparently targeted the canonical February nadir at 14.8° N. This is visible in the base date for the Dresden Venus Table, Copán Stela C, the Palenque Temple of the Foliated Cross, and Naranjo Altar 1. In addition, historical commemoration of both actual and canonical February nadirs is apparent in multiple inscriptions, particularly as a common date for the accession of kings in Copán, Tortuguero, and Naranjo (Grofe, 2011b).

Analysis of the back-calculated February 8, 310 BC canonical nadir from Naranjo Altar 1 also reveals that it would have placed the sun at a lunar node during the heliacal rise of Venus and in precisely the same sidereal position in which it historically appeared 304,263 days later, the interval given by the distance number. This suggests that Maya astronomers were able to calculate the sidereal year, since 304,624 days is very nearly a whole multiple of 834 sidereal years. The value for the sidereal year here results in 365.2553957 days, while the actual current value is 365.25636 days. Evidence for this kind of sidereal year calculation has also been proposed within the immense distance numbers from the Serpent Series in the Dresden Codex that exceed 15,000 and 30,000 years. Similar calculations are apparent in Copán Stela J, Tortuguero Monument 6, and in the Palenque Temple of the Inscriptions and Temple of the Cross (Grofe, 2007, 2011b). Like proposed measurements of the tropical year, these proposals remain controversial, and it is not entirely clear from the evidence whether these measurements of the sidereal year were distinguished from the measurement of the tropical year. Certainly, making such a distinction would indicate that Maya astronomers were well aware of the precession of the equinoxes, a proposal that finds some support in the 3–11 Pik title (Grofe, 2003, 2011a; MacLeod, 2008). Given to Maya kings who have reached an advanced age, the 3–11 Pik title represents a 33 Bak'tun cycle, or 13,200 cycles of 360 days, approximating one-half of a precessional cycle of some 26,000 years. A bone from Burial 116 in Tikal indicates that this count began on the Era base, while an inscription from the Caracol in Chichen Itza suggests that another cycle was completed on the Era base. Together, these two cycles comprise a full cycle of precession. Additionally, a smaller interpretation of the same Calendar Round reached by this larger interval is equivalent to 25,980 days, approximating 1 day of precessional drift between the sidereal year and tropical year.

Further analyses of numerous distance numbers from the Maya hieroglyphic inscriptions and codices promise to either reveal or refute the intentionality of proposed astronomical calculations and patterns and the potential significance of their associated texts. A more complete, interdisciplinary understanding of the capabilities of Mesoamerican astronomers likewise requires a more fully developed exploration of the religious and political motivations of these observations and the persistence of astronomical knowledge that has endured as a living tradition. The unique features of Mesoamerican astronomy necessitate that scholars be aware of the tendency to incorrectly attribute their own motivations to peoples quite different from themselves. While remaining rigorously skeptical and open to what the evidence does or does not reveal, it is equally important and enlivening to recognize our shared humanity and the structural similarities that are evident in the historical development of widely separated astronomical traditions.

References

Aimers, J. J., & Rice, P. (2006). Astronomy, ritual, and the interpretation of Maya "E-Group" architectural assemblages. *Ancient Mesoamerica, 17*, 79–96.

Aldana, G. V. (2011). The Maya calendar correlation problem. In J. M. Steele (Ed.), *Calendars and years II: Astronomy and time in the ancient and medieval world*. Oxford: Oxbow Books.

Aveni, A. F. (2001). *Skywatchers*. Austin, TX: University of Texas Press.

Aveni, A. F., Bricker, H. M., & Bricker, V. R. (2003). Seeking the sidereal: Observable planetary stations and the ancient Maya record. *Journal for the History of Astronomy, 34*, 145–161.

Bricker, V. R. (2001). A method for dating Venus Almanacs in the Borgia Codex. *Journal for the History of Astronomy, 26*, 21–44.

Bricker, H. M., & Bricker, V. R. (1983). Classic Maya prediction of solar eclipses. *Current Anthropology, 24*, 1–23.

Broda, J. (2006). Zenith observations and the conceptualization of geographical latitude in ancient Mesoamerica: A historical interdisciplinary approach. In *Viewing the sky through past and present cultures: Selected papers from the Oxford VII International Conference on Archaeoastronomy*. Phoenix, AZ: Pueblo Grande Museum Anthropological Papers.

Closs, M., Aveni, A. F., & Crowley, B. (1984). The planet Venus and Temple 22 at Copan. *Indiana, Berlin, 9*, 221–247.

Coggins, C. C. (1983). *The Stucco decoration and architectural assemblage of Structure 1-sub, Dzibilchaltun, Yucatan, Mexico* (Middle American Research Institute, Publication 49). New Orleans, LA: Tulane University.

Girard, R. (1948). *El calendario Maya-Mexica: Origen, función, desarrollo y lugar de procedencia*. Mexico City: Editorial Stylo.

Girard, R. (1949). *Los chortis ante el problema maya* (Vol. 2). Mexico City: Editorial Stylo.

Girard, R. (1962). *Los mayas eternos*. Mexico City: Libro Mex Editores.

Goodman, J. T. (1897). The Archaic Maya Inscriptions. In A. P. Maudslay (Ed.), *Appendix to Biologia Centrali-Americana (Archaeology) VI*. London: Porter. http://www.jstor.org/stable/1624039

Grofe, M. J. (2003). Calculations of the tropical year and precessional cycles: Two bone fragments from Tikal Burial 116. *Archives of the Maya Hieroglyphic Database Project*, June 5, 2003.

Grofe, M. J. (2007). *The serpent series: Precession in the Maya Dresden Codex*. Dissertation for the Department of Native American Studies. University of California at Davis.

Grofe, M. J. (2011a). Measuring deep time: The sidereal year and the tropical year in Maya inscriptions. In C. Ruggles (Ed.), *Ethnoastronomy and archaeoastronomy: Proceedings from the ninth Oxford international symposium on archaeoastronomy* (pp. 214–230). Cambridge: Cambridge University Press.

Grofe, M. J. (2011b). The sidereal year and the celestial caiman: Measuring deep time in Maya inscriptions. *Archaeoastronomy: The Journal of Astronomy in Culture, XXIV* (pp. 56–101).

Kaufman, T., & Justeson, J. S. (2001). *Epi-Olmec hieroglyphic writing and texts*. Austin, TX: Texas Workshop Foundation.

Lounsbury, F. G. (1978). Maya numeration, computation, and calendrical astronomy. In C. C. Gillespie (Ed.), *Dictionary of scientific biography* (Vol. 15, pp. 759–818). New York: Charles Scribner's Sons.

Lounsbury, F. G. (1983). The base of the Venus tables of the Dresden codex and its significance for the calendar-correlation problem. In A. F. Aveni, & G. Brotherston (Eds.), *The proceedings of the 44th international congress of Americanists* (BAR international series 174, pp. 1–26). London: Oxford University Press.

MacLeod, B. (2008). The 3-11-Pik formula, Lecture delivered at UT Austin Maya meetings, March 2, 2008, University of Texas.

Malmström, V. (1973). Origin of the Mesoamerican 260-day calendar. *Science, 181*(4103), 939–941.

Malmström, V. (1978). A reconstruction of the chronology of Mesoamerican calendrical systems. *Journal for the History of Astronomy, 9*, 105–116.

Malmström, V. (1997). *Cycles of the Sun, mysteries of the Moon: The calendar in Mesoamerican civilization*. Austin, TX: University of Texas Press.

Malmström, V. (1999). *An observation on correlating the Mesoamerican and European calendars* [Electronic document]. Retrieved from www.dartmouth.edu/~izapa/correlation.html

Martin, S., & Skidmore, J. (2012). Exploring the 584286 correlation between the Maya and European calendars. *The PARI Journal, 13*(2), 3–16.

Mendez, A., Barnhart, E. L., Powell, C., & Karasik, C. (2005). Astronomical observations from the Temple of the Sun. *Archaeoastronomy: The Journal of Astronomy in Culture, 19*, 44–73.

Merril, R. H. (1945). Maya sun calendar dictum disproved. *American Antiquity, 10*, 307–311.

Milbrath, S. (1988). Astronomical images and orientations in the architecture of Chichen Itza. In A. F. Aveni (Ed.), *Proceedings of the 46th international congress* *of Americanists* (BAR international series, pp. 57–80). Amsterdam: Oxford University Press.

Milbrath, S. (1999). *Star Gods of the Maya: Astronomy in art, folklore, and calendars*. Austin, TX: University of Texas Press.

Nuttall, Z. (1928). Nouvelles lumières sur les civilizations americaines et le système du calendrier. In *Proceedings of the 22nd international congress of Americanists*, Rome, pp. 119–148.

Rice, P. M. (2007). *Maya calendar origins: Monuments, mythistory, and the materialization of time*. Austin, TX: University of Texas Press.

Saturno, W., Stuart, D., Aveni, A. F., & Rossi, F. (2012). Ancient Maya astronomical tables from Xultun, Guatemala. *Science, 336*, 714–717.

Sprajc, I. (2009). Astronomical and cosmological aspects of Maya architecture and urbanism. In J. A. Rubiño-Martín, J. A. Belmonte, F. Prada, & A. Alberdi (Eds.), *Cosmology across cultures* (ASP conference series, Vol. 409). San Francisco: Astronomical Society of the Pacific.

Tedlock, B. (1982). *Time and the highland Maya*. Albuquerque, New Mexico: University of New Mexico Press.

Teeple, J. (1930). Maya astronomy. *Contributions to American Archaeology, 1*(2). (Washington, DC: Carnegie Publication No. 403, 29–116).

Thompson, J. E. S. (1927). A correlation of the Mayan and European calendars. *Anthropological Series, 27*(1), 3–22. (Field Museum of Natural History Publication. No. 241).

Astronomy in Native North America

Edwin C. Krupp
Griffith Observatory, Los Angeles, CA, USA

Introduction

The astronomical activities and traditions of the American Indians north of Mexico were based upon practical observation of the sky but were not supported by a written language. For that reason, our knowledge of North American Indian astronomy relies upon the archaeological data, ethnohistoric reports from early encounters between Europeans and the indigenous peoples, and ethnographic information collected more recently by anthropologists. Although this material is distorted and incomplete, it enables us to outline the general character of North American Indian astronomy and to understand some of it in detail. All of these sources confirm that North American Indians farmed, hunted, and gathered by the sky. They developed calendric techniques to order the sacred and ordinary dimensions of their lives. They timed ceremonies by the sky. They extracted symbols from the sky. They told stories about the sky. Throughout all of the cultural territories, physical environments, and linguistic traditions of North America, celestial phenomena were incorporated into ritual, iconography, myth, shamanic activity, and worldview (Krupp 1978, 1983, 1984, 1991, 1996).

North American Indians were familiar, of course, with the fundamental cycle of day and night, the daytime path of the sun, and the unmoving pole of the night sky. Cardinal directions, which emerge from the daily rotation of the sky and the circular parade in which the stars march at night, were important to many groups. The moon's phases were monitored, and each monthly cycle was often associated with a seasonal change on earth. The seasonal shift of sunrise, sunset, and the sun's daily path was known. Solstices were recognized, and the rising and setting points of the summer and winter solstice sun sometimes established an alternate directional scheme. Seasonal appearances and disappearances of stars were noted. Constellations were contrived from conspicuous and useful stars. In the historic era, unusual events like eclipses, bright comets, fireballs, and meteor showers attracted notice and sometimes provoked ritual response. Planets were recognized by at least some groups, but explicit evidence of detailed indigenous knowledge of their cyclical behavior has not survived (Williamson 1984).

Like traditional peoples everywhere, the Indians of North America saw the sky as a realm of power. Access to that power required knowledge of the sky. They acquired that knowledge through careful observation and used that knowledge to order and stabilize their lives. This practical understanding of the sky – the sun, the moon, and the stars – is not the same thing as modern scientific astronomy, for it did not attempt to test and abandon metaphors of nature in the same way science does today. It did, however, help integrate human behavior with nature and consolidate social cohesion. Celestial objects were not just convenient metronomes. They were powerful, supernatural beings, and they revealed the basic structure – the fundamental order of the world. Because cosmic order is, in part, what is meant by the sacred, the Indians' interaction with the sky was an encounter with the sacred.

Main Text

The earliest account of North American Indian astronomy was reported in 1524 by the Italian explorer Giovanni di ve Verrazzano (Wroth 1970). He encountered the Narragansett Indians of Rhode Island and mentioned that their seeding and cultivation of legumes were guided by the moon and the rising of the Pleiades (Ceci 1978). The Pleiades comprise a distinctive cluster of stars. Its value as a signal of seasonal change was recognized throughout the continent. In California, for example, there is explicit evidence of Pleiades lore in all but 12 of the 58 native cultural territories. Those 12 actually correspond to a very small fraction of the entire area and population of the state, and their lack of Pleiades tradition is primarily due to linguistic and cultural extinction. Despite the extraordinary linguistic diversity represented by the 75 mutually unintelligible California Indian languages and 300 different dialects, names for the Pleiades, myths about the Pleiades, and seasonal references to the Pleiades are documented in all five major families of indigenous California languages.

Studies of North American Indian astronomy have emphasized the prehistoric Southwest and the historic Pueblos (Malville & Putnam 1989). This is due to the survival of Ancestral Pueblo architectural monuments and rock art and to the preservation of some information about historic Pueblo astronomical techniques and celestial lore in ethnological reports. Close to the end of the last century, Stephen (1936) described in detail the horizon calendar used by the Hopi Sun Chief to establish key dates in the ceremonial and agricultural cycles of the village of Walpi. More recently, historian of science McCluskey (1977) demonstrated that Hopi observations of the sun were accurate to 4 arcmin. This is, however, an average error, and it is difficult to do much better than 30 arcmin in any single horizon event. McCluskey verified that the Hopi actually allowed themselves a few days' leeway in scheduling the winter solstice ceremony.

If Stephen had not seen the Sun Chief perform his duties, we would not know where his sunwatching station was located. Nothing marks the point out at the end of a mesa or on the roof of the highest house. Other references to North American horizon observatories suggest that many were just as subtly blended into the community landscape, and that makes the identification of prehistoric observatories a challenge. Symbolic astronomy was, however, often incorporated into monumental architecture and rock art. By analyzing alignments and iconography, it is sometimes possible to spot the hand of the ancient skywatcher. For example, Pueblo Bonito, an 800-room, five-story, D-shaped apartment-town in Chaco Canyon, New Mexico, makes good use of passive solar heating to stabilize room temperatures in summer and winter. It was completed in the twelfth century AD, and its east–west front wall is oriented cardinally with an accuracy of 8 arcmin. Such accuracy is achievable with simple surveying techniques that rely upon the unaided eye, but it is nevertheless respectable. In addition, archaeologist Jonathan Reyman interpreted corner windows in two rooms as winter solstice sunrise apertures (Krupp 1978; Williamson 1984).

The Ancestral Pueblo built large subterranean community ceremonial chambers known as Great Kivas. Most of these, like Chaco Canyon's Casa Rinconada, possess cardinal orientation, and the plan of a Great Kiva is thought to mirror the Pueblo concept of the cosmos.

There are many pictographs and petroglyphs in Chaco Canyon, and the star and crescent on a panel near the Penasco Blanco ruin have been promoted by some as a representation of the AD 1054 Crab supernova explosion. Prehistoric Indians in the American Southwest very likely saw that spectacular event, but there is no way to verify that the Penasco Blanco pictographs are an eyewitness record of it. The supernova interpretation of star/crescent elements in Southwest rock art was first offered in 1955 as an explanation for two sites in northern Arizona. Since then, the number of reported star/crescent groupings has multiplied, but opinion on the supernova is divided. Reyman argues thoughtfully that the Penasco Blanco site is actually a sunwatcher's shrine and implies that the Crab supernova has nothing to do with these star/crescent designs. Even if they do depict the supernova rising with the waning crescent moon on the morning of 5 July 1054, they tell us nothing substantive about Ancestral Pueblo astronomy. In 1990, Robbins and Westmoreland (1991) revived the argument all over again with an analysis of numerical symbolism on prehistoric Mimbres ceramics. One of these has a rabbit in the shape of a crescent moon accompanied by a "star" with 23 rays. This detail is argued to be consistent with the Chinese historical account of the Crab supernova, for the Chinese reported it was visible in the daytime for 23 days.

A spiral petroglyph on Fajada Butte, the most conspicuous landmark in Chaco Canyon, interacts with "daggers" of midday sunlight at the solstices and the equinoxes. These light-and-shadow effects, first reported by Sofaer et al. (1979), received a great deal of international attention and inspired considerable controversy. Initially, the "Anasazi Sun Dagger" was interpreted as a "precise solar marker," but it may be more correct to regard it as a symbolic seasonal display.

One of the best candidates for a sunwatcher's observing platform is also located in Chaco Canyon, on an upper ledge on a rincon (a square-cut recess or hollow in a cliff) near Wijiji ruin. Rock art on the ledge includes elements as old as the Ancestral Pueblo and as recent as the Navajo. A line-of-sight to the southeast coincides with a natural rock chimney on the other side of the rincon, and this feature dramatically marks the winter solstice sunrise.

Astronomer Zeilik has emphasized the importance of "anticipatory" observations of the solstices and other astronomical events (Zeilik 1985). The Sun Chief must know ahead of time, with accuracy, when the solstice is due in order to mobilize the community for the ceremonial activity that culminates in the solstice. This is exactly what Walpi's Sun Chief did, and Wijiji has the ability to deliver advance information and confirmation of the solstice. The site is interpreted, then, by extending significant information from the historic period back into the prehistoric context.

Astronomical components have been identified at many other sites in the Southwest, including Hovenweep, Yellow Jacket, Chimney Rock, Casa Grande, and Mesa Verde (Malville 1991). Celestial rock art elements are present throughout the Southwest. Few of these involve accurate mapping of constellations, but several seem to invoke magical power attributed to the stars. Chamberlain (1989) has studied Navajo star ceilings in Canyon de Chelly and concluded that most of them are connected with symbolic protection or other celestial magic. Schaafsma (1990) interprets war and star imagery in the petroglyphs of New Mexico's Galisteo Basin as part of a tradition of Southern Tewa celestial war magic.

Nine years after astronomer Hawkins (1963) rekindled interest in ancient and prehistoric astronomy in 1963, with his studies of solar and lunar astronomical alignments in Stonehenge, another astronomer, Eddy (1984), identified celestial sightlines in the Bighorn Medicine Wheel, a North American antiquity *Time* magazine headlined as "Stonehenge USA." The Bighorn Medicine Wheel is located at an elevation of 9,600 ft, above the timberline on Wyoming's Medicine Mountain. It is a ring, 87 ft in diameter, drawn in small rocks. Originally, the Wheel had 27 or 28 spokes of stones that converged on the main cairn at the center. Five other cairns were constructed on the Wheel's rim, and the one spoke that extends beyond the rim ends in its own cairn. The ring is actually a flattened circle. Its axis of symmetry coincides with the spoke that reaches from the outside cairn, southwest of the rim, to the cairn at the center. Eddy demonstrated that this line also continues to the northeast horizon and the point of summer solstice sunrise.

He associated other lines between cairns with the sequential risings of three bright stars in the predawn sky in summer. Although the age of the Bighorn Medicine Wheel is uncertain, a radiocarbon date for a piece of wood retrieved from the central cairn associates it with the seventeenth century. Eddy thought that the Bighorn Medicine Wheel might have been used at that time by historic Plains Indians to make astronomical observations.

It seems likely, however, that the Bighorn Medicine Wheel is much older. It resembles other similar structures, especially in southern Canada, that are known to be thousands of years old. Who built the Bighorn Medicine Wheel and when it was built are still not known with certainty. There is reason to be skeptical about the practical value and validity of the stellar alignments, but the summer solstice sunrise line is congruent with the design. If the solstice alignment were part of the original plan, it may have had as much to do with vision quests and shamanic retreat as with calendric observation.

In the historic era, Plains Indians incorporated the sky into symbols and ritual. The well-known Sun Dance was intended to inspire prayer and visions through self-infliction of pain, fasting, and thirst. Gazing at the sun while suspended from a pole with ropes looped through the flesh of the chest was thought to purify and spiritually strengthen the participant. Although not all Plains tribes practiced this demanding regimen in the Sun Dance, acquisition of sacred power was a common theme. The enclosure in which the ceremony took place is called a Sun Dance Lodge, and it is sometimes built with 28 posts said to represent the days of the lunar month. Originally, the ritual was performed at the time of the summer full moon nearest to the time of the bison hunt.

Another Plains group, the Skidi band of the Pawnee, is known to have possessed a rich and detailed tradition of star lore. This knowledge has been reviewed and analyzed by Chamberlain (1982) in *When the Stars Came Down to Earth*. The Skidi Pawnee Morning Star sacrifice was timed by the movements of planets, especially Mars and Venus, and mythologically, the planets were key players in the Skidi Pawnee Creation myth.

In Nebraska, the Omaha devised a symbol of social cohesion and tribal stability out of the Sacred Pole that was erected ceremonially at tribal gatherings. Omaha myth and ritual allow us to deduce that the Sacred Pole was oriented on the north celestial pole. Its power was linked to the stabilizing character of the hub of the sky.

It is a curious fact that so much public interest in ancient North American Indian astronomy has been directed toward the prehistoric Southwest and the Bighorn Medicine Wheel. Although these sites are valid targets of study, they belong to relatively unpopulated parts of the continent. Even the well-documented traditions of the Plains Sun Dance, the Skidi Pawnee Morning Star Sacrifice, and polar axis symbolism of the Omaha Sacred Pole must be considered marginal traditions of North America.

The mainstream, on the other hand, belongs to the most populated zones of North America. To understand, then, the true character of North American Indian astronomy, it is necessary to look at the Mississippi Valley and California. Nowhere north of Mesoamerica had a comparable population density.

Unfortunately, we know relatively little about the astronomical traditions of the ancient Mississippi Valley. In 1961, however, archaeologist Wittry (1973) excavated a feature he called the Sun Circle at Cahokia, a great population center and powerhouse of regional trade in central Illinois between AD 700 and 1200. Cahokia is best known for its large mounds, some of which supported temples and residences. Others hosted burials. Monks Mound, the largest prehistoric earthen construction in the world, is the centerpiece of what was the Chicago of the prehistoric Midwest.

Originally, the Sun Circle was a 410-foot-diameter ring of 48 tall posts (perhaps 30 ft high), with a pole in the middle of the circle but offset apparently intentionally 5 ft from the true center. Three of the posts that once occupied the holes that now remain combined with the center pole to deliver alignments to the rising sun at summer solstice, winter solstice, and the equinoxes. Wittry believed that the Sun Circle's purpose was calendric. It is difficult to understand, however, why a complete ring of posts would be needed and why the posts were so tall. On the other hand, the intentional displacement of the central post makes the astronomical alignments possible.

Despite the ambiguity that persists with Cahokia's Sun Circle, archaeologist Fowler verified the ancient Cahokians' interest in cardinal directions. The city's limits were established by a particular type of earthen mound, and these mounds also defined the primary, and cardinal, axes of the site. In 1994, Fowler described another post circle on the main north–south axis of Cahokia. Its design, size, and astronomical potential mimic the Sun Circle.

The Incinerator Site, a smaller stockaded Mississippian village near Dayton, Ohio, included an arrangement of posts also thought to have astronomical meaning. The largest post, 2 ft in diameter, was located in a plaza, and it formed a line with a post inside a nearby building. This line pointed to the sunrise on April 24 and August 20. Both dates potentially have agricultural significance. The April date could mark the end of the frost and the beginning of planting. The August date is linked to the Green Corn Ritual, performed in the historic era when the corn filled the husk but was not yet ripe. Cardinally oriented logs were kindled at this time into the New Fire, which also had solar associations.

European explorers encountered the descendants of the Mississippian mound builders in the southeast United States. The chief of the Natchez was known as the Great Sun. He claimed to be the brother of the sun and greeted the sun each morning, when it first appeared from the top of his residence mound. We also know the Natchez subdivided the daylight hours into four periods based upon the position of the sun. They measured the year in months based on the observed phases of the moon and named each lunation for an appropriate seasonal phenomenon.

In the Far West, before Columbus, California competed respectably with the Mississippi Valley for the distinction of being the most populous and densely populated zone north of Mesoamerica. Some indigenous astronomical traditions persisted in California until quite late, and valuable information was collected by ethnographers, especially Harrington. The revival of interest in California Indian astronomy was largely initiated by Hudson and Underhay (1978), whose book, *Crystals in the Sky*, reconstructed the sky lore of southern California's Chumash Indians. Explicit references to horizon observations of the solstice sun and solstice rituals have been collected from the entire state. The moon's phases were counted, and the lunar months were named by most California groups. They recognized familiar patterns of stars, including the Big Dipper and the Belt of Orion. They named many other stars and used them as seasonal signals. They saw the Milky Way as a route to the sky followed by the souls of the deceased. Elaborate Milky Way ceremonialism is known among the Luiseño, who incorporated it into ritual initiation of the youth, mourning songs for the dead, sacred myth, and rock art.

California possesses many rock art sites and some of the most complex rock art in the world. Some of these sites have been associated with solstitial light-and-shadow events that interact with the rock art. Often, particularly at winter solstice, the light develops into a pointed, knife-like shape that pierces a carved or painted element. These effects appear to be symbolic, for they do not generally pinpoint the solstice with high accuracy. Rather, they "work" over a solstice "season" perhaps 2–4 weeks long. Although there is no explicit evidence that links solstice effects with California rock art, we do know the names of two Chumash shamans who went into the mountains at the time of winter solstice to paint on the rocks.

Conclusion

In detailed application, Native American astronomy was richly varied in North America, but its purpose and basic character were broadly the same throughout the continent. For that reason, we can rely upon Francisco Patencio, Chief of the Palm Springs Indians of southern California, for words that could apply to nearly all Indians:

> When the sun swung to the north and the moon showed quartered by day overhead, or west, they knew by the signs of the sun and the moon when the seeds of certain plants were ripe, and they got ready to go away and gather the harvest. Every plant that grew, the nesting time of all birds, the time of the young eagles, everything they learned by the signs of the sun and the moon. *Stories and Legends of the Palm Springs Indians* (Los Angeles: Times Mirror, 1943).

See Also

- ▶ Medicine Wheels
- ▶ Time
- ▶ Time in Native North America

References

Chamberlain, V. D. (1989). Navajo Indian star ceilings. In A. F. Aveni (Ed.), *World archaeoastronomy* (pp. 331–340). Cambridge: Cambridge University Press.

Ceci, L. (1978). Watchers of the pleiades: Ethnoastronomy among native cultivators in Northeastern North America. *Ethnohistory, 25*(4), 301–317.

Chamberlain, V. D. (1982). *When the stars came down to Earth: Cosmology of the Skidi Pawnee Indians of North America*. Los Altos, CA: Ballena Press.

Eddy, J. A. (1984). Astronomical alignment of the big horn medicine wheel. *Science, 184*, 1035–1043.

Fowler, M. L. (1975). A pre-columbian urban center on the mississippi. *Scientific American, 233*, 92–101.

Harrington, J. P. (no date). *Unpublished notes on the Chumash and Kitanemuk*. MS 6017, Boxes 2, 3, 5, 9, 12, 538, 543, 545, 550, 651, 705, 745, 747. Washington, DC: United States National Anthropological Archives.

Hawkins, G. S. (1963). Stonehenge decoded. *Nature, 200*, 306–308.

Hudson, D. (1978) *Travis and Ernest Underhay. Crystals in the sky*. Socorro: Ballena Press.

Krupp, E. C. (Ed.). (1978). *Search of ancient astronomies*. Garden City, NY: Doubleday.

Krupp, E. C. (1983). *Echoes of the ancient skies*. New York: Harper & Row.

Krupp, E. C. (Ed.). (1984). *Archaeoastronomy and the roots of science*. Boulder, CO: Westview Press.

Krupp, E. C. (1991). *Beyond the blue horizon – Myths and legends of the sun, moon, stars, and planets*. New York: HarperCollins.

Krupp, E. C. (1996). *Skywatchers, Shamans & Kings: Astronomy and the archaeology of power*. New York: Wiley.

Malville, J. M. (1991). Prehistoric astronomy in the American Southwest. *The Astronomy Quarterly, 8*(1), 1–36.

Malville, J. M., & Putnam, C. (1989). *Prehistoric astronomy in the Southwest*. Boulder, CO: Johnson Publishing Company.

McCluskey, S. C. (1977). The astronomy of the Hopi Indians. *Journal for the History of Astronomy, 8.3*, 174–195.

Robbins, R. R., & Westmoreland, R. B. (1991). Astronomical imagery and numbers in mimbres pottery. *The Astronomy Quarterly, 8*(2), 65–88.

Schaafsma, P. (1990). War imagery and magic: Petroglyphs at Comanche Gap, Galisteo Basin, New Mexico. Paper prepared for Social Implications of Symbolic Expression in the Prehistoric American Southwest, Symposium at the 55th Annual Meeting of the Society for American Archaeology, Las Vegas, Nevada, April 1990.

Sofaer, A., Zinser, V., & Sinclair, R. M. (1979). A unique solar marking construct. *Science, 206*(4416), 283–291.

Stephen, A. M. (1936) *Hopi journal of Alexander M. Stephen*. In E. C. Parsons (Ed.) (Vol. 2). New York: Columbia University Contributions to Anthropology, p. 23.

Williamson, R. A. (1984). *Living the sky: The cosmos of the American Indian*. Boston: Houghton Mifflin Company.

Wittry, W. (1973) The American Woodhenge. *Explorations into Cahokia archaeology*. Urbana: Illinois Archaeological Survey, University of Illinois, pp. 43–48.

Wroth, L. C. (1970). *The voyages of Giovanni da Verrazzano* (pp. 1524–1528). New Haven: Yale University Press for the Pierpont Morgan Library.

Zeilik, M. (1985). The ethnoastronomy of the historic Pueblos. 1. Calendrical sun watching. *Archaeoastronomy Supplement to Journal for the History of Astronomy, 168*, S1–S24.

Astronomy in Sub-Saharan Africa

Keith Snedegar

At the turn of a new millennium the study of astronomical practices in precolonial African societies remains an open field. Major sources of evidence have yet to be fully scrutinized – astronomical texts in Arabic, Ge'ez, Hausa, Malagasy and Swahili, celestial iconography in the African arts, and perhaps most importantly, astronomical knowledge encoded in the vast reservoir of oral tradition. It should be no surprise that Muusa Galaal's groundbreaking monograph on Somali ethnoastronomy derives wholly from oral literature (Galaal, 1992). As for the built environment, a few African architectural structures have been surveyed for astronomically meaningful features with interesting if not definitive results; further archaeoastronomical research would doubtless reveal more about the cosmologies behind African material culture. Nonetheless, scholars from various disciplines have already demonstrated that African time reckoning, divination systems, performance art and literature utilized the sky as a cultural resource. Jarita Holbrook of the University of Arizona is a leader of a new generation of scholars exploring African cultural astronomy (Holbrook, 2004, 2005). At a popular level the documentary film *Cosmic Africa* (2003), featuring the South African astronomer Thebe Medupe, has done much to introduce the subject to wider audiences.

Sahara Region

Ancient astronomically aligned structures have been discovered in a megalithic complex in the southern Egyptian desert at Nabta, where nomadic pastoralists made their summer camps by a playa, or seasonal lake, between 6,500 and 5,300 years ago. The Nabta site probably served as a ceremonial center. It comprises several oval clusters of stones and isolated megaliths, and numerous tumuli containing cattle and sheep burials. The burials are analogous with ritual practices of modern African pastoralists who slaughter animals to mark socially important occasions. Archaeoastronomer McKim Malville used theodolite and GPS measurements to map the site. He found three lines of megaliths radiating from the largest structure. A nearby stone circle containing four sets of upright slabs, which may have been used to fix positions along the horizon, exhibits two line-of-sight "windows," along a north-south axis and at an azimuth of 62°; the rising mid-summer sun would have been visible through the second line of sight circa 6,000 years ago. Malville has theorized that the geometry of the standing stones reifies a conceptual system integrating death, water, seasonal fertility, and the motion of the sun (Malville, McKim, Wendorf, Mazar, & Schild, 1998). Presumably, the ancient Nabtans correlated solstice observations with the onset of summer monsoon rains. It is intriguing that the megaliths, located in the playa deposits, would have stood in the shallow lake water. The rising and falling water level marked against the stones could have been a powerful indicator of seasonality. With climatic change bringing hyperaridity and desertification to the Sahara region around 4,800 years ago, the seasonal occupation of Nabta came to an end. The Nabtan pastoralists may have migrated to the Nile Valley, contributing their practice of solar observation as well as their reverence for cattle to the cultural development of predynastic Egypt (Wendorf & Schild, 2001).

While Nabta is the earliest Saharan site thought to have astronomical alignments, surveys of pre-Islamic tombs in the Tassili N'Ajjer region of Algeria and parts of southern Morroco have also indicated structural orientations suggestive of some calendrical purpose (Belmonte et al., 1999, 2002). In the historic period the nomadic Tuareg people have practiced celestial navigation in their travels across the great desert. When traveling north the Tuareg oriented themselves according to the mother camel constellation *Taləmt* (Ursa Major), and when traveling south they watched the gazelle stars *Ineren* (α and β Centauri). *Əmanar*, "The Guide" (Orion) and Tələzdak, the date palm (Scorpius) are other important asterisms in the Tuareg sky (Donaint, 1975).

West Africa

By the first millennium AD the trade between West Africa and Mediterranean North Africa was functioning as an important mechanism for cultural exchange. The transmission of Islam to West Africa would engender formal academic traditions based on written texts in Arabic. From the fifteenth century onward a number of scholars in Timbuktu and other Islamic centers studied astronomy as an adjunct to the Quranic sciences. The corpus of Arabic scientific writings of West African provenance has yet to be analyzed in any detail, but a number of manuscripts preserve meteorological observations, particularly floodings of the Niger River, and details of solar and lunar calendars (Saad, 1983). Rebstock (1990) located numerous mathematical, astronomical and astrological texts in Mauretania, 13 of them having to do with the Islamic calendar. Results of a study by the Al Furqan Foundation suggest that roughly 1 % of Arabic manuscripts in West Africa contain astronomical material (Hunwick, 1997). There are probably several hundred texts yet to be identified and analyzed. A Library of Congress exhibit of manuscripts from Timbuktu afforded a glimpse of this raw material, including tracts entitled *The Important Stars among the Multitude of the Heavens* and *The Rise and Setting of Auspicious Stars* (Library of Congress, 2003).

The existence of these texts indicates that at least some West African scholars engaged Arabic mathematical astronomy at rather advanced level. However, the reputed fascination of Aḥmad Bābā al-Tinbuki (1556–1627) and al-ḥājj Muḥammad al-'Iraqi (fl. 1650) with esoteric astrology likely typifies the chief matter of interest. Many West African literati dabbled in celestial divination; others considered astrological prediction spiritually dangerous. The great Fulani scholar Muḥammad al-Wali (d.1688) wrote a diatribe against astrology and its practitioners. Ironically, his pupil Muḥammad ibn Muḥammad gained fame with an astrological opus, *al-Durr al-Manzūm* (Strung Pearls). It was not an original work. Its chief source was the *Secret Concerning the Dialogue with the Stars* of the Persian sage, Fakhr al-Dīn ▶ al-Rāzī (Ullmann, 1972). The lack of any coherent school of astronomy or astrology in West Africa is perhaps attested by Muḥammad Bello of Sokoto, who recorded his observations of a bright comet in 1825. Several people asked him to explain the phenomenon so he wrote a treatise on it. Unable to find any scientific writings on comets, he was reduced to quoting theological opinions to assure his readers that the object did not signify the end of the world (Ogunbiyi, 1991–1992) (Fig. 1).

The science of the stars did not remain solely in the Arabic language. Savants in the city of Kano translated Arabic star lore into Hausa. The anonymous pedagogical text, *Hisabi 'Assawwakai*, gives an elementary account of Islamic astronomy, and is still circulating in northern Nigeria (Kani, 1992). The Hausa took up astrology with enthusiasm, astrological verse becoming a prominent genre of vernacular literature. A Hausa poem attributed to Abdullah ibn Muḥammad describes the 28 *anwā*', 12 signs of the Zodiac, and planetary rulership of parts of the sky, according to the foreign practice. Ibn Muḥammad apparently learned his astrological theory from the writings of Moroccan practitioners such as 'Abd al-Hāqq, whose *Kitāb al-falak* (Book of the Planets), was widely read in Northern Nigeria. While the Ibn Muḥammad text largely retains Arabic terminology, other Hausa works apply indigenous epithets for the stars which were not derivations from the Arabic but reflect local tradition (Hiskett, 1967, 1975).

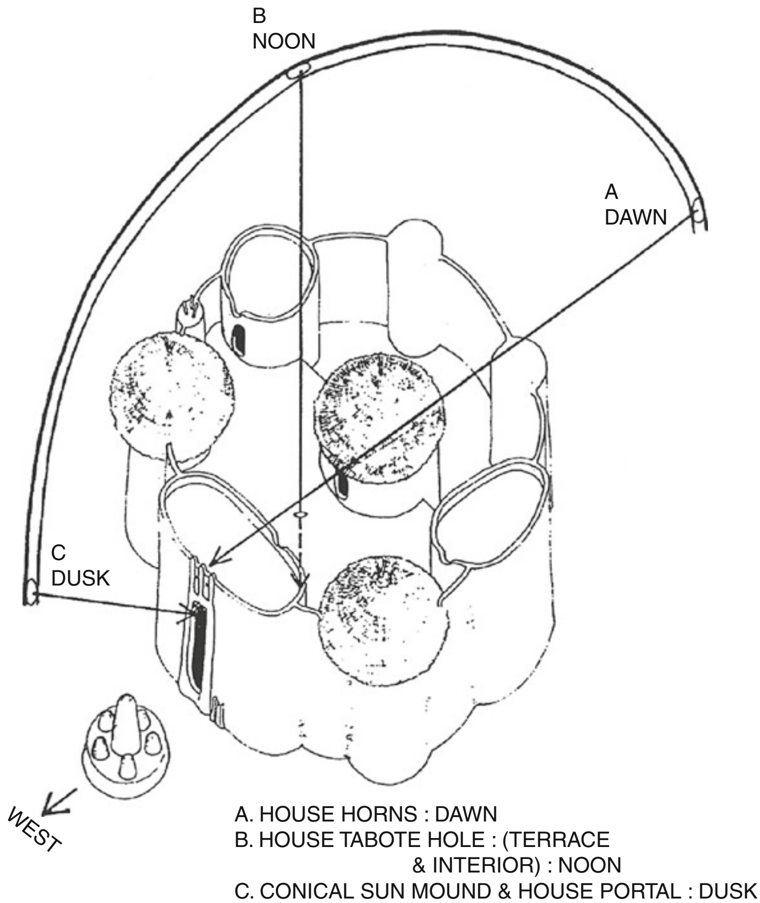
As for the built environment in West Africa, studies by Drucker-Brown (1984) and Blier (1987) have shown that certain vernacular architectures perform a symbolic as well as a functional purpose; home design not only manages light and heat resources but incorporates visual metaphors of directional affiliation and spatial organization alluding to the sun's diurnal and annual motion. Among the Mamprusi of northern Ghana the *zonga* or entranceway of one's home faces west so that the rays of the setting sun are directed into an area where family elders sit. It is here where in the late afternoon the position of light falling onto a wall is judged as an indication of the agricultural seasons. Elaborating on this theme, the Batammaliba people of Togo and Benin believe that the home should be representative of the solar deity, Kuiye. When a house is constructed, the builders perform a ritual in hour of Kuiye. It occurs at local noon when the sun is on the meridian, the "center" of the sky, and

Astronomy in Sub-Saharan Africa, Fig. 1 A page from *Kashf al-Ghummah fi Nafa al-Ummah* (The important stars among the multitude of the heavens). Mamma Haidara Commemorative Library, Timbuktu, Mali (Library of Congress, 2003)

involves the placement of cooked cereal on the *tabote* stone in the center of the homestead. The home itself is aligned on an east-west axis, with its portal and family shrines facing west. This allows the rays of the setting sun to strike the shrines of the family's deceased elders; it is believed that when such shrines are illuminated, Kuiye communicates with the ancestors about the affairs of living family members. Batammaliba granaries are also identified with Kuiye's domain, being divided into three sections, each associated with a different crop harvested in accordance with the three seasons delimited by tradition (Fig. 2).

Unfortunately, while West African astronomical traditions have not as a whole attracted much attention, an inordinate amount of publicity has surrounded exaggerated claims for an advanced state of knowledge on the part of the Dogon people of Mali. Based on their fieldwork conducted in the 1930s, Griaule and Dieterlen (1950, 1965) reported that the Dogon were aware of Sirius B, a small star invisible to the unaided eye. Such was the fuel for Temple (1975), among others, who claimed for the Dogon a heliocentric model of the solar system and independent knowledge of the satellites of Jupiter and the rings of Saturn. Thanks to television series such as "In Search of . . ." (1979) the Dogon have entered the popular imagination. Penetrating criticism by respected scientists and a field evaluation of Griaule's reportage, determining many elements, including the astronomical portions, to be either misconstrued or altogether unsupported by ethnographic evidence, have done little to stay the proliferation of misinformation on Dogon cosmology (Van Beek, 1991).

Astronomy in Sub-Saharan Africa, Fig. 2 The sun's path and corresponding parts of a Batammaliba homestead (Blier, 1987)



East Africa and Madagascar

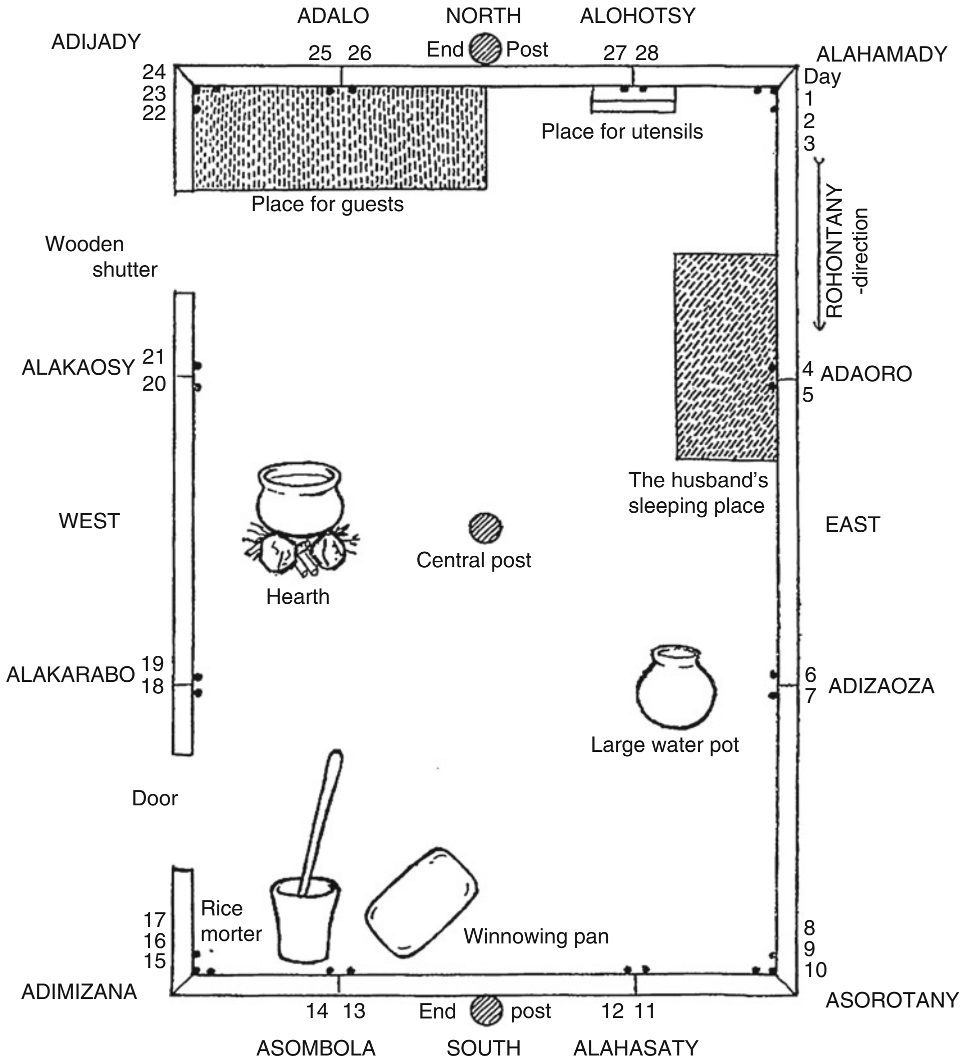
By the shores of Lake Turkana a megalithic site designated ► Namoratunga II, comprising 19 basalt pillars and at least one grave marked by upright slabs, has been surveyed for possible astronomical alignments (Lynch & Robbins, 1978). Although there is no proof positive that the Namoratunga stones were erected with an observational purpose in mind, they appear to be nonrandomly aligned in directions corresponding with the rising positions of seven conspicuous stars and asterisms – Bellatrix, Orion's Belt (δ, ε, ζ Orionis), Saiph, Sirius, the Pleiades, Aldebaran, and Triangulum – on the local horizon ca. 300 BCE. These stars may have served as calendrical markers for the ancient Cushitic people who erected Namoratunga. However, efforts to elucidate a cultural linkage between the purported Namoratunga tradition and calendrical practices of the Borana people in the historical period have met with doubtful results (Soper, 1982; Doyle & Wilcox, 1986). Most scholars have identified the Borana asterism *Lami* as the constellation Triangulum, but when Tablino (1994) asked Borana time-reckoning experts to identify *Lami* they invariably pointed out α and β Arietis. The Triangulum alignment at Namoratunga, at least, looks to be questionable.

Christian Ethiopia has a tradition of skywatching documented in manuscripts dated back to the Middle Ages. Neugebauer (1979, 1981) found that Ethiopian astronomical knowledge applied almost exclusively in religious contexts. The astronomical chapters of the Ethiopic *Book of Enoch* contain simple arithmetical schemes for the motion of the sun and moon. The origins of this treatment are obscure, but they are more likely to derive from the rudimentary astronomical traditions of Egyptian Judeo-Christian communities than from early Babylonian schemes. Other texts and Easter tables of the Ethiopian Church reflect the computus of Alexandrian Christianity. A thirteenth-century computus of Abu Shaker of Alexandria, for reckoning Easter and other movable feasts, is extant in a number of Ethiopic manuscripts dating from the sixteenth century. Ethiopian chronicles record comets, eclipses, and other astronomical events from the fifteenth century onward.

The folk astronomy of Islamic Somalia appears to be directly influenced by the practices of south Arabia. Nomadic Somali herders know Polaris as *Hhiddigo*, the Prayer Star; by noting its direction after establishing an evening camp, they can orient themselves toward Mecca for their five daily prayers. Somalis have also adopted the 7 day week, and the folk practice of *taawil*, or assigning a good or evil value to each day. The most telling indicator of Arabic influence, however, is the recognition of lunar stations (Arabic: *anwā*'), 28 stars or asterisms, noted for their risings and settings over the year. Although the camel and sheep herding peoples of Somali used the *anwā*' (called *god* in Somali dialects) as a framework for a seasonal calendar, they viewed lunar stations primarily as divinatory signifiers. It is still held by many Somalis that the Moon's passage through the stations releases favorable or unfavorable celestial influence. *Dirir* (Spica) which means "good omen" is the most important station, as it is believed to govern the summer rains. Traditional Somali weather experts judge the quantity of future rain when *Dirir* is in conjunction with the Moon; a majority consider the Moon and *Dirir* rising in conjunction to be an auspicious sign. However, if the Moon passes north of *Dirir* a drought is expected. A child born on the night of a conjunction is thought to possess *buruud*, the ability to inspire respect among the people. A *Dirir* child will also have good fortune in owning camels and horses. At all events, a considerable body of Somali proverbs, songs and folktales has grown around the import of lunar stations (Galaal, 1992).

Peoples of the East African coast have for centuries engaged in long distance trade with the Middle East and South Asia. The fifteenth-century master seafarer Aḥmad ► ibn Mājid left behind an Arabic memoir on Indian Ocean navigation techniques which relied heavily on stellar observation. He noted that navigators of Mombasa, Sofala, and Madagascar sailed by the stars of Ursa Major, which they called *al-Hīrāb* (Tibbetts, 1981). Swahili manuscripts at the University of Dar es Salaam also attest to celestial navigation on the part of East Africans. The Arabic element was considerable nonetheless: a majority of the 105 Swahili star names collected by Knappert (1993) are derived from Arabic, and Kiswahili lunar station vocabulary preserves the Arabic terminology essentially unaltered. Moreover, the adoption of Islam by Swahili-speaking peoples brought with it the Islamic lunar calendar and the practice of orienting mosques in the direction of Mecca. Nonetheless, the Swahili lived in an environment of parallel time-reckoning systems. The indigenous Bantu tradition of the Pleiades or *Kilimia* remained distinct from the *anwā*' system and continued to be used for the regulation of agricultural work. In Swahili the Pleiades are *Kilimia*, the Ploughing Stars. Referring to the *vuli* and *masika* monsoon periods, and their respective planting seasons, a proverb runs: "If the Ploughing Stars set in sunny weather they rise in rain, if they set in rain they rise in sunny weather." As viewed in the evenings from equatorial Africa the Pleiades disappear in the Sun's glare, they "set" about early May, reemerging in the morning sky just as June's *vuli* rains begin. Observed in the predawn sky *Kilimia* are seen to set at the end of the *masika* rains in November; when they are glimpsed rising in the evening twilight they herald a dry or "sunny" period. Alongside the Islamic lunar calendar Swahili-speaking peoples kept a 365-day year subdivided into 36 and a half "decades" of 10 days each. This solar year, which begins with the *Nairuzi* festival, appears to be of Persian origin (Gray, 1955).

On the island of Madagascar the highly syncretic *Mpandandro* astrological system appears



Astronomy in Sub-Saharan Africa, Fig. 3 Plan of a Malagasy house indicating directional associations with 12 months and 28 lunar stations (Ruud, 1960)

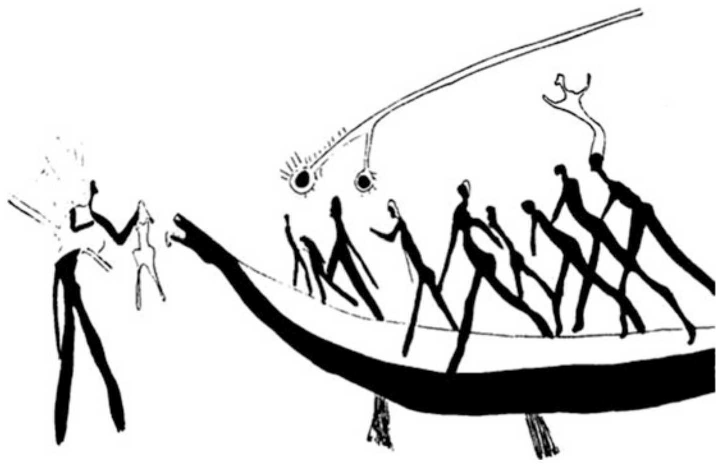
to integrate Arabic and South Asian practices with indigenous culture. Writing in a modified Arabic script, scholars among Antaimoro and Antambahaoka peoples of southeastern Madagascar compile *Sorabe*, or "great books" containing history, medicine, geomancy and astrology. Malagasy astrologers utilize lunar stations and assign favorable/unfavorable values to days within a 7-day week. The temporal scheme is represented spatially in the orientation and lay out of the traditional rectangular house (Verin & Rajaonarimanana, 1991) (Fig. 3).

Central and Southern Africa

The African states centered on Great Zimbabwe and Mapungubwe between the twelfth and fifteenth centuries presumably developed temporal and spatial ideologies involving the sky. Even so, there is no conclusive evidence for intentional astronomical alignments at Great Zimbabwe, despite the recent conjectures of independent archaeologist Richard Wade (Campbell, 2002). Other southern African sites have not been surveyed specifically for their archaeoastronomical potential, but the features of an Iron Age village called Ntsuanatsatsi are very suggestive. Situated a kilometer west of a prominent hill in the grassy highveld of the Orange Free State, South Africa, the stone-walled ruins face eastward. The place name, Ntsuatsatsatsi, attested to as early as the 1830s, means "sunrise" in the Sesotho language. For local Sotho clans the hill is reputed to have been where the first ancestors rose from the earth. In former times, Bafokeng chiefs held their councils on top of the ridge across from the hill. Their ability to gauge the annual motion of the sun by the sunrise locations on Ntsuanatsatsi hill may have contributed to the prominence of these early Sotho leaders (Maggs, 1976).

The ritual initiation of adolescents into full membership of the community is an important aspect of African society. A "morning star," usually identified in the literature as the planet Venus, traditionally had strong associations with male rites of passage in Central and Southern Africa. The Mbunda people looked for an object they called *gongonosi*; the Tsonga of Mozambique used the cognate term *ngongomela* "towering in strength." Victor Turner noted the visibility of such a morning star on the last morning of the Ndembu ceremonies he witnessed; he further recorded that the initiation title of the third boy to be circumcised was *kaselantanda*, "he of the morning star" (Turner, 1967). According to Junod (1927), Tsonga initiation schools were synchronized with the appearance of Venus in the morning sky during a winter month (June–September in the southern hemisphere). One of Junod's informants, the Tsonga elder Shinangana, chronicled a few of the schools in the last half of the nineteenth century: they occurred in 1862, 1873, 1881, 1887, and 1893. Venus was indeed a morning star in the first 3 years, but not in 1887 or 1893, although in the later year Jupiter was located in the morning sky and could have served as *ngongomela*. Hence, it would be rash to assert any correlation between periods of the morning visibility of Venus and the age-sets of Tsonga initiates. In a praise poem which inspired the young Nelson Mandela, Krune Mqayi sang of counting the years of manhood by the rising "Morning Star." For the Xhosa of South Africa this object was unquestionably the Pleiades, the dawn rising of which occurs late in June. It is said that the month of the Pleiades, *Eyesilimela*, symbolized new life; the coming-out ceremony of the *abakwtha* circumcision school was synchronized with the appearance of the star cluster (Snedegar, 1997). The morning star, however imprecise its own identity, was recognized across central and southern Africa as a key identifier of the male child's passage into the daylight of adulthood.

The night figures prominently in the cognitive universe of the Khoisan peoples, who articulate their knowledge in oral traditions which have been transmitted across generations. The evening campfire traditionally served as the venue for sky stories. Appropriately, many San groups recognize a "Fire Finisher" star whose position above the horizon indicates the time on cold winter nights. Fire Finisher is said to rise in the evening and set before dawn, about the time the night's fire has burned to embers. By all accounts, Fire Finisher is a brilliant star which seems to be alone in the sky. Three stars fit the profile and are in fact identified as Fire Finisher by different San groups: Antares (by the Nharo), Arcturus (!Xo), and Regulus (G/wi). Like Fire Finisher, all stars are associated with fire. In the Ju/'huoan dialect the act of stoking a fire, causing sparks to fly into the air, is described with the same words as a shooting star. One of the most famous myths concerns a girl of the "early race" who created the Milky Way by throwing ashes from her campfire into the sky. For many San, however, the Milky Way is the Backbone of the Night. There may be a connection with the moon. A nineteenth-century explanation of the Moon's waning phases claims that the Sun chases the Moon; as it catches up, the Sun slices away pieces of the Moon until nothing remains. But before the Moon is altogether devoured, it says, "Oh Sun! Leave for the children the backbone!" (Bleek & Lloyd, 1911). Sirius is often identified as the Hip Star or Thigh Star. In her fieldwork, Marshall (1986) discovered that the !Kung San see Canopus and Capella as "horns of *tshxum*," an identity, perhaps a magical rain bull, centered on the Pleiades. Predawn observation of *tshxum* and its horns indicated the coming of spring rains.



Astronomy in Sub-Saharan Africa, Fig. 4 San rock painting of bolide-like object near Bethlehem, South Africa (Thackeray, 1988)

In Khoisan mythology human ancestor spirits inhabit the night. They are accompanied by spirits of terrestrial animals including lions, elands, gemboks, hartebeests, steenboks, porcupines, hedgehogs, and giraffes. The starry sky becomes a great canvas for hunting stories, of which ≠Gao N!a, or G≠kao N!a'an, is often the leading man. According to a story collected by Marshall (1986), ≠Gao stood on the Large Magellanic Cloud one evening looking for game to hunt. He spotted three zebras, the three stars in Orion's Belt, and shot an arrow at the middle one. The arrow fell short; it is represented by the stars just south of the zebras. After his unsuccessful shot, ≠Gao decided to send the zebras down to earth for the San to hunt. Nineteenth-century Khoikhoi told a similar tale. Their rendition identified the hunter with the star Aldebaran, spurred on by his wives, the Pleiades. Having failed in his hunt, Aldebaran cannot return to his family, and is fixed in his place in the sky. Another story independently documented by Marshall and Biesele (1996), involves the sons of ≠Gao, !Xuma and Kha//'an, identified with α and γ Crucis, who went out hunting an eland but themselves were pursued and killed by two lions "the keepers of the west," α and β Centauri. ≠Gao suspected the lions. He hid a pair of magic horns in a tree, and invited the lions to dance under its branches. The horns fell onto the celebrating lions, killing them. ≠Gao then resurrected his sons. Celestial players reenact the story on October evenings when the stars of Crux, representing the two boys, set or "die" on the southwestern horizon; they are followed by α and β Centauri, the lions tricked into death. As viewed from San locations in the Kalahari Desert, where Crux is not quite circumpolar, α and γ Crucis rise again later in the night; the boys are visually resurrected.

Meteors have an important place in Khoisan folklore. These "shooting stars" are interpreted in various ways, but they are generally considered to signify creatures having supernatural powers. Some say meteors are antlions falling to earth in search of food; for others they are porcupines or hedgehogs. Hence a porcupine-skin bag is called a star skin, and hedgehog fat is a chief ingredient for amulets worn in curing dances (Traill, 1994). Through dance a shaman enters a trance state in which, it is believed, he is able to traverse the sky as a meteor, obtaining supernatural potency from the ancestors. Such potency is supposed to give him the mastery over disease as well as control of game animals and the spring rains. The meteoric trance experience is very probably illustrated in rock art. Although only a few rock art images suggestive of meteoric trance have been recorded, the territory in which these images have been found stretches from Zambia to Lesotho (Thackeray, 1988). One extraordinary rock painting in South Africa portrays a shamanistic dance; a bolide-like object appears to zoom over the dancers' heads and burst into two fragments (Fig. 4).

See Also

▶ Namoratunga

References

Belmonte, J. A., Esteban, C., Betancort, M. A. P., & Marrero, R. (2002). Archaeoastronomy in the Sahara: The tombs of the Garamantes at Wadi el Agial, Fezzan, Libya. *Archaeoastronomy, 27*, 1–20.

Belmonte, J. A., Esteban, C., Cuesta, L., Betancort, M. A. P., & González, J. J. J. (1999). Pre-Islamic burial monuments in Northern and Saharan Morocco. *Archaeoastronomy, 24*, 21–34.

Biesele, M. (1996). 'He stealthily lightened at his brother-in-law' (and thunder echoes in Bushman oral tradition a century later). In J. Deacon & T. A. Dowson (Eds.), *Voices from the past:/Xam Bushmen and the Bleek and Lloyd collection* (pp. 142–160). Johannesburg, South Africa: Witwatersrand University Press.

Bleek, W. H. I., & Lloyd, L. C. (1911). *Specimens of Bushman folklore*. London: George Allen.

Blier, S. P. (1987). *The anatomy of architecture: Ontology and metaphor in Batammaliba architectural expression*. Cambridge, MA: Cambridge University Press.

Campbell, K. (2002). Archaeo-astronomy of Southern Africa. *Engineering News, 22*(15), 19.

Cosmic Africa. (2003). Dir. Craig Foster and Damon Foster. Perf. Thebe Medupe. Aland Pictures.

Donaint, P. (1975). *Les cadres géographiques à travers les langues du Niger. Contribution a la pédagogie de l'é tude du milieu*. Niamey, Niger: Institut Nigérien de Recherches en Sciences Humaines.

Doyle, L. R., & Wilcox, T. J. (1986). Statistical analysis of Namoratunga: An archaeoastronomical site in sub-Saharan Africa? *Azania, 21*, 125–128.

Drucker-Brown, S. (1984). Calendar and ritual: The Mamprusi case. *Systèmes de Pensée en Afrique Noire, 7*, 57–84.

Galaal, M. H. I. (1992). *Stars, seasons, weather in Somali pastoral tradition*. Niamey, Niger: CELHTO.

Gray, J. (1955). Nairuzi or Siku ya Mwaka. *Tanganyika Notes and Records, 38*, 1–22.

Griaule, M., & Dieterlen, G. (1950). Un Système Soudanais de Sirius. *Journal de la Société des Africanistes, 20*, 273.

Griaule, M., & Dieterlen, G. (1965). *Le Renard Pale*. Paris: Institut d'Ethnologie.

Hiskett, M. (1967). The Arab star-calendar and planetary system in Hausa verse. *Bulletin of the School of Oriental and African Studies, 30*, 158–176.

Hiskett, M. (1975). *A history of Hausa Islamic verse*. London: School of Oriental and African Studies.

Holbrook, J. C. (2004). Astronomy. In P. M. Peek & K. Yankah (Eds.), *African folklore: An encyclopedia* (pp. 11–14). New York: Routledge.

Holbrook, J. C. (2005). Astronomy, African. In H. L. Gates Jr. & K. A. Appiah (Eds.), *Africana: The encyclopedia of the African and African American experience* (2nd ed.). Oxford, UK: Oxford University Press.

Hunwick, J. O. (1997). Towards a history of the Islamic intellectual tradition in West Africa down to the nineteenth century. *Journal for Islamic Studies, 17*, 4–27.

In search of ... the dark star. (1979). Perf. Leonard Nimoy. Alan Lansburg Productions.

Junod, H. A. (1927). *The life of an African tribe*. London: Macmillan.

Kani, A. (1992). Mathematics in the Central Bilad Al-Sudan. In G. Thomas-Emeagwal (Ed.), *The historical development of science and technology in Nigeria* (pp. 33–39). Lewiston, ME: Edwin Mellen Press.

Knappert, J. (1993). Al-Nudjum in East Africa. *The encyclopedia of Islam* (p. 105). Leiden: E.J. Brill.

Library of Congress. (2003). *The ancient manuscripts from the desert libraries of Timbuktu*. Washington, DC: Library of Congress. http://www.loc.gov/exhibits/mali/.

Lynch, B. M., & Robbins, L. H. (1978). Namoratunga: The first archaeoastronomical evidence in sub-Saharan Africa. *Science, 200*, 766.

Maggs, T. M. O. C. (1976). *Iron age communities of the Southern Highveld*. Pietermaritzburg, South Africa: Natal Museum.

Malville, J. M. K., Wendorf, F., Mazar, A. A., & Schild, R. (1998). Megaliths and neolithic astronomy in Southern Egypt. *Nature, 392*, 488–490.

Marshall, L. (1986). Some Bushman star lore. In R. Vossen & K. Keuthmann (Eds.), *Contemporary studies on Khoisan 2* (pp. 169–204). Hamburg, Germany: Helmut Buske Verlag.

Neugebauer, O. (1979). *Ethiopic astronomy and computus*. Vienna: Verlag der Oesterreichischen Akademie der Wissenschaften.

Neugebauer, O. (1981). *The 'astronomical' chapters of the ethiopic book of Enoch (72 to 82)*. Copenhagen, Denmark: Det Kongelige Danske Videnskabernes Selskab.

Ogunbiyi, I. A. (1991–1992). A record of a cometary sighting in a 19th century West African Arabic work by Muḥammad Bello b. 'Uthman b. Fudi (1779–1837). *Journal of Oriental and African Studies* [Athens], 3–4: 94–110.

Rebstock, U. (1990). Arabic mathematical manuscripts in Mauretania. *Bulletin of the School of Oriental and African Studies, 53*(3), 429–441.

Ruud, J. (1960). *Taboo, a study of Malagasy customs and beliefs*. Oslo, Norway: Oslo University Press.

Saad, E. N. (1983). *Social history of Timbuktu: The role of Muslim scholars and notables*. Cambridge, MA: Cambridge University Press.

Snedegar, K. (1997). Ikhwezi is the morning star. *Mercury, 26*(6), 12–15.

Soper, R. (1982). Archaeo-astronomical cushites: Some comments with further comment by Mark Lynch. *Azania, 17*, 145–162.

Tablino, P. (1994). The reckoning of time by the Borana Hayyantu. *Rassagna di Studi Ethiopici, 38*, 191–205.
Temple, R. G. (1975). *The sirius mystery*. London: Sidgwick and Jackson.
Thackeray, J. F. (1988). Comets, meteors and trance: Were these conceptually associated in Southern African pre-history? *Monthly Notes of the Astronomical Society of Southern Africa, 47*, 49–52.
Tibbetts, G. R. (1981). *Arab navigation in the Indian ocean before the coming of the Portuguese*. London: Royal Asiatic Society.
Traill, A. (1994). *A !Xoo dictionary*. Koln, Germany: Ruediger Koeppe Verlag.
Turner, V. (1967). *The forest of symbols: Aspects of Ndembu ritual*. Ithaca, NY: Cornell University Press.
Turton, D., & Ruggles, C. (1978). Agreeing to disagree: The measurement of duration in a southwestern ethiopian community. *Current Anthropology, 19*(3), 585–593.
Ullmann, M. (1972). *Die Natur- und Geheimwissenschaften im Islam*. Leiden, Netherlands: Brill.
Van Beek, W. E. A. (1991). Dogon restudied: A field evaluation of the work of Marcel Griaule. *Current Anthropology, 32*(2), 139–167.
Verin, P., & Rajaonarimanana, N. (1991). Divination in Madagascar: The antemoro case and the diffusion of divination. In P. M. Peek (Ed.), *African divination systems: Ways of knowing* (pp. 53–68). Bloomington, IN: Indiana University Press.
Wendorf, F., & Schild, R. (2001). *Holocene settlement of the Egyptian Sahara* (The Archaeology of Nabta Playa, Vol. 1). Dordrecht, Netherlands: Kluwer Academic Publishers.

Astronomy in the Argentinian Chaco

Sixto R. Giménez Benítez[1], Alejandro M. López[2,3] and Cecilia P. Gómez[2]
[1]Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, La Plata, Argentina
[2]Facultad de Filosofía y Letras, Universidad de Buenos Aires, Buenos Aires, Argentina
[3]Consejo Nacional de Investigaciones Científicas y Técnicas, Facultad de Filosofía y Letras, Universidad de Buenos Aires, Buenos Aires, Argentina

The Chaco Region

The Great Chaco region is located in central South America. It partially covers the south of Bolivia, Paraguay, and northwest Argentina. The Argentinean portion of this region includes the provinces of Chaco and Formosa, the oriental portion of the provinces of Salta and Santiago del Estero, and the north portion of Santa Fe.

The Argentinean Chaco was inhabited by various aboriginal groups and a complex non-aboriginal population. Before the arrival of the Spaniards, the social organization of the Argentinean Chaco aboriginal groups was based on small bands. Originally most of them were hunters and gatherers. The three most prominent linguistic groups were and still are the Guaycurú, Mataco-Mataguayo, and Guaraní.

These aboriginal people underwent several changes during colonial times and had complex relationships with the colonial society. Despite the fact that they were politically independent from the colonial government, many types of exchanges between these aboriginal groups and the Creole and European population existed from trade to military conflicts.

Between the eighteenth and nineteenth centuries, numerous religious actors arrived in the area, like the Jesuits and later on the Protestant missionaries. These presences played a key role in new Indian resignifications of Christian practices and cosmologies (López, 2014a, b).

Nowadays, a population of around 133,000 original people survive by working as rural laborers and by developing a variable amount of hunting and gathering (*INDEC. Encuesta Complementaria de Pueblos Indígenas* (*ECPI*) *2004–2005*).

Specific Groups

We will focus on two specific aboriginal groups in the region to exemplify some of the main characteristics concerning their conceptions of the sky. In the examples selected we analyze notions that are key to a large variety of Chaco groups, which indicates the relevance of exchanges in South American cosmologies, both in pre- and post-Columbian times (López, 2014a, b).

Toba of Western Formosa

The Toba (Guaycurú linguistic group) who settle in the west of the province of Formosa (Argentina) specifically reside in the Bermejo Department. Both among the Toba and other Chaco groups, the celestial sphere is mythically related to the female domain. The mythical origin of women is the sky, from which they descended. Stars are also considered to be female beings. Hence, there are well-defined links between the sky and the female world. An example of this is the relationship established with the moon. In the narrative level Moon is a masculine entity which conducts the mythological conformation of the Toba woman. Rafael Karsten's 1912 ethnography of the Bolivian Toba also suggests that they thought that menstruation was caused or influenced by the moon (Karsten, 1923, p. 26). The myth about sexual relationships between the moon and women who have had their first period can still be heard among the Toba. The moon is still thought of as a masculine entity which is responsible for the mythological conformation of Toba women. In the words of a Toba, "Moon is the first man of every woman." When their first period appears, mothers still say to their young daughters that the "Moon is to blame." Therefore, in this context mothers utter things such as "It is as if the moon had raped my daughter." As we have already said, according to Toba oral tradition, the moon is responsible for the mythical formation of femininity. Thus, the moon plays the role of the primordial hero "the fox," who let the primeval men in mythical times have sexual intercourse with women who had just descended from their celestial abode. Indeed, as the moon had his first sexual intercourse with the girls and thus helped them get married, the fox had his first sexual intercourse with the celestial women and helped them have their teeth removed from the vaginas and thus become the wives of men. Likewise, the lunar imaginary is used to measure diverse temporal cycles. The Toba explanation about the moon refers to a group of organic ideas which evoke youth, maturity, and death of a living agent (Gómez, 2014b).

Among the Toba of Western Formosa, political leadership is associated with the asterism known as *Dapi´chi*, which is represented by the Pleiades. This asterism controls cold in general. Its appearance also announces the arrival of a new bountiful period starting around December, when the bush abounds in algarroba, and they say that the asterism seems to "vanish" from the sky. According to the evidence gathered, *Dapi´chi* is "a very important man" wearing a red crown that can only be noticed when he first becomes visible, that is, when coming up in the east before dawn, in winter, during his heliacal rising. Just like the Toba leader, *Dapi´chi* is the "leader" because he knows all those under his control: the other stars. *Dapi´chi* is also reinterpreted concurrently with the changes in the blurred political leadership figures among the western Toba Indians (Gómez, 2014a; 2011). On the other hand, this asterism has been critical in accounting for the beginning of a new annual cycle.

Mocoví

The Moqoit or Mocoví belong to the Guaycurú linguistic group. They inhabit the southern area of the Chaco region, in the Argentinean provinces of Chaco and Santa Fe. We will underline two main components of their rich astronomy that are also present in other Chaco groups.

The Milky Way and the *Nayic* as a Conceptual Structure

For the Moqoit, the Milky Way holds many articulated meanings, which are highlighted according to the circumstances or the narrator. A common element throughout these meanings, however, is the structuring role that is played by the Milky Way in Moqoit cosmology (Giménez, López, & Granada, 2002).

Star brightness is related for the Moqoit people to the notion of the brightness of powerful beings. In this sense, the Milky Way and its myriad of stars make up a space seen as extremely powerful. The different positions of the Milky Way are used for finding the way in woodland at night and as a temporal marker. Beyond these, the Milky Way is seen by Moqoit as a path, a tree, and simultaneously a whirlwind that gives structure and maintains the communication between the different levels of the cosmos. But it is not simply a naive picture: tree, whirlwind, and path act as true models to think about key aspects of the fundamental dynamics and structure of reality as the Moqoit people experience it.

The Moqoit word *nayic* means "path," and it is related to the idea of going deep into nonhuman space. One such space is the forest, along which a sequence of markers unfolds, each one commemorating a pact with the ruling powers of the world. The notion of "path" is a general Moqoit conception to organize reality: a tale, the life of a human being, the community memory, and the universe itself. The Milky Way is seen as the path followed by the mythic Rhea, the Mañic, as it flees to the sky haunted by the ancestors of the Moqoit. Stories about these events make up a kind of serial narrative linked to the history of the "hunting of Mañic" and are "strung" by means of the Milky Way. In this sense, the representation of the Milky Way as a "path" structures the Mocoví's oral narrative about stars.

But this path in the sky is also seen as the road of the celestial powerful beings that descends to the Earth and the way in which the *pi'xonaq* or shamans obtain power. The *pi'xonaq*, the specialists of the sacred, have a capacity to see this structure of the universe. Their healing capacity is based on their capacity to travel around the world and build alliances with the entities governing it.

Iron Meteorites, Power, and Colonialism

Given the sediment composition of the Chaco plains, it is very rare to find rocky or metallic objects. The area inhabited by several Moqoit communities is dotted with pieces of this kind related to the sky – iron meteorite fragments making up the strewn field of Campo del Cielo (Giménez Benítez, López, & Granada, 2004). These pieces are seen as manifestations of the celestial presence on Earth. It is believed that, after falling from the sky and getting buried in the ground, meteorites start to come up to the surface and appear to those people they were designed for, bringing them luck, wealth, and health. The contact between humans and meteorites may cause rainfall, and only shamans are capable of manipulating them with no risk. To the Moqoit, the wealth-generating capacity of meteorite fragments is a manifestation of the power they confer as agents of the "powerful" of the sky.

In this context, the Moqoit believe that the inequality, violence, and exploitation they suffer from the non-aboriginal society are ultimately due to the way in which the latter has monopolized access to the cosmic sources of power. For these reasons, through texts (Martínez, 2006) and public actions, Juan Carlos Martínez and other young Moqoit leaders have demonstrated the connection that the Moqoit see between their notions about the cosmos and their land and cultural claims (López, 2011). In doing so they have emphasized the importance of the relationships between humans and powerful nonhuman beings in shaping Moqoit notions of territory and way of life. They used the Campo del Cielo crater field as a symbol of those relationships. The successful Moqoit resistance to the transportation of the largest meteorite found to Germany for the dOCUMENTA13 art exhibition should be understood in this context (López, 2014c).

Conclusions

The notions that the Chaco aboriginal groups have about the sky are not a whimsical set of quaint and naive fantastic stories. On the contrary, they are part of complex considerations about the world and the humans which involve the use of sophisticated metaphors and elaborate ideas of such notions as identity, personhood, body, causality, and power. Thus, structures are used both to organize the sky around the Milky Way and to shape the account of a person's life.

Just like the ideas of any human group about the world, these aboriginal conceptions of the sky are not static but change over time. Furthermore, they are related to the life of the societies that generate them, albeit not necessarily being their reflection. In this sense, the intense relations among the various groups in the region, even if belonging to different linguistic groups, are reflected in the multiple interactions between their astronomies. On the other hand and regarding the groups in question, the sky is strongly tied to abundance and power on Earth, so that all considerations about the sky are regarded as major political issues. As these societies are not hierarchical and many social actors vie for leadership, we are faced with a variety of competing versions of the sky and its inhabitants and of how humans can relate to them.

In the groups analyzed, the process of developing ideas about the sky and the competing interpretations thereof are in full force and are not merely a curious thing of the past. Their views of the celestial sphere play a major role in the current struggle for their cultural, territorial, and health-care rights.

References

Giménez Benítez, S., López, A., & Granada, A. (2004). Suerte, riqueza y poder. Fragmentos meteóricos y la presencia de lo celeste entre los mocovíes del Chaco, Etno y arqueoastronomía en las Américas. Memorias del Simposio ARQ-13: Etno y arqueoastronomía en las Américas, 51 Congreso Internacional de Americanistas, J.B.M. Boccas, E. Pereira, Santiago de Chile.

Giménez, B. S., López, A., & Granada, A. (2002). *Astronomía aborigen del Chaco: Mocovíes I: La noción de nayic (camino) como eje estructurador* (Vol. XXIII). Buenos Aires: Scripta Ethnológica, CAEA.

Gómez, C. (2011) *The Dapi'chi* (Pleiades) youth and old age: frost, air carnations and warriors. *Cambridge Journals 7 International Astronomical Union* Symposium. S278: *Archaeoastronomy and Ethnoastronomy. Building Bridges between Cultures*. C.L.N. Ruggles (Ed.). Cambridge University Press, Cambridge.

Gómez, C. (2014a). The sky among the Toba of western Formosa (Gran Chaco, Argentina). *Handbook of Archaeoastronomy and Ethnoastronomy*. C. Ruggles (Ed.). Heilderberg: Springer Science and Business Media.

Gómez, C. (2014b). Power, danger and liminality: moon, stars and women among the Toba of western Formosa (Gran Chaco, Argentina). Astronomy and Power. How Worlds are Structured. In M. Rappenglück, B. Rappenglück, & N. Campion (Eds.), *International Conference of the Société Européenne pour l'Astronomie dans la Culture*. Oxford: British Archaeological Reports (BAR International).

Karsten, R. (1923). *The Toba Indians of the Gran Chaco*. Helsingfors: Åbo Akademi.

López, A. M. (2011). New words for old skies: Recent forms of cosmological discourse among aboriginal people of the Argentinean Chaco, In C. L. N. Ruggles (Ed.), *Archaeoastronomy and ethnoastronomy: Building bridges between cultures, proceedings of the international astronomical union symposium Nº 278, Oxford IX international symposium on archaeoastronomy* (pp. 74–83). Cambridge: Cambridge University Press.

López, A. M. (2014a). Interactions between 'indigenous´ and 'colonial´ astronomies: Adaptation of indigenous astronomies in the modern world, en el *Handbook of archaeoastronomy and ethnoastronomy* to be published by Springer Science and Business Media.

López, A. M. (2014b). Cultural interpretation of ethnographic evidence relating to astronomy, en el *Handbook of archaeoastronomy and ethnoastronomy* to be published by Springer Science and Business Media.

López, A. M. (2014c). Astronomy in Chaco region, Argentina, en el *Handbook of archaeoastronomy and ethnoastronomy* to be published by Springer Science and Business Media.

Martínez, J. C. (2006). El secreto de la tierra, *Revista La Educación en nuestras manos*, Diciembre (77).

Astronomy in the Indo-Malay Archipelago

Gene Ammarell
Athens, OH, USA

All societies have their own systems of knowledge through which they seek to understand the natural environment and their relationship to it. Thus we may be better able to understand a society by going beyond the categories of Western science and begin to consider the interrelationship of a society with its environment from the viewpoint of the members of that society. It is this attempt to understand how members of a society, themselves, conceive of their environment that has come to be known as ethnoecology (Casiño, 1967). Ethnoastronomy, the subject of this article, may be seen as a branch of ethnoecology wherein the interrelationship of human populations with their celestial environment is the focus of interest.

The modern nation states of Indonesia and Malaysia have a combined population of approximately 260 million and encompass the homelands of well over 500 distinct ethno-linguistic groups whose cultures and languages form part of a common Austronesian heritage, a heritage they share with the majority of the peoples of the Philippines, Polynesia, and Micronesia, among others (In addition, there are at least 100 Papuan languages spoken in the Indonesian province of West Papua on the western half of the island of New Guinea.). Inhabiting mountainsides, river valleys, and coastal plains and faced with a somewhat unpredictable tropical monsoon climate, the peoples of Island Southeast Asia have developed diverse systems of agriculture that include both inundated rice farming and the shifting cultivation of rice and other food crops. Spread across an archipelago of over 17,000 islands (at least 6,000 inhabited), they have also developed sophisticated systems of navigation. These indigenous agricultural and navigational practices have been informed by an astronomical tradition that is, at once, unique to this cultural area and richly diverse in its local variation. This article describes several of the many techniques of astronomical observation that are known to have been employed by the peoples of Indonesia and Malaysia to help regulate their agricultural cycles and navigate their ships.

The Celestial Landscape

The passage of time is mirrored in all of nature: in the light and warmth of day and the dark and coolness of night, in the flowering of plants, in the mating and migratory behavior of animals, in the changes in weather, in the ebb and flood of the tides, and in the recurring cycles within cycles of the sun, moon, planets, and stars as they transit the celestial sphere. Of these cycles, perhaps the most obvious is the diurnal rising and setting of the sun, moon, planets, and stars, as well as the synodic or cyclic changes in the phase of the moon and in the time of day that it rises and sets. More subtle than these might be the annual changes in the sun and stars: the north-south shift in the path of the sun across the sky (including its rising and setting points and its relative distance above the horizon at noon) and the appearance, disappearance, and reappearance of familiar patterns of stars at various times of night. To the trained eye, nature is replete with signs of diurnal and seasonal change. As an integral part of the natural landscape, these recurring celestial phenomena have long provided farmers and sailors worldwide with dependable markers against which operations, agricultural as well as navigational, can be timed.

Likewise, orientation in space and the art of wayfinding have often relied upon knowledge of these same celestial phenomena, the English term "orient," itself, having been derived from the Latin for "rise" and later associated with the East as the direction in which the sun appears at dawn. Although the times that individual stars rise and set shift gradually throughout the year, as viewed from a given latitude, the azimuths at which a star rises and sets varies only slightly over a lifetime, thereby providing a reliable "star compass" by which to determine direction. So, too, the sun, moon, and planets rise and set generally ► east and west, depending upon their individual cycles, affording additional guides by that people are able to orient themselves on the land as well as on the sea.

Agricultural Time Keeping

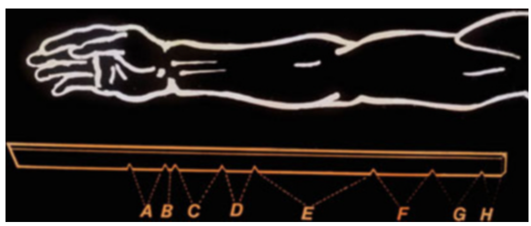
Many traditional, sedentary desert and plains cultures have used the shift in the rising and/or setting points of the sun along the horizon to both mark important dates and seasons and to commemorate the passage of years. Desert and plains environments are conducive to the development and use of these horizon-based solar calendars: a permanent location from which to make sightings, a series of permanent distant horizon markers, either natural or manufactured, and a clear view are all that is needed for such a calendar. England's Stonehenge and Wyoming's Big Horn Medicine Wheel provide striking examples. Such conditions, however, are not common across much insular Southeast Asia. Here the landscape may consist of anything from a nearby or distant mountain to, more often, nearby trees; the horizon is, therefore, a rather undependable device against which to sight and measure the rising and setting positions of the sun. But in cultivated areas of the region, even from swiddens located deep within the rainforest, one can usually find a field or home site from which much of the sky is visible.

There are several types of observations of annually recurring celestial phenomena that can be made where permanent, distant horizon markers are not commonly available. These include cyclic changes in the phases of the moon, the annual changes in the apparitions of familiar groups of stars, and the annual changes in the altitude of the sun at noon. Here I present variations of these types of observations that we know have been practiced among traditional farmers of Indonesia. For the sake of clarity, they are grouped using Western astronomical categories as follows: solar gnomons, apparitions of stars at dawn and dusk, and lunar-solar and sidereal-lunar observations.

Solar Gnomons. Most often seen on sundials in western cultures, a solar gnomon is simply a vertical pole or other similar device that is used to cast a shadow. The altitude of the sun above the horizon varies not only through the day, however, but through the year as well. By measuring the relative length of this shadow each day at local solar noon, one can observe and more or less accurately measure the changing altitude of the sun above the horizon (or, reciprocally, from the zenith) through the year and, thereby, determine the approximate date.

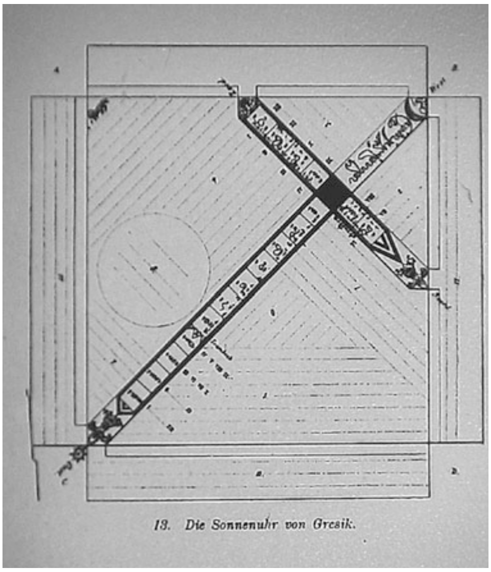
Two distinct types of solar gnomons have been reported in the region. Both measure the altitude of the sun at local solar noon to determine the date. One type has been attributed to various groups of the Kenyah of the Apo Kayan of Kalimantan and may still be in use (Fig. 1).

Astronomy in the Indo-Malay Archipelago, Fig. 1 Kenyah *tukar do* or solar gnomon (From Hose & McDougall, 1912)

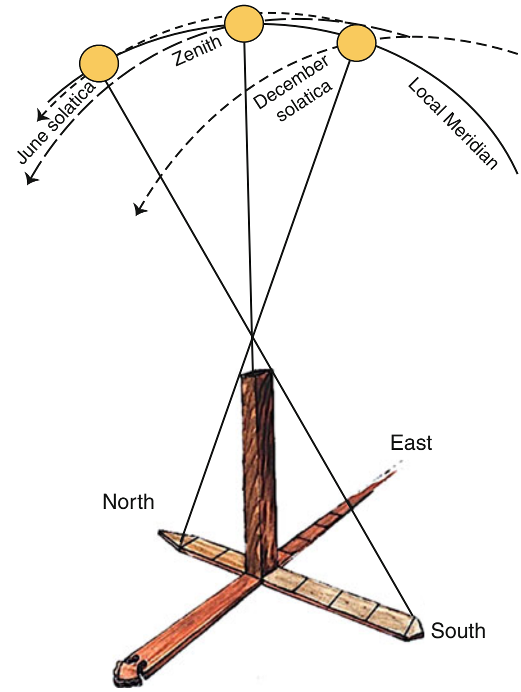


Astronomy in the Indo-Malay Archipelago, Fig. 2 Kenyah *aso do* or base of solar gnomon (Adapted from Hose, 1905)

It consists of a precisely measured (=span of maker's outstretched arms + span from tip of thumb to tip of first finger), permanently secured, plumbed, and decorated vertical hardwood pole (*tukar do*) and a neatly worked, flat measuring stick (*aso do*), marked with two sets of notches (Fig. 2). The first set corresponds to specific parts of the maker's arm and ornaments worn upon it, measured by laying the stick along the radial side of the arm, the butt end against the inside of the armpit.



Astronomy in the Indo-Malay Archipelago, Fig. 3 The base of the *bencet* or solar gnomon showing the grid used to measure the length of the sun's shadow (Maass, 1924)



Astronomy in the Indo-Malay Archipelago, Fig. 4 Javanese *bencet* and the annual motion of the sun (Adapted from Aveni, 1981)

To mark the date, the measuring stick is placed at the base of the vertical pole, butt end against the pole and extending southward. This is done at the time of day that the shadows are shortest, local solar noon. On the day that the pole's noontime shadow is longest (the June solstice), a notch is carved on the other edge of the stick to mark the extent of the shadow made by the pole. This observation indicates that the agricultural season is at hand. From then on, the extent of the noonday shadow is recorded every 3 days as a record-keeping device. Dates, both favorable and unfavorable, for various operations in rice cultivation, such as clearing, burning, and planting, are determined by the length of the shadow relative to the marks on the stick that correspond to parts of the arm and to the marks made every 3 days (Hose, 1905; Hose & McDougall, 1912).

On Java a highly accurate gnomon, called a *bencet*, was in use from about AD 1600 until 1855 (Figs. 3 and 4) (Maass, 1924; see also Ammarell, 1996, 1998; Aveni, 1981; van den Bosch, 1980). A smaller, more portable device than that employed by the Kayan and Kenyah, the *bencet* divides the year into 12 unequal periods, called *mangsa*, two of which begin on the days of the zenith sun, when the sun casts no shadow at local solar noon, and another two of which begin on the two solstices, when the sun casts its longest mid-day shadows.

At the latitude of Central Java, 7° south, a unique condition exists which is reflected in the *bencet*. As the illustration shows, when, on the June solstice, the sun stands on the meridian (that is, at local solar noon) and to the north of the zenith, the shadow length, measured to the south of the base of the vertical pole, is precisely double the length of the shadow, measured to the north, which is cast when the sun, on the December solstice, stands on the meridian (at noon) south of the zenith. By simply halving the shorter segment and quartering the longer, the Javanese produced a calendar with 12 divisions, divisions that are spatially equal but which range in duration from 23 to 43 days. The 12 *mangsa* with their starting dates and numbers of days are shown on Table 1.

Astronomy in the Indo-Malay Archipelago, Table 1 The Pranatamangsa calendar (Adapted from van den Bosch, p. 250)

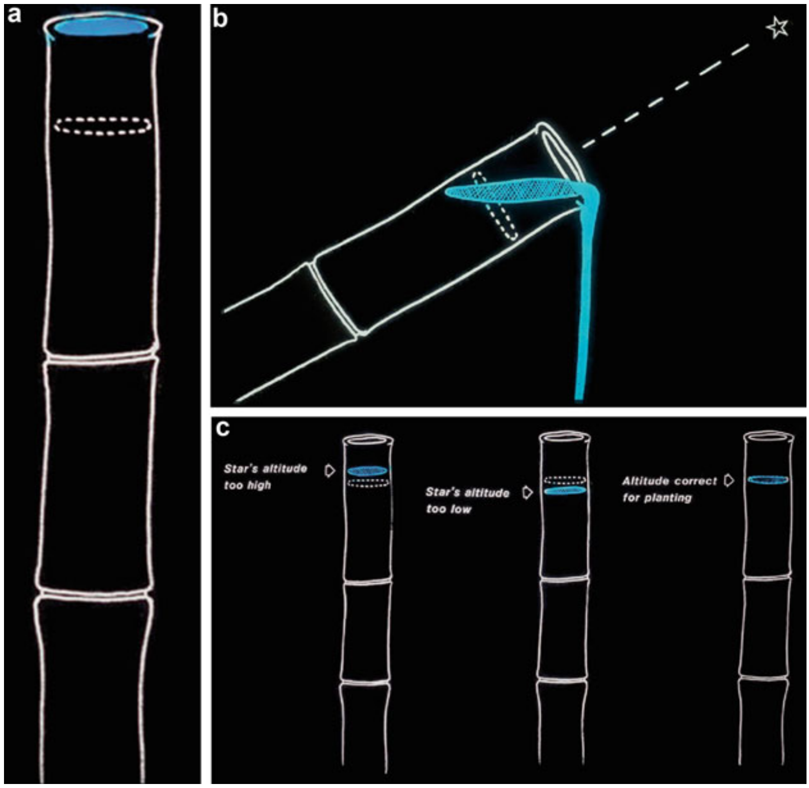
Ordinal number	Name(s) of *mangsa*	Duration (days)	First day(s) civil calendar
Ka – 1	*Kasa*	41	22 (21) June
Ka – 2	*Karo, Kalih*	23	2 (1) August
Ka – 3	*Katelu, Katiga*	24	25 (24) August
Ka – 4	*Kapat, Kasakawan*	25	18 (17) September
Ka – 5	*Kalima, Gangsal*	27	13 (12) October
Ka – 6	*Kanem*	43	9 (8) November
Ka – 7	*Kapitu*	43	22 (21) December
Ka – 8	*Kawolu*	26 (27)	3 (2) February
Ka – 9	*Kasanga*	25	1 March (ult. February)
Ka – 10	*Kasepuluh, Kasadasa*	24	26 (25) March
Ka – 11	*Desta*	23	19 (18) April
Ka – 12	*Sada*	41	12 (11) May

Apparitions of Stars at Dawn and Dusk. The second category of observational techniques regularly employed by traditional farmers of the region include all of those which involve apparitions of commonly recognized stars or groups of stars (which are herein referred to as "asterisms") at last gleam at dawn or first gleam at dusk (I use the term "asterism" to refer to a commonly recognized patterned grouping of stars. While these groupings are often referred to generically as "constellations," I reserve the latter term to refer to the 88 bounded regions of the sky generally accepted by international scientific astronomers, these regions often named for asterisms found within their borders. Note, however, in Western starlore, there may be two or more asterisms within one constellation (e.g., the "Big Dipper" and the "Great Bear" in Ursa Majoris).). Because of the earth's orbital motion about the sun, it can be observed that each star rises and sets approximately 4 min earlier each night. Similarly, each star appears to have moved about 1° west, when viewed at the same time, each night. As a result, around the time of its conjunction with the sun, any given star becomes lost in the sun's glare and is, therefore, not visible for approximately 1 month each year. It also means that the altitudes of stars above the horizon vary as a function of both the time of night and the day of the year, such that a certain star or group of stars, when observed at the same time each night (in this case near dusk or dawn) will appear at a given altitude above the eastern or western horizon on one and only one night of the year. Hence the use of any technique or device to measure the altitude of a star or group of stars as it appears at first or last gleam can provide the observer with the approximate date.

I use the term "acronical" to refer to any stellar apparition that occurs at first gleam while "cosmical" is used to describe stars at last gleam. A subset of these, "heliacal" (Greek *helios*: "sun") apparitions of stars are those that occur just prior to and shortly after conjunction with the sun. The heliacal setting of a star or group of stars occurs on the date that the star or stars are last observed before conjunction, just above the western horizon at dusk. Likewise, the heliacal rising of a star or group of stars occurs on the date that the star or stars are first observed above the eastern horizon at dawn after several weeks' absence.

Just about 3 months after its heliacal rising, the star, now about 90° west of the sun, appears on the meridian at first gleam, an event that may be termed a "cosmical culmination" of the star. Two months later, the star is nearing opposition with the sun and undergoes an "acronical rising" in the east at first gleam. In less than 1 month, after opposition, the "cosmical setting" of the star is seen in the western sky. After 2 more months the star may be seen on the meridian at first gleam, accomplishing its "acronical culmination." Finally, about 3 months later, the star undergoes "heliacal setting" as the sun once again outshines it.

I would like to emphasize that these categories are taken from what is often referred to as the "exact science" of Western mathematical astronomy and are used here as a way of organizing and presenting this material to the Western scholar. The reader is cautioned that the actual observations made by indigenous farmers may not always be as precise as their assigned astronomical categories might imply. The demand for such



Astronomy in the Indo-Malay Archipelago, Fig. 5 Bamboo device used by Kenyah-Kayan to measure the altitude of a star (Adapted from Hose & McDougall, 1912)

precision varies greatly between and within cultures and with local environmental conditions. Here it would not be unusual to find a local farmer, for example, first noting the heliacal rising of the star cluster known in the West as the Pleiades at dawn several days or more after its mathematically calculated reappearance. Note that for convenience, I refer in this article to stars and asterisms by their accepted international scientific names. Where I know the name of a star or asterism in the indigenous language, I will note it as well.

The apparitions of stars at first and last gleam have been systematically observed by traditional cultures worldwide. From island Southeast Asia there are references in the literature, too numerous to describe in detail here, to the calendrical use at both dusk and dawn of the stars known internationally as the Pleiades, Orion and, to a lesser extent, Antares, Scorpius, and Crux (for more Indo-Malay examples, see Ammarell, 1988, 1996; for examples from the Philippines, see Ambrosia, 1996). Culminations at both first and last gleam of the Pleiades, Orion, and Sirius are noted in the literature. Interestingly, the observation for calendrical purposes of such culminations seems to be unique to peoples of this culture area.

A small Dayak group related to the Kenyah-Kayan complex mentioned earlier practiced the first example in this category. Like their neighbors, they were ► swidden rice farmers. But unlike their neighbors who tracked the sun, they depended upon the stars to fix the date of planting. To do so, they nightly poured water into the end of a vertical piece of ► bamboo in which a line had been inscribed at a certain distance from the open end (Fig. 5a). The bamboo pole was then tilted until it pointed toward a certain star (unrecorded) at a certain time of night (also unrecorded), causing some of the water to pour out (Fig. 5b). It was then made vertical again and the level of the remaining water noted (Fig. 5c). When the level coincided with the mark, it was time to plant (Hose & McDougall, 1912).

Astronomy in the Indo-Malay Archipelago, Fig. 6 Javanese ritual specialist holding rice in open palm at dusk, pointing toward the rising *bintang weluku* "plough stars" (Orionis)

Near Yogyakarta, Central Java, a ritual practitioner was observed raising his hand toward the East in the direction of *bintang weluku* "plough stars" (Orionis) each day at dusk, rice seed in his open palm (Fig. 6). On the night it reached the altitude such that kernels of rice rolled off his palm (angle of repose), it was time to sow seed in the nursery (van den Bosch, 1980). Using a planetarium star projector, the author has determined the date of this event to be about 4 January (Ammarell, 1996).

Lunar Calendars. Lunar calendars comprise the third category. These calendars are based upon the 29.5-day synodic period, usually measured from new moon to new moon and often subdivided by phase. Because there is not an even number of lunar months in a solar year and because agricultural cycles are, after all, tied to the solar year, simple lunar calendars alone are of little use in farming. But when they are somehow pegged to the solar year by reference to the apparent annual changes in the positions of the sun or stars or to other phenomena in nature that regularly recur on an annual basis, a lunar calendar can be of use to the farmer.

Indigenous lunar calendars fall into two general categories: lunar-solar and sidereal-lunar. Examples of the lunar-solar calendar include the Balinese ceremonial calendar, still in use, and the old Javanese *Saka* calendar, used from the eighth to the sixteenth centuries. Both are apparently of a common Hindu origin and are primarily lunar; both employ complex mathematical techniques to provide the intercalary days that periodically synchronize the lunar with the solar year (Covarrubias, 1937; van den Bosch, 1980).

A second type of lunar calendar, best described as sidereal-lunar, uses the apparitions at dusk and dawn of stars and asterisms as well as the appearance of other signs in nature (such as winds, birds and flowers) to determine which month is current. In these cases, it is only important to know which month it is for a few months each year (that is, during the agricultural season), thereby obviating the need for codified schemes for realigning the lunar with the solar/stellar year. Such "short" lunar calendars are found spread throughout the region (see Ammarell, 1988). The Iban calendar provides a good example.

The Iban Calendar

Freeman (1970) describes the Iban as a riverine people practicing shifting agriculture in the vicinity of their longhouses, situated in low hills of Sarawak and West Kalimantan. The stars have played a central role in Iban mythology and agricultural practices. Several Iban stories tell how their knowledge of the stars was handed down to them by their deities and according to one village headman, "If there were no stars we Iban would be lost, not knowing when to plant; we live by the stars" (Freeman, 1970, p. 171). The Iban lunar calendar was annually adjusted to the cosmical apparitions of two groups of stars: the Pleiades and the three stars of Orion's belt.

The first observation was probably the most difficult. It was the reappearance of the Pleiades on the eastern horizon just before dawn after 2 month's absence from the night sky. This heliacal sighting, around 5 June of the civil calendar, informed the observer that the month, taken from new moon to new moon, that is current is, by convention, the fifth lunar month. It is during this month that two members of the longhouse went into the forest to seek favorable omens so that the land selected would yield a good crop. This may have taken from 2 days to a month, but once the omens appeared, they returned to the longhouse and work clearing the forest began. If it took so long for the omens to appear that Orion's belt rose before daybreak (heliacal rising around 25 June), the people had to "make every effort to regain lost time or the crop will be poor" (Freeman, 1970, p. 171). This reappearance of Orion at dawn occurred during the next or sixth lunar month, the time to begin clearing the land.

The remaining observations of the stars were more easily accomplished. They are all cosmical culminations, occurring "overhead" at last gleam, and could be seen to be approaching for several weeks. When the Pleiades underwent its cosmical culmination (3 September) and the stars of Orion's belt were about to do so (26–30 September), it was the eighth month and time to burn and plant. For good yields the burn should have occurred between the time that the two asterisms culminated at first gleam, usually when the two were in balance or equidistant from the meridian (16 September). Rice seed sown after the star Sirius had completed its cosmical culmination (October 15) would not have matured properly. It was okay for planting to carry into the tenth lunar month (October/November), but it had to be completed before the moon was full or the crop would fail. At this point the lunar calendar ended: only months five through ten were numbered and fixed while the remaining months varied according to how quickly the crop matured (e.g., *bulan mantun*, the "weeding month"). The lunar months from November to April were simply not numbered; it was difficult to see the stars during the rainy season and unimportant in any case.

Celestial Navigation

As we have just seen, the rice farmers of Indonesia have long noted correlations between celestial and terrestrial cycles and incorporated periodic changes in the sky into their agricultural calendars. Meanwhile, neighboring seafaring societies have used many of these same phenomena to orient themselves in both space and time for the purpose of navigation. Of these societies, the Bugis of South Sulawesi are perhaps the best known. Maintaining a tradition of seafaring and trade that spans at least four centuries, the Bugis are reputed to have established and periodically dominated strategic trade routes across Southeast Asia, stretching northeast from North Sumatra to Cambodia, north to Sulu and Ternate, and east to Aru and Timor. Their maritime prowess notwithstanding, Bugis systems of navigational knowledge and practice have only recently come under study (Ammarell, 1995, 1999).

Bugis navigators still employ a system of dead reckoning that depends upon the knowledge of a variety of features of the natural environment to negotiate the seas in their tall ships. Although these features include land forms, sea marks, currents, tides, wave patterns and shapes, and the habits of birds and fish, navigators rely most heavily upon the prevailing wind directions, guide stars, waves, swells, and, increasingly, the magnetic compass.

Winds and Directions. The major wind patterns across island Southeast Asia are governed by the monsoons. In the Java and Flores Seas, from approximately May through October, winds from the east and southeast bring generally fair weather and steady breezes; from November through April, the west monsoon brings first calm air, then rain and squalls to the region.

For the Bugis as well as a number of other regional ethnic groups whose languages share a common Austronesian heritage, these winds are of such fundamental importance that their names are synonymous with the local prevailing wind directions. Thus for the Bugis, both the monsoons and their prevailing directions in the vicinity of their homeland of South Sulawesi are: *bare*' "west" and *timo*' "east." (For an exceptionally thorough historical and comparative discussion of concepts of orientation is several South Sulawesian languages, see Liebner (2005).)

For the Bugis of the small coral islet of Balobaloang, located midway between Makassar on Sulawesi and Bima on Sumbawa, trade routes are generally north and south across the Flores Sea. In principle, this allows them to take advantage of both easterly and westerly winds by reaching in either direction, although storms and heavy seas usually confined them, in the past, to port during the west monsoon. Formerly voyages were undertaken during the west monsoon only if the captain was hard pressed financially. Now, with motorization and larger ships, the voyaging season has been increasingly extended such that confinement to port is restricted to brief periods of severe weather, usually lasting no more than a week or two at a time.

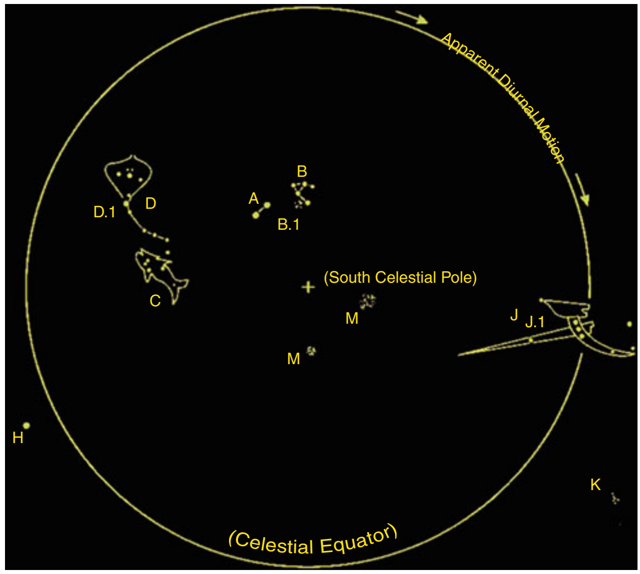
Stars and Asterisms. Bugis navigators have long relied upon the stars and star patterns to set and maintain course. Although most sailors seem to know a few star patterns and their use, the navigators have been found to know many more. These star patterns, or asterisms, are known to rise, stand, and/or set above certain islands or ports when viewed from others and thereby pinpoint the direction of one's destination forming a "star compass." For example, in late July and early August *bintoéng balué* "Alpha&Beta Centauri" (Asterism A, Fig. 7) is known to make its nightly appearance at dusk in the direction of Bima as viewed from Balobaloang, that is, to the south.

As the night passes and a given asterism is no longer positioned over the point of destination, the navigator's thorough Gestalt-like familiarity with the sky allows him mentally to adjust to the new conditions: he can derive through visualization the points on the horizon at which the stars rise or set relative to wherever they currently appear. When a certain asterism simply is not visible, other associated but unnamed stars may be used to remind the navigator where the original asterism set or is about to rise or they may be used instead of the missing asterism. This, by the way, appears to be analogous to the "star path, the succession of rising or setting guiding stars down which one steers" described by Lewis for several cultures in Polynesia and Micronesia (1972, pp. 46–47). The stars identified by Bugis navigators are listed in Table 2 and illustrated in Figs. 7 and 8; those which are most relied upon will now be described.

Perhaps the most frequently used asterism among the Bugis of Balobaloang is that *bintoé ng balué*, mentioned above. These two bright stars are used to locate Balobaloang from Makassar and Bima from Makassar or Balobaloang. With regard to their rise/set points, navigators observe that they appear "in the south" at dusk during toward the middle of the east monsoon, the peak period for sailing; they further note that they rise "southeast" and set "southwest." Their brightness makes them visible even through clouds. The name *balué* is derived from *balu* that means "widow from death of the betrothed before marriage" with the affix *é* forming the definite article. Hence: "the one widowed before marriage." No graphical figure is attributed to this asterism.

Just to the west of "Alpha&Beta Centauri" is *bintoéng bolaképpang* (Crux), visualized as an "incomplete house of which one post is shorter than the other and, therefore, appears to be limping" (B in Fig. 7). Crux is used in conjunction with Alpha and Beta Centauri to navigate along southerly routes; like Alpha and Beta Centauri, it is known to set "southwest." Interestingly, it was emphasized that Crux is also used to help in predicting the weather. This asterism is located in the Milky Way that is known to the Bugis as *bintoéng nagaé* "the dragon," whose head is in the south and whose tail wraps all around the sky. As such, a bright haze of starlight surrounds Crux. On the eastern side of the house, however, there is a small dark patch totally devoid of light which is seen as a *bembé*' 'goat'

Astronomy in the Indo-Malay Archipelago, Fig. 7 Bugis navigational stars: southern sky

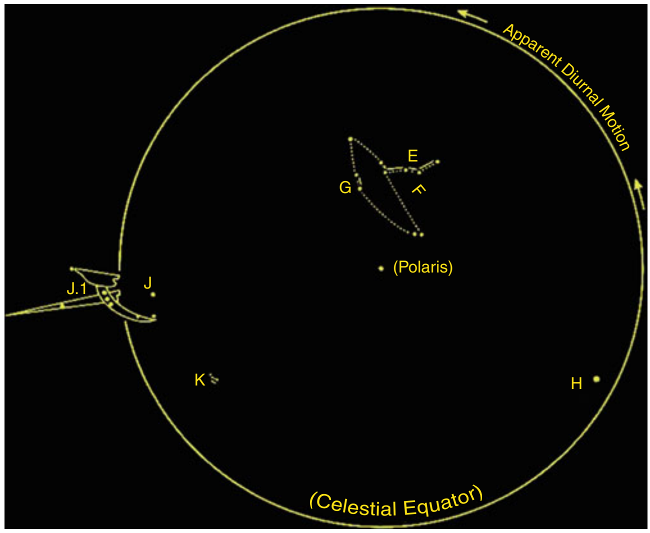


Astronomy in the Indo-Malay Archipelago, Table 2 Bugis stars and asterisms familiar to navigators

Asterism	Bugis name[a]	English gloss	International designation
A	*bintoéng balué*	Widow-before-marriage	Alpha and Beta Centauri
B	*bintoéng bola képpang*	Incomplete house	Alpha-Delta, Mu Crucis
B.1	*bembé*’	Goat	Coal Sack Nebula in Crux
C	*bintoéng balé mangngiweng*	Shark	Scorpius (south)
D	*bintoéng lambarué*	Ray fish, skate	Scorpius (north)
D.1	(Identified w/o name)	Lost Pleiad	Alpha Scorpii (Antares)
E	*bintoéng kappala’é*	Ship	Alpha-Eta Ursa Majoris
F	*bintoéng kappala’é*	Ship	Alpha-Eta Ursa Majoris; Beta, Gamma Ursa Minoris
G	*bintoéng balu Mandara*’	Mandar widow	Alpha, Beta Ursa Majoris
H	*bintoéng timo*’ or *bintoéng timoro*’ (Mak)[b]	Eastern star	Alpha Aquilae (Altair)
J	*pajjékoé* (Mak.)[b] or *bintoéng rakkalaé*	Plough stars	Alpha-Eta Orionis
J.1	*tanra tellué*	Sign of three	Delta, Epsilon, Zeta Orionis
K	*worong-porongngé bintoéng pitu*	Cluster seven stars	M45 in Taurus (Pleiades)
M	*tanra Bajoé*	Sign of the Bajau	Large and small magellanic clouds
[]	*wari-warié*	(No gloss)	Venus: morning
[]	*bintoéng bawi*	Pig star	Venus: evening
[]	*bintoéng nagaé*	Dragon stars	Milky way

[a]The Bugis term for “star(s)” is *bintoéng*; the suffix *é* may be translated as the definite article “the” in English
[b]Although *timoro*’ and *pajjékoé* are Makassar terms, they are more commonly used that the Bugis terms on Balobaloang

(B.1 in Fig. 7). Between the squall clouds of the rainy season the goat in the sky may be seen standing, as goats are wont to do, outside the house trying to get in out of the rain. There are nights, however, when the goat is gone from the protection of the house. Hidden by haze, the missing goat portends a period of calm air and little rain.



Astronomy in the Indo-Malay Archipelago, Fig. 8 Bugis navigational stars: northern sky

In the northern sky the asterism that figures most prominently in Bugis navigation is known as *bintoéng kappala'é*, "the ship stars" in the international constellation of Ursa Majoris (two versions, E and F, in Fig. 8). The "ship" is used when traveling north and is known to rise "northeast" and sets "northwest" over Kalimantan from the port city of Makassar and from Balobaloang. Associations of this group of stars with the hull of a boat or ship appear to be common throughout the region.

The two stars of *balu Mandara*' "widow of the Mandar" (G in Fig. 8) adjoin the "ship" and are likewise used to navigate northward. These two stars, Alpha and Beta Ursa Majoris, remind the Bugis of Alpha and Beta Centauri (thus the name *balu*), while "Mandar" recalls their northern seafaring neighbors.

Several asterisms and a planet are used for sailing ► east and west. They include: *timoro*' (Makassar) or *bintoéng timor*' (Bugis) "eastern star" (Altair; H in Fig. 8); *pajjékoé* (Makassar) or *bintoéng rakkalaé* (Bugis) "the plough stars" (Alpha-Eta Orionis; J in Figs. 7 and 8); *tanra tellué* "the sign of three" (Delta, Epsilon, Zeta Orionis; J.1 in Figs. 7 and 8); *wari-warié* [no gloss] or *bintoéng élé*' "morning star" (Venus in predawn sky); and *bintoéng bawi* "pig star" (Venus in evening sky), so named since it is believed that wild pigs will enter and destroy a garden or orchard when this object shines brightly in the west. Both the "pig star" and the "plough," by the way, speak to an agrarian lifestyle not practiced by Bugis seafarers but culturally shared with their kin who farm the lands of South Sulawesi as well as other islands of the archipelago. See Pelras (1987) for the astronomical knowledge of Bugis rice farmers.

Although the stars are useful guides, they are not always visible. Because it is possible to see landfall during the day, navigators appear to plan their voyages so as to maximize its usage. On a voyage from Balobaloang to Bima, the captain scheduled the departure for mid-afternoon allowing him to back-sight on Balobaloang and other islands of the atoll and observed the sun as it set in the west until dusk when Alpha and Beta Centauri appeared in the sky. There was, in fact, a period of about 30 min where both the receding island and the stars could be seen, providing a good opportunity to maintain course as attention was shifted from land forms to the stars.

Except during the height of the west monsoon, it is uncommon to experience extended periods of totally overcast skies. Should, however, the primary guiding asterism may be concealed by clouds, the navigator depends upon his knowledge of other asterisms or unnamed stars to fix his direction. If it is very cloudy, day or night, the navigator turns to wave directions and the magnetic compass to maintain course.

Although the more experienced navigators say that they could do without it and rely on wind, waves, and stars, the magnetic compass plays a central role in contemporary Bugis navigation and their presence should be of no surprise. Magnetic compasses, Liebner (2005) points out, have been used aboard the larger inter-island ships since the eighteenth century. On frequently sailed routes the helmsman knows from experience or from the navigator's instructions the proper compass bearing which will guide the boat toward its objective. At night under mostly clear skies, the helmsman points the ship's bow toward a succession of guide stars whose own azimuths change as the night passes. To compensate for this change, he checks the compass about once per hour, sometimes after several minutes of calling to a sleepy crew member for a flashlight or match by which to see it. On cloudy nights, when few or no stars are to be seen, the helmsman's job is much harder. Complicated by an often-unsteady helm, the helmsman is forced to check the compass every minute or so with a flashlight whose batteries are soon run down through constant use. By day the compass is generally observed more often regardless of the weather, although the sun, when low in the sky, is used as a reference.

Courses are committed to memory in terms of destinations and their required compass headings under various winds. That is, certain points of the compass are associated with certain destinations from various ports. For example, it is known that to sail from Balobaloang to Bima during the east monsoon, one must head due south, while during the west monsoon one heads south-southwest to southwest, depending on the strength of the wind and current. Likewise, to reach Makassar from the island during the east monsoon one travels somewhat east of north, while during the west monsoon a heading to the north-northwest is preferred. This difference, as navigators are quick to point out, takes into account drift from wind and currents, while true directions are also known. Practiced navigators have many of these bearings committed to memory and will refer to the experience of others as well as to charts and maps when they wish to travel to new or infrequent destinations.

On the author's initial voyage aboard a Bugis ship, the route traveled was well known to the seafarers of Balobaloang: Makassar to Bima via the island, a distance of about 212 nautical miles. Over the course of 4 days and 5 nights at sea without an auxiliary engine – and on later voyages after an engine had been installed – only occasionally were the helmsman or captain seen referring to the compass, and rarely at night or when in sight of land. When asked about this, both agreed that the compass could be used through the night, but to do so one would have to light the flashlight "so why not just use the stars?" Even if the compass were thrown overboard, we were assured the navigator could find his way.

Summary and Conclusion

This article has presented several examples of indigenous Indonesian calendrical and navigational systems and describes the celestial observations upon which they are based. It has also attempted to provide categories, drawn from international scientific astronomy, into which these observations may be placed.

With regard to the study of indigenous astronomical systems worldwide, there appear in regional agricultural calendars two types of celestial observations that may be unique to this cultural region. They are (1) observations of "cosmical" and "acronical" culminations – meridian transits at last and first gleam – of groups of stars and (2) observations of the lunar month for a limited number of months each year, creating discontinuous sidereal-lunar calendars. The use of stars by the Bugis navigators of South Sulawesi likewise appears represent a system that, along with its transformations used by Oceanic mariners, appears to be unique to the Austronesian world.

Implicit in the discussion of agricultural calendrical and navigation systems is the understanding that celestial observations do not stand alone. That is, many other environmental markers – changes in wind and weather and the appearances of flora and fauna also inform agricultural and navigational decision-making. It is suggested that by noting more carefully these and other signs in nature to which members of non-Western societies attend, we may gain a deeper appreciation of the true richness of human knowledge across cultures.

References

Ambrosia, D. (1996). Balátik and Moropóro: Stars of the Philippine sky. *Archaeoastronomy: The Journal of the Center for Archaeoastronomy* 17.

Ammarell, G. (1988). Sky calendars of the Indo-Malay archipelago: Regional diversity/local knowledge. *Indonesia, 45*, 84–104.

Ammarell, G. (1995). Navigation practices of the Bugis of South Sulawesi, Indonesia. In R. Feinberg (Ed.), *Seafaring in the contemporary Pacific Islands* (pp. 196–218). DeKalb, IL: Northern Illinois University Press.

Ammarell, G. (1996). The planetarium and the plough: Interpreting star calendars of java. *Archaeoastronomy: The Journal of the Center for Archaeoastronomy, 12–13*, 320–335 (This special issue of *Archaeoastronomy* is also published as *Songs from the Sky*: *Indigenous Astronomical and Cosmological Traditions of the World*. Ed. Chamberlain, Von Del, John B. Carlson, and M. Jane Young. College Park: Ocarina Books, 2005).

Ammarell, G. (1999). *Bugis navigation* (Monograph Series). New Haven, CT: Yale University of Southeast Asia Studies.

Aveni, A. (1981). Tropical archaeoastronomy. *Science, 213*, 161–171.

Casiño, E. S. (1967). Jama Mapun ethnoecology: Economic and symbolic. *Asian Studies, 5*, 1–3.

Covarrubias, M. (1937). *Island of Bali*. New York: Knopf.

Freeman, J. D. (1970). *Report on the Iban* (London School of Economics Monographs on Social Anthropology, Vol. 41). New York: Humanities Press.

Hose, C. (1905). Various methods of computing time among the races of Borneo. *Journal of the Straits Branch of the Royal Asiatic Society, 42*, 4–5. 209–10.

Hose, C., & McDougall, W. (1912). *The pagan tribes of Borneo*. London: Macmillan.

King, V. T. (1985). *The Maloh of West Kalimantan*. Cinnaminson, NJ: Foris.

Lewis, D. (1972). *We, the navigators*. Honolulu, HI: University of Hawaii Press.

Liebner, H. H. (2005). Indigenous concepts of orientation of south Sulawesian sailors. *Bijdragen to de Taal-, Land- en Volkenkunde, 161*(2/3), 269–317.

Maass, A. (1924). Sternkunde und Sterndeuterei im Malaiischen Archipel. *Tijdschrift Ind. Taal-, Land-, en Volkenkunde, 64*, 1–172. 347–459.

Pelras, C. (1987). Le Ciel et Les Jours. Constellations et Calendriers Agraires Chez Les Bugis (Celebes, Indonesie). *De La Voute Celeste Au Terroir, Du Jardin Au Foyer*. Éditions de l'École des Hautes Études en Sciences Sociales (pp. 19–39).

Soebardi. (1965). Calendrical traditions in Indonesia. *Indonesia Journal of Cultural Studies, 3*(1), 50–51.

van den Bosch, F. (1980). Der Javanische Mangsakalender. *Bijdragen tot de taal-, land- en volkenkinde, 136*, 251–252.

Astronomy in the Islamic World

David A. King
Frankfurt University, Frankfurt am Main, Germany

From the ninth to the fifteenth century, Muslim scholars excelled in every branch of scientific knowledge; their contributions in astronomy and mathematics are particularly impressive. Even though there are an estimated 10,000 Islamic astronomical manuscripts and close to 1,000 Islamic astronomical instruments preserved in libraries and museums, and even if all of them were properly catalogued and indexed, the picture that we could reconstruct of Islamic astronomy, especially for the eighth, ninth, and tenth centuries, would still be quite deficient. Most of the available manuscripts and instruments date from the later period of Islamic astronomy, i.e., from the fifteenth to the nineteenth century, and although some of these are based or modeled on earlier works, many of the early works are extant in unique copies and others have been lost almost without trace; i.e., we know only of their titles. The thirteenth century Syrian scientific biographer Ibn al-Qifṭī relates that the eleventh century Egyptian astronomer Ibn al-Sanbadī heard that the manuscripts in the library in Cairo were being catalogued and so he went to have a look at the works relating to his field. He found 6,500 manuscripts relating to astronomy, mathematics, and philosophy. Not one of these survives amongst the 2,500 scientific manuscripts preserved in Cairo today.

The surviving manuscripts thus constitute but a small fraction of those that were actually copied; nevertheless they preserve a substantial part of the Islamic scientific heritage, certainly enough of it for us to judge its level of sophistication. Only in the past few decades has the scope of the activity and achievements of Muslim scientists become apparent, and the days are long past when they were regarded merely as transmitters of superior ancient knowledge to ignorant but eager Europeans. Islamic astronomy is to be viewed on its own terms. The fact that only a small part of the available material, mainly Greek and Indian material in Arabic garb, was indeed transmitted to Europe is to be viewed as an accident of Islamic history. There is no need to apologize for using the expression “Islamic astronomy.” Within a few decades of the death of the Prophet Muḥammad in the year 632, the Muslims had established a commonwealth stretching from Spain to Central Asia and India. They brought with them their own folk astronomy, which was then mingled with local traditions, and they discovered the mathematical traditions of the Indians, Persians, and Greeks, which they mastered and adapted to their needs. Early Islamic astronomy was thus a pot-pourri of pre-Islamic Arabian starlore and Indian, Persian, and Hellenistic astronomy, but by the tenth century Islamic astronomy had acquired very distinctive characteristics of its own. Sabra (1987) labels this process “appropriation and naturalization.”

Astronomy flourished in Islamic society on two different levels: folk astronomy, devoid of theory and based solely on what one could see in the sky, and mathematical astronomy, involving systematic observations and mathematical calculations and predictions. Folk astronomy was favored by the scholars of the sacred law (*fuqahāʾ*), not least because of various religious obligations that demanded a basic knowledge of the subject; these legal scholars generally had no time (or need) for mathematical astronomy. That discipline was fostered by a select group of scholars, most of whose activities and pronouncements were, except in the case of astrological predictions, of little interest to society at large.

The astronomers also played their part in applying their discipline to certain aspects of Islamic religious practice. It was not Islam that encouraged the development of astronomy but the richness of Islamic society, a highly literate, tolerant, multiracial society with a predominant cultural language, Arabic: but neither did Islam, the religion, stand in the way of scientific progress. The Prophet had said: “Seek knowledge, even as far as China.” To be sure, overzealous orthodox rulers occasionally pursued, killed, or otherwise attacked “scientists” or destroyed or burnt their libraries, but these were exceptions. The scholars of the religious law, who saw themselves as the representatives of Islam, generally ignored the pronouncements of the scientists, even on matters relating to religious practice. Astronomy was the most important of the Islamic sciences, as we can judge by the volume of the associated textual tradition, but a discussion of it in the broader context of the various branches of knowledge, which has been attempted several times elsewhere, is beyond the scope of this essay.

Arab Starlore

The Arabs of the Arabian peninsula before Islam possessed a simple yet developed astronomical folklore of a practical nature. This involved a knowledge of the risings and settings of the stars, associated in particular with the acronychal settings of groups of stars and simultaneous heliacal risings of others, which marked the beginning of periods called *nawʾ*, plural *anwāʾ*. These *anwāʾ* eventually became associated with the 28 lunar mansions, a concept apparently of Indian origin. A knowledge of the passage of the sun through the 12 signs of the zodiac, associated meteorological and agricultural phenomena, the phases of the moon, as well as simple time-reckoning using shadows by day and the lunar mansions by night, formed the basis of later Islamic folk astronomy.

More than 20 compilations on the pre-Islamic Arabian knowledge of celestial and meteorological phenomena as found in the earliest Arabic sources of folklore, poetry, and literature are known to have been compiled during the first four centuries of Islam. The best known is that of ► Ibn Qutayba, written in Baghdad about the year 860. Almanacs enumerating agricultural, meteorological, and astronomical events of significance to local farmers were also compiled; several examples of these survive from the medieval Islamic period, one such being for Cordoba in the year 961. The Yemen possessed a particularly rich tradition of folk astronomy, and numerous almanacs were compiled there.

Since the sun, moon, and stars are mentioned in the *Qurʾān*, an extensive literature dealing with what may well be labeled Islamic folk cosmology arose. This was inevitably unrelated to the more "scientific" Islamic tradition based first on Indian sources and then predominantly on Greek ones. Since it is also stated in the *Qurʾān* that man should use these celestial bodies to guide him, the scholars of the religious law occupied themselves with folk astronomy.

Persian and Indian Sources

The earliest astronomical texts in Arabic seem to have been written in Sind and Afghanistan, areas already conquered by the Muslims in the seventh century. Our knowledge of these early works is based entirely on citations from them in later works. They consisted of texts and tables and were labeled ► zīj after a Persian word meaning "cord" or "thread" and by extension "the warp of a fabric," which the tables vaguely resemble. The Sasanian *Shahriyārān Zīj* in the version of Yazdigird III was translated from Pahlavi into Arabic as the *Shāh Zīj*, and the astronomers of al-Manṣūr chose an auspicious moment to find his new capital Baghdad using probably an earlier Pahlavi version of this *zīj*. The various horoscopes computed by Māshāʾallāh (Baghdad, ca. 800) in his astrological world history are based on it.

Significant for the subsequent influence of Indian astronomy in the Islamic tradition was the arrival of an embassy sent to the court of the Caliph al-Manṣūr from Sind ca. 772. This embassy included an Indian well versed in astronomy and bearing a Sanskrit astronomical text apparently entitled the *Māhasiddhānta* and based partly on the *Brāhmasphuṭasiddhānta*. The Caliph ordered al-Fazārī to translate this text into Arabic with the help of the Indian. The resulting *Zīj al-Sindhind al-kabīr* was the basis of a series of *zījes* by such astronomers as al-Fazārī, ► Yaʿqūb ibn ṭāriq, ► al-Khwārizmī, and others, all prepared in Iraq before the end of the tenth century. The *Sindhind* tradition flourished in Andalusia, mainly through the influence there of the *Zīj* of al-Khwārizmī (see below). As a result, the influence of Indian astronomy is attested from Morocco to England in the late Middle Ages.

Greek Sources

The *Almagest* of Ptolemy (Alexandria, ca. 125) was translated at least five times in the late eighth and ninth centuries. The first was a translation into Syriac and the others were into Arabic, the first two under ► al-Maʾmūn in the middle of the first half of the ninth century, and the other two (the second being an improvement of the first) towards the end of that century. All of these were still available in the twelfth century, when they were used by Ibn al-ṣalāḥ for his critique of Ptolemy's star catalogue. The translations gave rise to a series of commentaries on the whole text or parts of it, many of them critical, and one, by Ibn al-Haytham (ca. 1025), actually entitled *al-Shukūk fī Baṭlamiyūs* (Doubts about Ptolemy). The most commonly used version in the later period was the recension of the late ninth century version by the polymath ► Naṣīr al-Dīn al-Ṭūsī in the mid-thirteenth century. Various other works by Ptolemy, notably the *Planetary Hypotheses* and the *Planisphaerium*, and other Greek works, including the short treatises by Autolycos, Aristarchos, Hypsicles, and Theodosios, and works on the construction known as the analemma for reducing problems in three dimensions to a plane, were also translated into Arabic; most of these too were later edited by al-Ṭūsī. In this way Greek planetary models, uranometry, and mathematical methods came to the attention of the Muslims. Their redactions of the *Almagest* not only reformulated and paraphrased its contents, but also corrected, completed, criticized, and brought the contents up to date both theoretically and practically.

Theoretical Astronomy

The geometrical structure of the universe conceived by Muslim astronomers of the early Islamic period (ca. 800–1050) is more or less that expounded in Ptolemy's *Almagest*, with the system of eight spheres being regarded essentially as mathematical models. However, in Ptolemy's *Planetary Hypotheses* these models are already taken as representing physical reality; this text also became available in Arabic. Several early Muslim scholars wrote on the sizes and relative distances of the planets, and one who proposed a physical model for the universe was Ibn al-Haytham (fl. Cairo, ca. 1025). In order to separate the two motions of the eighth sphere, the motion of the fixed stars due to the precession of the equinoxes, and the motion of the fixed stars due to the apparent daily rotation, he proposed a ninth sphere to impress the apparent daily rotation on the others.

Of considerable historical interest are various Arabic treatises on the notion of the trepidation of the equinoxes. This theory, developed from Greek sources, found followers who believed that it corresponded better to the observed phenomena than a simple theory of uniform precession. The mathematical models proposed were complex and have only recently been studied properly (notably those of Pseudo-Thābit (date unknown) and ► Ibn al-Zarqāllu (Andalusia, ca. 1070), who seems to have relied on his predecessor Ṣāʿid al-Andalusī). The theory of trepidation continued to occupy certain Muslim scholars (in the late period mainly in the Maghrib), as it did European scholars well into the Renaissance.

Other significant Islamic modifications to Ptolemaic planetary models, devised to overcome the philosophical objections to the notion of an equant and the problem of the variation in lunar distance inherent in Ptolemy's lunar model, belong to the later period of Islamic astronomy. There were two main schools, one of which reached its fullest expression in Maragha in northwestern Iran in the thirteenth century (notably with al-Ṭūsī and his colleagues) and Damascus in the fourteenth (with Ibn al-Shāṭir), and the other developed in Andalusia in the late twelfth century (with al-Biṭrūjī). The latter tradition was doomed from the outset by a slavish adherence to (false) Aristotelian tenets and by mathematical incompetence. The former was based on sophisticated modifications to Ptolemy's models, partly inspired by new observations; Ptolemy himself would have been impressed by it, as have been modern investigators, for the tradition has been rediscovered and studied only in the latter half of this century. In the 1950s Kennedy discovered that the solar, lunar, and planetary models proposed by Ibn al-Shāṭir in his book *Nihāyat al-suʾl* (the Final Quest Concerning the Rectification of Principles) were different from those of Ptolemy; indeed they were mathematically identical to those of Copernicus some 150 years later. In this work Ibn al-Shāṭir laid down the details of what he considered to be a true theoretical formulation of a set of planetary models describing planetary motions, and actually intended as alternatives to the Ptolemaic models. He maintained the geocentric system, whereas Copernicus proposed a hypothesis, which he was unable to prove, that the sun was at the center of things. Nevertheless this important discovery raised the interesting question of whether Copernicus might have known of the works of the Damascene astronomer. Since the 1950s we have progressed to a new stage of inquiry: we now know that there was a succession of Muslim astronomers from the eleventh to the sixteenth century who concerned themselves with models different from those of Ptolemy, all designed to overcome what were seen as flaws in them. The question we may now ask is: was Copernicus influenced by any of these Muslim works? The answer is unsatisfactory, namely, that he must have been; definitive proof is, however, still lacking.

Mathematical Astronomy: The Tradition of the *Zījes*

The Islamic *zījes* constitute an important category of astronomical literature for the historian of science, by virtue of the diversity of the topics dealt with, and the information that can be obtained from the tables. Kennedy (1956) published a survey of about 125 Islamic *zījes*. We now know of close to 200, and material is available for a revised version of Kennedy's ► zīj survey. To be sure, many of these works are lost, and many of the extant ones are derived from other *zījes* by modification, borrowing, or outright plagiarism. Nevertheless, there are enough *zījes* available in manuscript form to reconstruct a reasonably accurate picture of Muslim activity in this field.

Most *zījes* consist of several hundred pages of text and tables; the treatment of the material presented may vary considerably from one *zīj* to another. The following topics are handled in a typical *zīj*:

1. Chronology
2. Trigonometry
3. Spherical astronomy
4. Solar, lunar, and planetary mean motions
5. Solar, lunar, and planetary equations
6. Lunar and planetary latitudes
7. Planetary stations
8. Parallax
9. Solar and lunar eclipses
10. Lunar and planetary visibility
11. Mathematical geography (lists of cities with geographical coordinates), determination of the direction of Mecca
12. Uranometry (tables of fixed stars with coordinates)
13. Mathematical astrology

As noted above, by the eighth century a number of Arabic *zījes* had been compiled in India and Afghanistan. These earliest examples, based on Indian and Sasanian works, are lost, as are the earliest examples compiled at Baghdad in the eighth century. With the *zījes* compiled in Baghdad and Damascus in the early ninth century under the patronage of the Caliph ► al-Maʾmūn, we are on somewhat firmer ground. These follow either the tradition of Ptolemy's *Almagest* and *Handy Tables* or the Indian tradition. Manuscripts exist of the *Mumtaḥan Zīj* of ► Yaḥyā ibn Abī Manṣūr and the Damascus *Zīj* of Ḥabash, each of which was based on essentially Ptolemaic theory rather than Indian. The *Zīj* of ► al-Khwārizmī, based mainly on the Persian and Indian traditions, has survived only in a Latin translation of an Andalusian recension. Amongst the most important and influential later works of this genre are: the *ṣābīʾ Zīj* of ► al-Battānī of Raqqa, ca. 910; the *ḥākimī Zīj* of Ibn Yūnus, compiled in Cairo at the end of the tenth century; the *zīj* called *al-Qānūn al-Masʿūdī* by al-Bīrunī, compiled in Ghazna about 1025; the *Zīj* of Ibn Isḥāq, compiled in Tunis, ca. 1195; the I *lkhānī Zīj* of ► Naṣīr al-Dīn al-Ṭūsī, prepared in Maragha in northwestern Persia in the mid-thirteenth century; and the *Sulṭānī Zīj* of Ulugh Beg from early fifteenth century Samarqand.

Although the *zījes* are amongst the most important sources for our knowledge of Islamic mathematical astronomy, it is important to observe that they generally contain extensive tables and explanatory text relating to mathematical astrology as well. Islamic astrological texts form an independent corpus of literature, mainly untouched by modern scholarship. Often highly sophisticated mathematical procedures are involved. It should also be pointed out that in spite of the fact that astrology was anathema to Muslim orthodoxy, it has always been (and still is) widely practiced in Islamic society.

All early Islamic astronomical tables have entries written in Arabic alphanumerical notation (*abjad*) and expressed sexagesimally, i.e., to base 60. A number written in letters equivalent to "23 30 17 s" (Ulugh Beg's value for the obliquity) stands for $23 + 30/60 + 17/3{,}600^{\circ}$, i.e., $23^{\circ}30'17''$. In sexagesimal arithmetic, more so than in decimal arithmetic, it is useful to have a multiplication table at hand, and such tables, with 3,600 or even 216,000 entries, were available.

Already in the early ninth century Muslim astronomers had restyled the cumbersome Indian sine function using the Greek base 60 (which the Greeks had used for their even more cumbersome chord function). Likewise the Indian shadow functions, unknown in Greek astronomy, were adopted with different bases (12, 6, $6\frac{1}{2}$, and 7, and also 60, and occasionally 1). Most *zījes* contain tables of the sine and (co)tangent function for each whole, or half, or quarter degree of arc. Entries are generally given to three sexagesimal digits, corresponding roughly to five decimal digits. However, certain Muslim scholars compiled more extensive sets of trigonometric tables that were not included in *zījes*. In the early tenth century al-Samarqandī prepared a set of tables of the tangent function with entries to three sexagesimal digits for each minute of arc. Later in the same century Ibn Yūnus tabulated the sine function to five sexagesimal digits, equivalent to about nine decimal digits, for each minute of arc, also giving the differences for each second. He also tabulated the tangent function for each minute of arc, and the solar declination for each minute of solar longitude. His trigonometric tables were not sufficiently accurate to warrant this number of significant figures, and indeed over four centuries were to elapse before the compilation in Samarqand of the magnificent trigonometric tables in the *Sulṭānī* ► Zīj of Ulugh Beg, which display the values of the sine and tangent to five sexagesimal digits for each minute of argument and are generally accurate in the last digit.

Planetary Tables and Ephemerides

Given the Ptolemaic models and tables of the mean motion and equations of the sun, moon, and planets were available to Muslim astronomers in the *Almagest* and *Handy Tables*, or the corresponding tables based on Indian models that exemplify the *Sindhind* tradition, Muslim astronomers from the ninth to the sixteenth century sought to improve the numerical parameters on which these tables were based. Most of the leading Muslim astronomers of the early period made solar observations and computed new solar equation tables. Ibn Yūnus is the only astronomer from the first four centuries of Islam known to have compiled a new set of lunar equation tables. The majority of Islamic planetary equation tables are Ptolemaic, and where exceptions do occur, such as in the tables of Ibn al-Aʿlam and Ibn Yūnus for Mercury, we find that they are based on a Sasanian parameter rather than on any new observations.

Ptolemy used the same data as Hipparchus for his determination of the solar apogee and hence obtained the same result. The Muslims thus inherited the notion that the solar apogee is fixed with respect to the fixed stars (although the planetary apogees move with the motion of precession), and it is to their credit that their earliest observations established that the solar apogee had moved about 15° since the time of Hipparchus. Most early Muslim astronomers accepted the *Mumtaḥan* value of 1° in 66 Persian years (actually a parameter attested in earlier Persian sources) for both precession and the motion of the apogees. Ibn Yūnus possessed all the necessary data that could be used to demonstrate that the motion of the solar apogee is not the same as the motion due to precession, but he chose to use the same value for both, 1° in $70\frac{1}{4}$ Persian years, which happens to be remarkably close to the actual rate of precession. ► Al-Bīrūnī (Central Asia, ca. 1025) seems to have been the first to distinguish the proper motion of the solar apogee from the motion of precession (this discovery is sometimes erroneously attributed to al-Battānī). It was ► Ibn al-Zarqāllu (Andalusia, ca. 1070) who was the first to assign a numerical value to both motions, although he also subscribed to the theory of trepidation.

All Islamic *zījes* contained tables of mean motions and equations for computing solar, lunar, and planetary positions for a given time. Some of the equation tables are arranged in a form more convenient for the user (so that one simply has to enter the mean motions, and calculations are avoided). Auxiliary tables were sometimes available for generating ephemerides without the tedious computation of daily positions from mean-motion and equation tables. From the ninth to the nineteenth centuries Muslim astronomers compiled ephemerides displaying solar, lunar, and planetary positions of each day of the year, as well as information on the new moons and astrological predictions resulting from the position of the moon relative to the planets. Al-Bīrūnī described in detail how to compile ephemerides in his astronomical and astrological handbook *al-Tafhīm fī ṣināʿat al-tanjīm* (Instruction in the Art of Astrology). Manuscripts of ephemerides had a high rate of attrition since the tables could be dispensed with at the end of the year: the earliest complete extant examples are from fourteenth century Yemen, discovered in Cairo in the 1970s and still unpublished; on the other hand, literally hundreds of ephemerides survive from the late Ottoman period.

Stellar Coordinates and Uranography

Most *zījes* contain lists of stellar coordinates in either the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course) or the equatorial systems, or occasionally in both. A survey of the stellar coordinates in Islamic *zījes* would be a valuable contribution to the history of Islamic astronomy, and could help to determine the extent to which original observations were made by Muslim astronomers. An impressive amount of research on Arabic star names and their later influence in Europe has been conducted in the last few years by Paul Kunitzsch.

In his *ṣuwar al-kawākib* (Book of Constellation Figures) the tenth century Shiraz astronomer ► al-Ṣūfī presented lists of stellar coordinates as well as illustrations of the constellation figures from the Hellenistic tradition and also information on the lunar mansions following the Arab tradition. Later Islamic works on uranography are mostly restricted to Persian and Turkish translations of al-Ṣūfī, although some astrological works also contain illustrations of the constellations that have recently attracted the attention of historians of Islamic art.

Spherical Astronomy and Spherical Trigonometry

Most *zījes* contain, in their introductory text, the solutions of the standard problems of spherical astronomy, such as, to give only one example, the determination of time from solar and stellar altitude. Rarely any explanation given of how the formulae outlined in words in the text were derived. There were two main traditions. In the first, the problems relating to the celestial sphere are reduced to geometric or trigonometric problems on a plane. The construction known as the analemma was a singularly powerful tool for solutions of this kind. In the second, the problems are solved by applications of rules of spherical trigonometry. Both techniques are ultimately of Greek origin, and Muslim scholars made substantial contributions to each.

There is some confusion about these contributions in the modern literature. It has been assumed by modern writers that when a medieval writer used a medieval formula that is mathematically equivalent to the modern formula derived by a specific rule of spherical trigonometry, the medieval scholar must have known the equivalent of the modern rule of spherical trigonometry. In fact, however, the medieval formula may have been derived without using spherical trigonometry at all. The first known Islamic treatise dealing with spherical trigonometry independently of astronomy is by the eleventh century Andalusian Ibn Muʿādh. The contributions to spherical astronomy by scholars such as Thābit ibn Qurra, ► al-Nayrīzī, Abu'l-Wafāʾ al-Būzajānī, ► al-Khujandī, Kūshyār ibn Labbān, ► al-Sijzī, and Abū Naṣr are outlined in the recently rediscovered *Maqālīd fī ʿilm al-hayʾa* (Keys to Astronomy) of ► al-Bīrūnī, also from the eleventh century.

Already in the work of Ḥabash in the mid-ninth century we find a Muslim astronomer at ease with both spherical trigonometrical methods and analemma constructions for solving problems of spherical astronomy. In the *Zījes* of scholars of the caliber of Ibn Yūnus and al-Bīrūnī we find various methods for solving each of the standard problems of medieval spherical astronomy. The auxiliary trigonometric tables compiled by such scholars as Ḥabash, Abū Naṣr (Khwārizm, ca. 1000), and al-Khalīlī (Damascus, ca. 1360) for solving all of the problems of spherical astronomy for any latitude are a remarkable testimony to their mastery of the subject.

Observation Programs and Regional Schools of Astronomy: Al-Maʾmūn's Circle

In the early ninth century the Abbasid Caliph ► al-Maʾmūn patronized observations first in Baghdad and then in Damascus, gathering the best available astronomers to conduct observations of the sun and moon. Some of the results were incorporated into a ► zīj called *al-Mumtaḥan*, "tested," although the details of the activities at the two observation posts are somewhat confusing. The *Mumtaḥan Zīj* was apparently compiled in Baghdad by ► Yaḥyā ibn Abī Manṣūr, but upon his death, according to Ḥabash, the Caliph ordered his colleague Khālid al-Marwarrūdhī to prepare some new instruments and conduct a 1-year program of solar and lunar observations in Damascus in order to compile a new *zīj*. According to Ḥabash this was done, but no such *zīj* is otherwise known to have been prepared before Ḥabash's own *Damascus Zīj*. Also simultaneous observations of a lunar eclipse were conducted at Baghdad and Mecca, and the longitude difference used together with the newly measured latitudes of the two localities to find the *qibla* at Baghdad.

These observations, like later ones, were mainly directed towards determining the local latitude and current value of the obliquity, and towards deriving improved parameters for the Ptolemaic planetary models and more accurate star positions. The armillary sphere, the meridian quadrant, and the parallactic ruler were known to the Muslims from the *Almagest*, and they added new scales and other modifications, often building larger instruments even when smaller ones would have sufficed. Our knowledge of the instruments used by al-Maʾmūn's astronomers is meager. An armillary sphere used by Yaḥyā in Baghdad was said to display markings for each 10 min of arc, but even contemporary astronomers were not impressed by the precision of the results obtained using it. A mural quadrant made of marble with a radius of about 5 m was used in Damascus, as well as a vertical gnomon made of iron standing about 5 m high. Al-Maʾmūn also patronized measurements of the longitude difference between Baghdad and Mecca in order to establish the *qibla* at Baghdad properly, as well as measurements of the length of 1° of terrestrial latitude.

Other Observational Programs

Besides the officially sponsored observations conducted in Baghdad and Damascus in the early ninth century, there are numerous instances of other series of observations conducted in different parts of the Muslim world.

The two brothers called ► Banū Mūsā made observations in their own house in Baghdad and also in nearby Samarra about 30 years after the *Mumtaḥan* observations. They also arranged for simultaneous observations of a lunar eclipse in Samarra and Nishapur in order to determine the difference in longitude between the two cities. In view of their proficiency in mathematics, it is most unfortunate that neither of the two *zījes* compiled by them has survived.

► Al-Battānī carried out observations during the period 887–918 in Raqqa in northern Syria. He appears to have financed his observational activity himself, and although we have no description of the site where he made his observations, the instruments mentioned in the *zīj* based on his observations include an armillary sphere and mural quadrant, as well as a parallactic ruler, an astrolabe, a gnomon, and a horizontal sundial.

The observational activities of the Baghdad family known as the Banū Amājūr were almost contemporaneous with those of al-Battānī in Raqqa. Father and two sons, and also a freed family slave, all made observations and each compiled a ► zīj, none of which survives. In the accounts of their ► eclipse observations recorded by Ibn Yūnus it appears that the place where they conducted their observations had some kind of a balcony fitted with slits for observation, but the details are obscure. A particularly interesting account of a solar eclipse in the year 928 that they observed by reflection in water includes a remark that the altitude of the sun was measured on an instrument marked for each third of a degree.

A large mural quadrant was erected at Rayy (near modern Tehran) about the year 950, but we have information only on its use to establish the local latitude and obliquity of the ecliptic. In Shiraz not long thereafter, ► al-Ṣūfī used an armillary sphere with a diameter of about 5 m to derive the same parameters and to "observe" equinoxes and solstices. Al-Ṣūfī is best known for his work on the fixed stars, but it seems that this was based more on "observation," looking at the heavens with the naked eye, than on "measurement," looking at the heavens with precision instruments and making estimates of positions. Another contemporary astronomer who conducted observations on which we have no information other than the main parameters of his *zīj* was Ibn al-Aʿlam.

In the late tenth century the distinguished mathematician and astronomer Abu'l-Wafāʾ al-Būzajānī made observations in Baghdad. Most of these appear to have been directed towards the determination of the solar parameters, and the obliquity of the ecliptic and the latitude of Baghdad, although Abuʾl-Wafāʾ also collaborated with ► al-Bīrūnī in Khwārizm (modern Khiva in Turkmenistan) on the simultaneous observation of a lunar eclipse in the year 997. We have no information on the nature of the site where Abu'l-Wafāʾ made his observations, other than its location in a specific quarter of Baghdad.

Contemporaneous with the activity of Abu'l-Wafāʾ was the establishment in 988 of an observatory in the garden of the Baghdad residence of the Buwayhid ruler Sharaf al-Dawla. The organization of a building and program of observations was entrusted to Abū Sahl al-Qūhī, a mathematician of considerable standing. We know from contemporary historical records that a special building was erected for the observations, which in turn were witnessed by "judges, scientists and scholars of note, astronomers, and engineers." In view of the favorable conditions under which this observatory was established, and the competence of its director, it is somewhat surprising that the two recorded "observations" that were witnessed by so many dignitaries were the entry of the sun into Cancer and Libra in the year 988. Al-Bīrūnī describes the main instrument that was constructed as a hemisphere of radius 12.5 m on which the solar image was projected through an aperture at the center of the hemisphere. Activity at the observatory stopped in 989 with the death of Sharaf al-Dawla, so that the institution lasted not much more than a year.

In 994 Abū Maḥmūd ► al-Khujandī made a measurement of the obliquity using a meridian sextant of about 20 m radius. This instrument was erected in Rayy, but al-Khujandī confessed to al-Bīrūnī that it was so large that the center of the sextant had become displaced from its intended position.

The Egyptian astronomer Ibn Yūnus made a series of observations of eclipses, conjunctions, and occultations, as well as equinoctial and solstitial observations. We are extremely fortunate to have not only his reports of these observations, but also his citations of earlier observations of the same kind made by individuals such as Ḥabash and the Banū Amājūr. Ibn Yūnus' purposed in making these observations and recording them in the introduction to his ► Zīj is somewhat obscured by the fact that he does not list those observations or present those calculations with which he derived his new solar, lunar, and planetary parameters. Neither does he mention any locations for his observations other than his grandfather's house in Fustat and a nearby mosque in al-Qarāfa. The popular association of Ibn Yūnus with an observatory on the Muqaṭṭam Hills outside Cairo is, as Aydm Sayili has shown, a myth. Nevertheless, Ibn Yūnus mentions at least one instrument, probably a meridian ring, that was provided by the Fatimid Caliphs al-ʿAzīz and al-ḥākim. In a later medieval Egyptian source Ibn Yūnus is reported to have received 100 dinars a day from al-ḥākim, and it may be that such extremely high payments were made to Ibn Yūnus when he was making satisfactory astrological predictions for the Caliph. Al-ḥākim made an abortive attempt to find an observatory in Cairo, but this was after the death of Ibn Yūnus in 1009. At some time during his reign there was an armillary sphere in Cairo with nine rings, each large enough that a man could ride through them on horseback.

The observations of ► al-Bīrūnī were conducted between 990 and ca. 1025 in several localities between Khwārizm and Kabul. His recorded observations include determinations of equinoxes and solstices, eclipses, and determinations of the obliquity and local latitude.

The corpus of tables known as the *Toledan Tables* was compiled in the eleventh century, based on observations directed by Ṣāʿid al-Andalusī and continued by ► Ibn al-Zarqāllu. Only the mean motion tables in this corpus of tables are original; most of the remains were lifted from the *zījes* of ► al-Khwārizmī and ► al-Battānī.

In the thirteenth century there was a substantial observational program at Maragha. The results are impressive only in so far as theoretical astronomy is concerned. Otherwise the trigonometric and planetary tables in the major production of the Maragha astronomers were modified or lifted in toto from earlier sources. This is not a happy outcome for a generously endowed observatory fitted with the latest observational instruments, known to us from texts. In the early fifteenth century the scene had moved to Samarqand in Central Asia: there, a group of astronomers, directed by the astronomer-prince Ulugh Beg, did impressive work. Only the 40-m meridian sextant survives from the observatory. These men produced a set of tables which it would be foolish to judge before they have been properly studied. The same is true for the short-lived observatory in Istanbul under the direction of Taqiʾl-Dīn (1577).

Regional Schools of Astronomy

After the tenth century they developed regional schools of astronomy in the Islamic world, with different interests and concentrations. They also had different authorities (for example, in the furthest East al-Bīrūnī and al-Ṭūsī, and in Egypt Ibn Yūnus). The main regions were Iraq, Iran and Central Asia, Muslim Spain, Egypt and Syria, the Yemen, the Maghrib, and later also the Ottoman lands. Only recently have the complex tradition of Muslim Spain (tenth to fourteenth centuries), the colorful tradition of Mamluk Egypt and Syria (thirteenth to early sixteenth centuries), the distinctive tradition of Rasulid Yemen (thirteenth to sixteenth centuries), and the staid tradition of the Maghrib (twelfth to nineteenth centuries) has been studied. The traditions of Ottoman Turkey and Mogul India are currently being researched.

Transmission to Europe

The Europeans learned of Islamic astronomy mainly through Spain, a region where, because of political problems and the difficulty of communications, the most up-to-date writings were not always available. This explains, for example, how it came to pass that the Europeans came across two major works of Muslim astronomers from the East, al-Khwārizmī and al-Battānī, at a time when these works were no longer widely used in the Islamic East. It also explains why so few Eastern Islamic works became known in Europe. None of the Eastern Islamic developments to Ptolemy's planetary theory was known in Andalusia or in medieval Europe. Al-Biṭrūjī's unhappy attempt to develop planetary models confused Europeans for several centuries; he must be worth reading, they naïvely thought, because he was trying to reconcile Ptolemy with Aristotle. As far as astronomical timekeeping was concerned, this does not seem to have been of much concern to the Muslims in Spain; hence nothing of consequence was transmitted.

On the other hand, some early Eastern Islamic contributions, later forgotten in the Islamic East, were transmitted to Spain and thence to Europe; they have been considered European developments because evidence to the contrary has seemed to be lacking. A good example is the horary quadrant with movable cursor (the so-called *quadrans vetus*), which was invented in Baghdad in the ninth century and (at least in the version with the cursor) virtually forgotten in the Islamic East thereafter; it came to be the favorite quadrant in medieval Europe. What, if any, astronomical knowledge was transmitted through Islamic Sicily remains a mystery, and nothing of consequence is known to have been learned about the subject by the Crusaders.

In the European Renaissance there was no access to the latest Islamic works. So the Europeans contented themselves with new editions of the ancient Greek works, with occasional, almost nostalgic, references to Albategnius ► (al-Battānī), Azarquiel (al-Zarqāllu), Alpetragius ► (al-Biṭrūjī), and the like. A few technical terms derived from the Arabic, such as alidade, azimuth, almucantar, nadir, saphea, and zenith, and a few star names such as Aldebaran, Algol, Al-tair, and Vega, survived. When the Europeans did come to learn of some of the major Islamic works and to try to come to terms with them it was as orientalists and historians of astronomy, for by this time the Islamic materials other than observation accounts were of historical rather than scientific interest. Thanks to orientalists like the Sédillots in Paris, works that had been completely unknown to Europeans and mainly forgotten by Muslims were published, translated, and analyzed. Islamic astronomy was highly respected by such scholars and others, like the historian of astronomy Delambre, who, innocent of Arabic, took the trouble to read what his colleagues had written about the subject. However, Islamic astronomy, indeed Islamic science in general, received a blow below the belt from Duhem, a physicist and philosopher ignorant of Arabic who simply ignored what scholars like the Sédillots had written. His thesis, that the Arabs were incapable of scientific thought and that whatever merits their science may have had were due to the intellectually superior Greeks, still has many followers, but only amongst those ignorant of the research of the past 150 years.

In the period after ca. 1500 Islamic astronomy declined. All of the problems had been solved, some many times over. Much of the innovative activity had led into a cul-de-sac, from which it would not emerge until modern times, thanks to investigations of manuscripts and instruments. Not that interest in astronomy died out. From Morocco to India the same old texts were copied and studied, recopied, and restudied, usually different texts in each of the main regions, but there was no new input or output of any consequence. Astronomy continued to be used as the handmaiden of astrology, and for the regulation of the calendar and the prayer times. Where there was innovation – such as, for example, in the remarkable device made in Isfahan ca. 1700 that correctly displays the direction and distance of Mecca for any locality – one must suspect the existence of an earlier tradition. However, the old traditions died hard, and Muslim astronomers for several centuries spent more time copying old treatises and tables than compiling new ones.

During the millennium beginning ca. 750 and especially in the period up to ca. 1050, although also in the period up to ca. 1500, Muslim astronomers did first-rate work, most of which was not known in medieval Europe at all. Those few Islamic works from the early period that were transmitted, notably the *zījes* of ► al-Khwārizmī and al-Battānī (especially through the *Toledan Tables*) and the banal summary of the *Almagest* by ► al-Farghānī, convey only an impression of classical astronomy in Arabic garb. However, they were in no way representative of contemporary Islamic astronomy in the East, and whilst the Europeans labored for centuries to come to terms with them, Muslim astronomers were making substantial contributions to their subject that have only been revealed by modern scholarship.

There is a wealth of material relating to this subject that remains untouched. Very few Islamic astronomical works have been published or have received the attention they merit. Three out of close to 200 Islamic *zījes* have been published in the optimum way (text, translation, and commentary). We have no published edition of the Arabic versions of the *Almagest* (except for the star catalogue), or of any Arabic recensions or commentaries. Many of the published Arabic scientific texts were printed in Hyderabad, most with no critical apparatus. Likewise most of the historically important Islamic astronomical instruments are still unpublished, although the catalogue currently in preparation in Frankfurt promises to make them better known.

In 1845 Sédillot, whose privilege it was to have access to the rich collection of Arabic and Persian scientific manuscripts in the Bibliothèque Nationale in Paris, wrote: “Each day brings some new discovery and illustrates the extreme importance of a thorough study of the manuscripts of the East." Sédillot also realized the importance of Islamic astronomical instruments. Given the vast number of manuscripts and instruments now available in libraries and museums elsewhere in Europe, the United States, and the Near East, and the rather small number of people currently working in this field, Sédillot's statement is no less true today than it was a century and a half ago.

See Also

- ▶ al-Battānī
- ▶ al-Bīrūnī
- ▶ al-Biṭrūjī
- ▶ al-Khwārizmī
- ▶ *Almagest*: Its Reception and Transmission in the Islamic World
- ▶ al-Maʾmūn
- ▶ al-Ṣūfī
- ▶ Armillary Spheres in India
- ▶ Astrology in Islam
- ▶ Astronomical Instruments in the Islamic World
- ▶ Ibn Al-Haytham (Alhazen)
- ▶ Ibn Al-Zarqāllu
- ▶ Ibn Muʿādh
- ▶ Ibn Qutayba
- ▶ Lunar Mansions in Islam
- ▶ Marāgha
- ▶ Māshāʾallāh
- ▶ Naṣīr al-Dīn al-Ṭūsī
- ▶ Observatories in the Islamic World
- ▶ Precession of the Equinoxes
- ▶ Qusṭā ibn Lūqā
- ▶ Religion and Science in Islam I: Technical and Practical Aspects
- ▶ Ṣāʿid al-Andalusī
- ▶ Stars in Arabic-Islamic Science
- ▶ Time
- ▶ Ulugh Bēg
- ▶ *Zīj*

References

Berggren, J. L. (1986). *Episodes in the mathematics of medieval Islam*. Berlin, Germany: Springer.

Goldstein, B. R. (1985). *Theory and observation in ancient and medieval astronomy*. London: Variorum.

Heinen, A. (1982). *Islamic cosmology*. Beirut, Lebanon: Franz Steiner.

Kennedy, E. S. (1956). A survey of Islamic astronomical tables. *Transactions of the American Philosophical Society, 46*(2), 121–177.

Kennedy, E. S., et al. (1983). *Studies in the Islamic exact sciences*. Beirut, Lebanon: American University of Beirut Press.

King, D. A. (1986a). *A survey of the scientific manuscripts in the Egyptian national library*. Winona Lake, IN: Eisenbrauns.

King, D. A. (1986b). *Islamic mathematical astronomy*. London: Variorum. (1993a). 2nd rev. ed. Aldershot, UK: Variorum.

King, D. A. (1992). Some remarks on Islamic scientific manuscripts and instruments and past, present and future research. In J. Cooper (Ed.), *The significance of Islamic manuscripts* (pp. 115–144). London: Al-Furqan Islamic Heritage Foundation.

King, D. A. (1993). *Astronomy in the service of Islam*. Aldershot, UK: Variorum.

King, D. A. (1996). Islamic astronomy. In C. Walker (Ed.), *Astronomy before the telescope* (pp. 143–174). London: British Museum.

King, D. A. (1999). *World-maps for finding the direction and distance to Mecca. Innovation and tradition in Islamic science*. Leiden, The Netherlands: Brill.

King, D. A. (2004). *Synchrony with the heavens: Studies in astronomical timekeeping and instrumentation in medieval Islamic civilization*. The Call of the Muezzin (Studies I–IX) (Vol. 1). Leiden, The Netherlands: Brill. (2005). Instruments of mass calculation (Studies X–XVIII) (Vol. 2). Leiden, The Netherlands: Brill.

King, D. A., & Samsó, J. (2001). With a contribution by Bernard R. Goldstein. Astronomical handbooks and tables from the Islamic world (750–1900): An interim report. *Suhayl – Journal for the History of the Exact and Natural Sciences in Islamic Civilisation* (Barcelona), *2*, 9–105.

King, D. A., & Saliba, G. (Eds.). (1986). *From deferent to equant: Studies in the history of science in the ancient and medieval near east in honor of E. S. Kennedy* (Annals of the New York academy of sciences, Vol. 500). New York: New York Academy of Sciences.

Kunitzsch, P. (1961). *Untersuchungen zur Sternnomenklatur der Araber*. Wiesbaden, Germany: Otto Harrassowitz.

Kunitzsch, P. (1989). *The Arabs and the stars*. Northampton, UK: Variorum.

Lorch, R. P. (1995). *Arabic mathematical sciences. Instruments, texts, transmission*. Aldershot, UK: Variorum.

Ragep, F. J. (1993). *Naṣīr al-Dīn al-Ṭūsī's memoir on astronomy (al-Tadhkira fīʿilm al-hayʾa)* (Vol. 2). Berlin, Germany: Springer.

Sabra, A. I. (1987). The appropriation and subsequent naturalization of Greek science in medieval Islam. *History of Science, 25*, 223–243.

Saliba, G. (1991). The astronomical tradition of Maragha: A historical survey and prospects for future research. *Arabic Science and Philosophy, 1*, 67–99.

Saliba, G. (1994). *A history of Islamic astronomy. Planetary theories during the golden age of Islam*. New York: New York University Press.

Samsó, J. (1992). *Las ciencias de los antiguos en al Andalus*. Madrid, Spain: Mapfre.

Samsó, J. (1994). *Islamic astronomy and medieval Spain*. Aldershot, UK: Variorum.

Sayili, A. (1960). *The observatory in Islam*. Ankara, Turkey: Turkish Historical Society. (1981). Rpt. in New York: Arno Press.

Sezgin, F. (1974, 1978, 1979). *Geschichte des arabischen Schrifttums*. V: *Mathematik*, VI: *Astronomie*, VII: *Astrologie, Meteorologie und Verwandtes*. Leiden, The Netherlands: E.J. Brill.

Suter, H. Die Mathematiker und Astronomen der Araber und ihre Werke. *Abhandlungen zur Geschichte der mathematischen Wissenschaften* 10 (1900), and 14 (1902), 157–185. Both Rpt. in Amsterdam: Oriental, 1982.

van Dalen, B. (1993). *Ancient and mediaeval astronomical tables – Mathematical structure and parameter values*. Utrecht, The Netherlands: Utrecht University.

Varisco, D. M. (1993). *Medieval agriculture and Islamic science – The almanac of a Yemeni Sultan*. Seattle, WA: University of Washington Press.

Wright, R. R. (1934). *The book of instruction in the elements of astrology by al-Bīrūnī*. London: Luzac.

Astronomy in Tibet

Yukio Ōhashi

Tibetan astronomy is a living form of traditional astronomy, and is the basis of the Tibetan calendar which is used in Tibet and in Tibetan communities in India, and other places in the world.

There are four branches of Tibetan astronomical science (*rtsis*). The most important branch is *skar-rtsis* (star calculation) which is based on the *Kālacakra* astronomy of India. Another branch is *dbyaṅs-'char* which is based on Indian divination, *svarodaya*. Another is *nag-rtsis* (black calculation), based on Chinese astrology and natural philosophy, and the last branch is *rgya-rtsis* (Chinese calculation), based on the Shixian calendar of China.

Indo-Tibetan Astronomy

The Tibetan *Tripitaka* is a collection of Tibetan translations of Buddhist works, some of which include astronomical information. There is a Tibetan translation of the *Śārdūlakarṇa-avadāna*, which is a Buddhist work in which early Indian astronomy and astrology of the Vedāṅga period, the post-Vedic period before Greek influence, are mentioned. There is also a Tibetan translation of an early Indian astrological text ascribed to Sage Garga. Astronomical knowledge in these texts is from an early period, and not of *skar-rtsis*. The most important texts from an astronomical point of view are the Tibetan translation of the *Kālacakra-tantra* and its commentary, *Vimalaprabhā*.

Kālacakra-yāna Buddhism is the last stage of Esoteric Buddhism in India. Its most fundamental text is the *Kālacakra-tantra*. It is not known when and where it was composed. Some people say it was introduced into Tibet in AD 1027, and was introduced into India from Central Asia 60 years before. I believe that it was composed in the eleventh century, because the year 1027 is used as the beginning of the 60-year cycle (*bṛhaspaticakra*) in the text itself. I also believe that it was composed in India, because it adopts the Hindu system of astronomy without any apparent influence of Chinese or other astronomy.

According to the commentary *Vimalaprabhā*, there was the original text or *Mūla-tantra*, where the *Siddhānta* system of astronomy was explained, and the text on which it comments is the abridged text or *Laghu-tantra*, where the *Karaṇa* system of astronomy is explained. The *Mūla-tantra* is not extant, and it is difficult to say whether it actually existed as a whole or not, but some fragments are quoted in the *Vimalaprabhā*. The *Siddhānta* system of astronomy is called *grub-rtsis* in Tibetan, and the *Karaṇa* system is called *byed-rtsis*. In Tibetan astronomy, these two systems are basically the same, and only the length of a year and a month are different. In the *Siddhānta* system, one sidereal year = 365.270645 days and one synodic month = 29.530587 days. In the *Karaṇa* system, a sidereal year = 365.258675 days, while a synodic month = 29.530556 days.

In the Tibetan calendar, there are 2 intercalary months for 65 ordinary months. This is harmonious with the *Siddhānta* system, but not with the *Karaṇa* system. The *grub-rtsis* is usually followed now.

Since about the twelfth century, the *Kālacakra* calendar has been followed in Tibet. In the fourteenth century, a comprehensive treatise of *Kālacakra* astronomy entitled *mKhas-pa-dga'-byed* (AD 1326) was composed by an encyclopaedic scholar Bu-ston Rin-chen-grub (1290–1364). After Bu-ston, lHun-grub-rgya-mtsho wrote the *Pad-dkar-źal-luṅ* (AD 1447), and his system was developed as the Phug school. The most famous work of this school is the *Vaiḍūrya dkar-po* (AD 1683) written by Saṅs-rgyas-rgya-mtsho, who was the regent of the fifth Dalai Lama. Another famous work is the *Ñin-byed-snaṅ-ba* (AD 1714) of Dharmaśrī.

There is another school, mTshur-phu, whose fundamental text is the *Ñer-mkho-bum-bzan* (AD 1732) written by Karma Ṅes-legs-bstan-'dzin.

Let us use astronomical calculation in the *mKhas-pa-dga'-byed* as a case study. It is one of the earliest treatises of the *skar-rtsis* branch of Tibetan astronomy and will give a general idea of *skar-rtsis*. As *skar-rtsis* is based on *Kālacakra* astronomy, it is similar to Hindu astronomy. First, mean motions of the planets are calculated, and then the equation of the center and the epicyclic correction are applied. The operation of the equation of the center (Sanskrit: *manda-karman*) is called *dal-ba'i-las* in Tibetan, and the operation of the epicyclic correction (Sanskrit: *śī ghra-karman*) is called *myur-ba'i-las*.

Three kinds of days are used. They are *ñin-źag* (Sanskrit: *sāvana-dina*), *tshes-źag* (Sanskrit: *tithi*), and *khyim-źag* (Sanskrit: *saura-dina*). A *ñin-źag* is a civil day measured from sunrise to sunrise. A mean *tshes-źag* is a 13th part of a synodic month. The equation of the center of the sun and moon are applied so as to make a *tshes-źag* correspond to the change of 12° of the longitudinal difference between the sun and moon. A mean *khyim-źag* is a 360th part of 1 year.

The ecliptic is divided into 12 *khyim* (Sanskrit: *rāśi*) or zodiacal signs, and also into 27 *rgyu-skar* (Sanskrit: *nakṣatra*) or lunar mansions. Each day as well as *rgyu-skar* is divided into 60 *chu-tshod* (Sanskrit: *nāḍī*). One *chu-tshod* is further divided into 60 *chu-sraṅ* (Sanskrit: *vināḍī*). One *chu-sraṅ* is divided into six *dbugs* (Sanskrit: *prāṇa*).

The mean motion of the sun and moon is calculated from the following simple formulae, which correspond to the *grub-rtsis* system:

$$\text{Length of a } \textit{khyim-źag} = \text{length of a } \textit{tshes-źag} \times \left(1 + \frac{2}{65}\right)$$

$$\text{Length of a } \textit{tshes-źag} = \text{length of a } \textit{ñin-źag} \times \left(1 + \frac{1 + \frac{1}{707}}{64}\right)$$

The equation of the center of the sun is given for each zodiacal sign. Twelve zodiacal signs are divided into four quadrants. Then 6/135, 4/135, and 1/135 of the mean daily motion of the sun are subtracted from or added to the mean daily motion of the sun in each sign. The variables 6, 4, and 1 are called *dal-rkaṅ* (slow step). The ecliptic is divided into the first half (*rim-pa*) and the second half (*rim-min*). The first as well as the second half is further divided into the first part (*sṅa-rkaṅ*) and the second part (*phyi-rkaṅ*). So, one part consists of three signs. The first point of the first half is the apogee.

This *dal-rkaṅ* is, in fact, the difference between the mean motion and the true motion of the sun during one zodiacal sign's movement of the mean sun in terms of *chu-tshod*. Hence, the maximum equation is the total of the variables, that is 11 *chu-tshod* or 2°26′40″. The solar apogee is located at the first point of Cancer in this system.

One anomalistic month is roughly considered as 28 *tshes-źag*, and a correction is applied to the length of each *tshes-źag*. This correction is called *zla-ba'i-myur-rkaṅ* (fast step of the moon). The word *myur* (fast) shows that it was considered to be the epicyclic correction rather than the equation of center. Since the period of 28 *tshes-źag* is a little longer than the actual anomalistic month, a special correction is also applied so as to diminish the period of 28 *tshes-źag* at the rate of one *tshes-źag* per 3,780 *tshes-zag*. So, one anomalistic month becomes about 27.55459 civil days.

One anomalistic month is divided into four quadrants, each of which consists of seven *tshes-źag*. Then 5, 5, 5, 4, 3, 2, and 1 *chu-tshod* are added to or subtracted from the length of each *tshes-źag*. These values were probably originally meant to be the difference between the mean motion and the true motion of the moon during one *tshes-źag* in terms of *chu-tshod*. Since the time interval during which the moon moves the arc of one *chu-tshod* is about 1.01 *chu-tshod*, this was considered to be one *chu-tshod*, and the same value was used for the correction of the length of a *tshes-źag*. The maximum equation is the total of the variables, that is 25 *chu-tshod* or 5°23′20″.

Five planets are divided into *źi-ba'i-gza'* which corresponds to inner planets, and *drag-gza'* which corresponds to outer planets. The sidereal period (*dkyil-'khor*) of each planet is given as follows:

Mercury (*lhag-pa*): 87 days 58 *chu-tshod* 12 *chu-sraṅ*
Venus (*pa-saṅs*): 224 days 42 *chu-tshod*
Mars (*mig-dmar*): 687 days
Jupiter (*phur-bu*): 4,332 days
Saturn (*spen-pa*): 10,766 days

Just as in the case of the sun, *dal-rkaṅ* (slow step) for each zodiacal sign is given for each planet. The mean daily motion of each planet in the case of outer planets, or of the sun in the case of inner planets, is corrected as follows.

Corrected daily motion $= A \mp A(d/135)$, where A is the mean daily motion, and d is *dal-rkaṅ*. The value of *dal-rkaṅ* for each planet is:

Mars: 25, 18, and 7
Mercury: 10, 7, and 3
Jupiter: 11, 9, and 3
Venus: 5, 4, and 1
Saturn: 22, 15, and 6

The total of the value of *dal-rkaṅ* is the maximum equation in terms of *chu-tshod*. The maximum equation of each planet is:

Mars: 50 *chu-tshod* or 11°6′40″
Mercury: 20 *chu-tshod* or 4°26′40″
Jupiter: 23 *chu-tshod* or 5°6′40″
Venus: 10 *chu-tshod* or 2°13′20″
Saturn: 43 *chu-tshod* or 9°33′20″

The longitude of the apogee of each planet in this system is Mars: 126°40′, Mercury: 220°, Jupiter: 160°, Venus: 80°, and Saturn: 240°.

The "parameter of step" (*rkaṅ-'dzin*) is used to count steps of epicyclic correction. The period of 60 *chu-tshod*'s change of the "parameter of step" is considered one step. Sixty *chu-tshod* correspond to 1 lunar mansion, and there are 27 lunar mansions, so 1 cycle consists of 1,620 *chu-tshod*. One cycle is divided into 2 halves, and each consists of 14 steps. The 14 step of the first half and the first step of the second half consist of 30 *chu-tshod* only.

In the case of the outer planets, daily motion of the "parameter of step" is the mean daily motion of the sun minus the daily motion of the planet which has been corrected by its equation of center. In the case of the inner planets, the daily motion of the "parameter of step" is the daily motion of "parameter of fast step" (*myur-rkaṅ-'dzin*) minus the true daily motion of the sun. The "parameter of fast step" is, in fact, the daily motion of the planet's revolution, because it is defined as the quotient of 1,620 *chu-tshod* divided by the planet's sidereal period. The variable of the epicycle correction is given as *myur-rkaṅ* (fast step) for each step.

The method of the correction is as follows: let M be the true daily motion of the planet, D the daily motion of the planet in the case of an outer planet and the daily motion of the sun in the case of an inner planet, both of which have been corrected by the equation of center of the planet itself, K the daily motion of the "parameter of step," and m the *myur-rkaṅ*. Then, for the steps from the first step to the 13 step of the first half and from the second step to the 14 step of the second half, the following equation gives the true daily motion of the planet

$$M = D \pm K\frac{m}{60}.$$

For the 14 step of the first half and the first step of the second half, the following equation is used

$$M = D \pm K\frac{m}{30}.$$

The first half (*rim-pa*) as well as the second half (*rim-min*) are further divided into the first part (*sṅa-rkaṅ*) and the second part (*phyi-rkaṅ*). The correction is plus in the first part of the first half and the second part of the second half, and minus in the second part of the first half and the first part of the second half.

The values of *myur-rkaṅ* for each planet are shown in Table 1. The values are arranged for the first half. In the second half, the same value is used in reverse order.

The total of the value of *myur-rkaṅ* in one part is the maximum epicyclic correction in terms of *chu-tshod*. The maximum correction of each planet is:

Mars: 182 *chu-tshod* or 40°26′40″
Mercury: 97 *chu-tshod* or 21°33′20″
Jupiter: 52 *chu-tshod* or 11°33′20″
Venus: 208 *chu-tshod* or 46°13′20″
Saturn: 28 *chu-tshod* or 6°13′20″

In a paper written in 1986, I compared the astronomical constants used by Bu-ston with those of some schools of Hindu astronomy, and pointed out that they are close to those of the Ārdharātrika school of Hindu astronomy.

Sino-Tibetan Astronomical Science

The *nag-rtsis* is said to have been introduced into Tibet from China in the seventh century. It is based on Chinese astrology and natural philosophy. According to the *Zla-ba'i-'od-zer* (AD 1684) of Dharmaśrī, a popular work of *nag-rtsis*, the most fundamental elements of the *nag-rtsis* are as follows.

Astronomy in Tibet, Table 1 The values of *myur-rkaṅ* for each planet

Planet	First part	Second part
Mars	24, 23, 23, 23, 21, 21, 18, 15, 11, and 3	11, 38, 80, and 53
Mercury	16, 16, 15, 14, 13, 11, 7, 5, and 0	4, 11, 20, 28, and 34
Jupiter	10, 10, 9, 8, 6, 6, 2, and 1	3, 6, 9, 11, 16, and 7
Venus	25, 25, 25, 24, 24, 22, 22, 18, 15, and 8	6, 30, 99, and 73
Saturn	6, 5, 5, 4, 4, 2, 2, and 0	2, 4, 5, 6, 8, and 3

1. *Khams* (also called'*byuṅ-ba*), which are the five elements of Chinese natural philosophy: wood, fire, earth, metal, and water.
2. *Lo-'gros*, which are 12 animals used to name each year of a 12-year cycle: rat, ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, bird, dog, and boar. This 12-year system is the Chinese system, which is widely used in East Asia. The combination of the *khams* and *lo-'gros* is used to name each year of a 60-year cycle. This is also the Chinese system.
3. *Sme-ba*, which is the Chinese "nine stars" used for astrological purposes.
4. *sPar-kha*, which is eight symbols of Chinese natural philosophy, of which the most fundamental text is the famous Yijing (I Ching, Book of Changes).
5. *Zla-ba*, which is 12 months for each of which 12 animals are attributed. The first month of spring is a tiger, and so on.
6. *Tshes*, which is the date of the month.
7. *Dus-tshod*, which is a 12th part of a day, for each of which 12 animals are attributed. The midnight is rat, and so on.
8. *gZa'*, which is eight planets: the sun, moon, five planets, and *rāhu*. The *rāhu* (dragon's head, or the ascending node of the lunar orbit) is not Chinese, but of Indian origin.
9. *sKar-ma*, which is the Chinese 28 lunar mansions or lodges.

The *rgya-rtsis* is based on the Tibetan version (AD 1725) of the Mongolian translation (AD 1711) of the Chinese astronomical work

Xiyang xinfa suanshu (AD 1669) compiled in the Qing dynasty, which is the theoretical text on the Shixian calendar. The Shixian calendar is the last luni-solar calendar in China.

The traditional Tibetan calendar, which is based on the Phug school of *skar-rtsis*, is still used by Tibetan people. Also, several Tibetan astronomical texts are extant, and the process of astronomical calculation is explained in detail in these texts. More extensive study of Tibetan astronomy by historians of astronomy will be fruitful. In 1987, Chinese scholars Huang Mingxin and Chen Jiujin published a *skar-rtsis* text of epoch AD 1827, the *Rigs-ldan-sñiṅ-thig* of Phyag-mdzod gsuṅ-rab, with Chinese translation and astronomical commentary. This is a good introduction to Tibetan astronomy.

See Also

► Lunar Lodges in Chinese Astronomy
► Mean Motions in Indian Astronomy

References

Primary Sources: Tibetan Translations of Sanskrit Texts

Raghu, V., & Chandra, L. (Eds.) (1966). *Kālacakratantra and other texts*, Part 1, (Śata-piṭaka Series, Vol. 69). New Delhi, India: International Academy of Indian Culture. (This book includes Sanskrit, Tibetan, and Mongolian texts of the *Kālacakra-tantra*.)

Tibetan Tripitaka. (1955–1961). Peking edition, Reprint, Vol. 168. Tokyo-Kyoto: Tibetan Tripitaka Research Institute (The *Kālacakra-tantra* is in Vol. 1, (text no.4). The *Vimalaprabhā* is in Vol. 46 (text no. 2064)).

Primary Sources: Tibetan Classical Texts

Bu-ston Rin-chen-grub. (1987). *rTsis-kyi bstan-bcos mkhas-pa dga'-byed*. Xizang, China: Xizang renmin chubanshe.

Bu-ston Rin-chen-grub. (1992). *Bu-ston skar-rtsis phyogs-bsgrigs*. Lanzhou, China: Gansu minzu chubanshe.

Chandra, L. (Ed.). (1965). *The collected works of Bu-ston, part 1*. New Delhi, India: International Academy of Indian Culture.

Dharma-śrī. (1983). *rTsis-kyi man-ṅag ñin-byed snaṅ-ba'i rnam-'grel gser-gyi śiṅ-rta*. Xizang, China: Xizang renmin chubanshe.

Dharma-śrī. (1990). *rTsis-kyi man-ṅag ñin-mor byed-pa'i snaṅ-ba*. Xizang, China: Xizang renmin chubanshe.

Karma Ṅes-legs-bstan-'dzin. (1977). *rTsis-kyi lag-len ñer-mkho'i bum-bzaṅ*. New Delhi, India: T.G. Dhongthog Rinpoche.

mKhyen-rab-nor-bu. (1976). *rTsis-kyi man-ṅag rigs-ldan sñiṅ-thig*. Leh, India: O-rgyan-rnam-rgyal.

Saṅs-rgyas-rgya-mtsho. (1971). *Vaiḍūrya-g. ya'-sel* (Vol. 2). New Delhi, India: T. Tsepal Taikhang.

Saṅs-rgyas-rgya-mtsho. (1978). *Baiḍūr-dkar-po* (Vol. 2). Dehra Dun, India: Sakya Centre.

sMin-gliṅ Lo-chen Chos-dpal. (1968). *'Byuṅ-rtsis man-ṅag zla-ba'i od-zer*. Dharamsala, India: Bod-gźuṅ chos-don lhan-khaṅ.

sMiṅ-gliṅ Lo-chen Dharmaśrī. (1976). *rTsis-kyi man-ṅag ñin-mor byed-pa'i snaṅ-ba*. Leh, India: Dondup Tashi.

Primary Sources: Tibetan Modern Texts

Bod-ljoṅs groṅ-khyer lHa-sa sman-rtsis-khaṅ-gi Bod-gi lo-tho rtsom-sgrig-khaṅ. (1978). *Bod-ljoṅs skar-rtsis gnam-rig-gi dus-rtags gnam-dpyad*. Xizang, China: Xizang renmin chubanshe.

bSam-'grub-rgya-mtsho. (1990). *sKar-rtsis kun-'dus nor-bu* (Vol. 2). Qing-hai, China: Zhongguo zangxue chubanshe.

Tshe-tan-źabs-druṅ. (1980). *rGya-rtsis-gi-don*. Lanzhou, China: Gansu minzu chubanshe.

Tshe-tan-źabs-druṅ. (1985). *Mi'u-thuṅ sgyu-ma'i gom-'gros*. Xining, China: Qinghai minzu chubanshe.

Secondary Sources

Huang, M. (2002). *Xizang de tianwen lisuan (the astronomical calendar of Tibet, in Chinese)*. Xining, China: Qinghai renmin chubanshe.

Huang, M., & Chen, J. (1987). Tibetan title: *Bod-kyi rtsis-rig-gi go-don daṅ lag-len*. Chinese title: *Zangli de yuanli yu shijian*. (The principle and practice of Tibetan calendar, in Tibetan and Chinese). Beijing, China: Minzu chubanshe.

Ōhashi, Y. (1986). Putun no tenmon-rekihō. (Mathematical astronomy of Bu-ston, in Japanese). In Yamaguchi Zuiho (Ed.), *Chibetto no Bukkyō to Shakai* (pp. 629–646). Tokyo: Shunjusha.

Ōhashi, Y. (2000). Remarks on the origin of Indo-Tibetan astronomy. In H. Selin (Ed.), *Astronomy across cultures* (pp. 341–369). Dordrecht, The Netherlands: Kluwer.

Petri, W. (1968). Tibetan astronomy. *Vistas in Astronomy, 9*, 159–164.

Schuh, D. (1973). *Untersuchungen zur Geschichte der Tibetischen Kalenderrechnung*. Wiesbaden, Germany: Franz Steiner Verlag.

Tshul-khrims-chos-sbyor. (1983). *sKar-nag-rtsis-kyi lo-rgyus phyogs-bsdud mu-tig phreṅ-ba* (A concise history of *skar-rtsis* and *nag-rtsis*, in Tibetan). Lhasa, China: Xizang-renmin-chubanshe.

Yamaguchi, Z. (1973). Chibetto no rekigaku (Tibetan calendrical science, in Japanese). *Suzuki gakujutsu zaidan kenkyu nenpo, 10*, 77–94.

Astronomy of the Australian Aboriginal People

Roslynn D. Haynes

The Australian Aborigines were almost certainly the world's first astronomers. Their complex systems of knowledge and beliefs about the heavenly bodies have been handed down through song, dance, and ritual for some 40,000 years, predating by many millennia those of the Babylonians, the ancient Greeks, the Chinese, or the Incas. The legends which have survived, until very recently, within a virtually unchanged cultural context, show how natural phenomena, including celestial bodies and events, were assimilated by the Australian Aborigines into a holistic value system which was predicated on the close relationship of the individual with the whole natural world: It is significant, in this regard, that theirs was the only known culture with no myth of alienation from Nature, such as the expulsion from Eden of the Judeo-Christian tradition. On the contrary they believed that through their Great Ancestors of the Dreaming they, too, were continuing co-creators of the natural world. Hence they used their knowledge of the stars not only to predict and explain natural occurrences but also to provide celestial parallels with tribal experiences and behavioral codes.

The Aborigines' knowledge of the "crowded" southern sky was probably the most precise possible for people dependent on naked-eye astronomy. They made accurate observations, not only of first- and second-order stars, but also of the more inconspicuous fourth-magnitude stars. Pattern was apparently more important in recognition than brightness, for the Aborigines often identified a small cluster of relatively obscure stars while ignoring more conspicuous single stars in the vicinity. Thus the people of Groote Eylandt named as *Unwala* (the Crab) the small cluster of relatively insignificant (average magnitude 4.4) stars Sigma, Delta, Rho, Zeta and Eta Hydrae, while disregarding the adjacent bright stars Procyon (α Canis Minoris) and Regulus (α Leonis) (magnitude 0.36 and 1.35, respectively) which are not part of an obvious group. Members of the Boorong tribe of the Mallee District of Victoria limited their identification procedures to linear patterns of three or more stars. Unlike the familiar Greek designations, based on a join-the-dot pictorial image, the Aborigines identified a group of stars with the whole cast of characters in a story, the relationship being conceptual rather than visual. Color was also an important factor in the aboriginal designation of stars. The Aranda tribes of Central Australia distinguish red stars from white, blue, and yellow stars. They classify the bright star Antares (α Scorpii) as *tataka indora* (very red) while the stars of the V-shaped Hyades cluster are divided into a *tataka* (red) group and a *tjilkera* (white) group. The former are said to be the daughters of the conspicuously red star Aldebaran (α Tauri).

The Aborigines also differentiated between the nightly movement of the stars from east to west and the more gradual annual shift of the constellations. From this latter displacement they devised a complex seasonal calendar based on the location of constellations in the sky, particularly at sunrise or sunset. The Aranda and Luritja tribes around Hermannsburg in Central Australia knew that certain stars lying to the south, namely *Iritjinga* and the Pointers of the Southern Cross, are visible throughout the year, although their position in the sky varies. This amounts to a realization that stars within a certain distance of the South Celestial Pole never fall below the horizon.

Yet what the Aborigines did with their astronomical knowledge was fundamentally different from the procedures of Western science. Tribal Aborigines paid no attention to two of the most basic concepts of western science, numeracy and temporality; they made no measurements of space or time, nor did they engage in even the most elementary mathematical calculations. Their observations of the stars were conducted for essentially pragmatic reasons. Either they were an attempt to discover predictive correlations between the position of the stars and other natural events important to the survival of the tribe – the availability of specific foods or the onset of particular weather conditions, or they provided a system of moral guidance and education in tribal lore – a function regarded as equally necessary to the continuation of tribal identity.

As hunter – gatherers, dependent for their survival on a foreknowledge of environmental changes, the Aborigines noted the correlation between the movements and patterns of stars and changes in the weather or other events related to the seasonal supply of food. Thus the significance attributed to these sidereal occurrences varied with the diet and lifestyle of different tribes. On Groote Eylandt the appearance in the evening sky toward the end of April of Upsilon and Lambda Scorpii indicated that the wet season had ended and that the dry south-easterly wind or *marimariga* would begin to blow, causing changes in climate and animal behavior. At nearby Yirrkalla the appearance of Scorpio in the morning sky in early December heralded the arrival of the Malay fishermen who came in their canoes to collect trepang or *bêche de* mer which they sold to the Chinese. In winter, the most spectacular individual stars in the southern sky are Arcturus (α Bootis) and Vega (α Lyrae). When Arcturus could be seen in the eastern sky at sunrise, the Aborigines of Arnhem Land knew that it was time to harvest the spike-rush or *rakia*, a reed valuable for making fish traps and baskets for carrying food, and a local legend about Arcturus served as an annual reminder of this. On the other hand, amongst the *Boorong* tribe of the Mallee district of western Victoria, Arcturus was personified as *Marpeankurrk* the tribal hero who showed them where to find *bittur*, the pupa of the wood ant, a staple item of diet during August and September. The constellation Lyra represented the spirit of *Neilloan*, or the Mallee-hen who taught the tribe how to finds its eggs, an important source of food in October. Other notable events, like the ripening of tubers and bulbs and the appearance of migratory birds and animals, were correlated with specific positions of Orion, the Pleiades and the Southern Cross at different seasons of the year. For the Pitjantjatjara tribe in the Western Desert, the appearance of the Pleiades in the dawn sky in autumn was the sign that the annual dingo-breeding season had begun. Fertility ceremonies were performed for the dingoes, or native dogs, and some weeks later the tribe raided the lairs, culling and feasting on the young pups. The legends ensured that these nutritional associations were not forgotten and stressed their importance for the continuing survival of the race.

Equally important to the preservation of the tribe was its sense of identity, involving tribal beliefs orally transmitted across generations. These myths outlined the role of the Ancestors of the Dreaming in the scheme of the universe and the behavior appropriate to their descendants. Explanations of natural events which emphasized pattern, order, and laws, rather than unpredictable effects, reinforced the sense of an organic relationship between natural phenomena and social behavior. Many of these legends involved the constellations, so that the night sky provided a periodic reminder of the moral lessons enshrined in the myths.

Like all explanatory systems, including Western science, these legends represented attempts to understand, predict, and hence to obtain some control over the natural world. However, unlike the essentially analytical, materialistic, and particularizing approach of Western science, the underlying premise of all the aboriginal myths was a belief in the close spiritual unity of human beings, not only with other species, but also with inanimate objects. Astronomy was an integral part of the Aborigines' total philosophy about the natural world, so the legends emphasized the parallels between the personified heavenly bodies and their earthly counterparts, humanizing and integrating natural phenomena with tribal institutions and customs.

The meaning which a tribe attributed to the celestial bodies was conceptual rather than perceptual. It could not be understood by personal experience or by the intellect, but only through initiation into tribal lore which stressed the intimate, causal association between physical events and the human dramas of good and evil. Lessons about compassion, brotherhood, and respect for the land as Mother, the prohibition of incest and adultery, and taboos on killing or eating totemic animals were nightly reinforced by being enacted in the sky world which thereby established the universal validity of the tribe's ethical laws.

The many and diverse aboriginal myths associated with the heavenly bodies include stories about the Sun, the Moon, the Milky Way, the Magellanic Clouds, Mars, Venus, and the several constellations which form distinctive patterns in the southern sky – notably the Southern Cross and its pointers, the Pleiades, Orion's Belt, Scorpio, Gemini, and Aldebaran. The following are a representative selection of these myths.

In most of the Aboriginal creation stories, the Sun is the life-giving spirit. Amongst the Murray River tribes the origin of the Sun is linked to the tossing of a giant emu egg into the sky where it struck a heap of dry wood and burst into flame, bringing light to the hitherto dark world. Thereupon, the Great Spirit *Baiame*, seeing how much the world was improved by sunlight, decided to rekindle the woodpile each day.

In contrast to the ancient Greeks, the Amerind Indians and the Quechua Indians of Peru, all of whom designated the Sun as male and the Moon as female, whereas the Australian Aborigines represented the Sun as female and the Moon as male. In most areas, the Sun is regarded as a woman who daily awakes in her camp in the east and lights a fire to kindle the bark torch she will carry across the sky, thus providing the first light of dawn. She decorates herself with powder made from crushed red ochre, coloring the clouds red in the process. At evening she renews her powder in the western sky before beginning her long passage underground back to her camp in the east. It was probably this underground journey which was instrumental in the classification of the Sun as female, for her torch is thought to bring warmth and fertility to the interior of the Earth, causing the plants to grow. However, in Arnhem Land, where the Sun sets in the sea, she is thought to become a great fish, swimming under the Earth to return in the east next morning while the Moon becomes a fish, passing beneath the earth during the day.

The Moon, being male, is generally accorded greater status, and in many areas powers of death and fertility are accorded to him. An eclipse of the Sun is interpreted as indicating that the Moon Man is uniting with the Sun Woman. Several legends have evolved to account for the Moon's cycles. In coastal areas the correlation between the phases of the Moon and the tides was noted. In Arnhem Land and Groote Eylandt, where high tides occur when the new or full Moon sets at sunset or sunrise, respectively, and low tides when the moon is in the zenith at sunrise or sunset, the local Aborigines believe that the high tides, running into the Moon as it sets into the sea, make it fat and round. (Although the new Moon may appear thin, they deduce from the faint outline of the full circle that it too is round and full of water.) Conversely, when the tides are low, the water pours from the full Moon into the sea below and the moon consequently becomes thin.

In most areas the Moon was regarded as more mysterious, and hence more dangerous, than the Sun. Because of the association of the lunar cycle with the menstrual cycle, the Moon was linked with fertility and young girls were warned against gazing at the Moon unless they wished to become pregnant.

The Milky Way was regarded by the Aborigines as a river in the Sky World, the large bright stars being fish and the smaller stars water-lily bulbs. Central Australian tribes believed that the Milky Way divided the sky people into two tribes and thus it served as a perpetual reminder that a similar equitable division of lands should be observed between neighboring tribes. Various legends regarding taboo marriages, adultery, and reminders to celebrate tribal heroes, many of them involving a moral lesson, have evolved in different areas to account for the formation of the Milky Way and the dark region, known to Europeans as the "Coal Sack."

A Queensland version of the origin of the Milky Way associates it with *Priepriggie*, an Orpheus-like hero, as famed for his songs and dances as for his hunting. When he disappeared, his people tried unsuccessfully to perform his dance until they heard singing in the sky. Then the stars, hitherto randomly dispersed, arranged themselves to the rhythm of *Priepriggie*'s song.

Thus the Milky Way serves as a reminder that the tribal hero should be celebrated with traditional songs and dancing.

Because of its diagrammatic shape, the Southern Cross features in association with various characteristic objects in different areas. Around Caledon Bay on the east coast of Arnhem Land, it is taken to represent a stingray being pursued by a shark – the Pointers. On Groote Eylandt, where fish is the staple diet, the four stars of the Cross represent two brothers, the *Wanamoumitja* (Alpha and Beta Crucis), and their respective camp fires (Delta and Gamma Crucis) where they cook a large black fish (the Coal Sack) which they have caught in the Milky Way. The Pointers are their two friends, the *Meirindilja*, who have just returned from hunting. Desert tribes, on the other hand, see in the kite shape of the Cross the footprint of the wedge-tailed eagle *Waluwara* while the pointers represent his throwing stick and the Coal Sack his nest.

Venus, the Morning Star, was an important sign to the Aborigines, who arose at early dawn to hunt. It, too, was personified and frequently associated with death. Arnhem Land legends identify the home of the morning star, *Barnumbir*, as Bralgu, the Island of the Dead. Afraid of drowning, *Barnumbir* could be persuaded to light her friends across the sea at night only if she were held on a long string by two old women, who at dawn would pull her back to Bralgu and keep her during the day in a basket. Because of this connection, the morning star ceremony is important in the local rituals for the dead since a dead person's spirit is believed to be conducted by the star to *Bralgu*.

One of the most widespread Aboriginal myth cycles concerns the constellations of Orion and the Pleiades and these bear a striking similarity to the Greek story of the seven daughters of Atlas who, when pursued by Orion, flew into the sky as doves to form the constellation of the Pleiades. All identify them with a group of seven young women and nearly all portray them as fleeing from the amorous hunter Orion who, in some versions, is castrated as a punishment and warning to other potential wrongdoers. The whole cluster of Pleiades stories therefore forms part of a much larger group of myths of sexual conquest and submission.

Amongst the Pitjantjatjara tribe, the practical connection between the dingo-breeding season and the appearance of the Pleiades in the dawn sky in autumn is preserved in a local legend. The *Kungkarungkara* or ancestral women kept dingoes to protect them from a man *Njiru* (Orion), but he succeeded in raping one of the girls, the obscure Pleiad, who died. Even though the women assumed their totemic form of birds and flew into the sky to escape from him, he defies their dingoes and follows the women across the sky, armed with a spear (the stars of Orion's Belt) which has ritual phallic significance. Like the Greek Orion, *Njiru* was also a hunter, and pairs of smaller stars which arise near the constellation of Orion are said to represent his footsteps as he pursues the *Kungkarungkara*.

At Yirrkalla on the coast of Arnhem Land, the constellation of Orion is regarded as a group of fisherman arriving from the east in a canoe with a turtle they have caught, while the Pleiades represent their wives in another canoe with two large fish. As they approached the shore a heavy storm capsized the canoes, drowning the people. All the representative stars are visible in the sky during the wet season – a warning against the dangers of fishing when storms are imminent. In north-eastern Arnhem Land the story carries the added moral that the fishermen drowned as a punishment for catching catfish, forbidden to this tribe by totemic law.

Although relatively insignificant to the naked eye, the Large and Small Magellanic Clouds feature in many aboriginal legends as the camps of sky people. On Groote Eylandt they are believed to be the camps of an old couple, the *Jukara*, grown too feeble to catch their own food. Other star people catch fish and lily bulbs for them in the Milky Way and bring them to the *Jukara* to cook on their fires. The space between the Clouds is their cooking fire, while the bright star Achernar (Alpha Eridani, magnitude 0.49) represents their meal. This story suggests a celestial model of compassion for the aged. At Yirrkalla the Magellanic Clouds are said to be the homes of two sisters. During the middle of the dry season the elder sister (Large Cloud) leaves her younger sister (Small Cloud), but during the wet season she returns so that they can collect yams together. This story reflects the observed fact that at this latitude (12° S) only the Small Cloud is visible during most of the dry season (April to September), whereas both Magellanic Clouds can be seen during the wet season.

Meteors have been variously interpreted by different aboriginal tribes. In north-eastern Arnhem Land, because of their speed and unpredictability, they are believed to be spirit canoes carrying the souls of the dead to their spirit home in the sky. To the Tiwi tribe of Bathurst and Melville Islands, each is the single eye of the one-eyed spirit men, the *Papinjuwari*, who steal bodies and suck the blood of their victims, and their evil eyes are seen blazing as they streak across the sky looking for their prey. In other legends, meteors are associated with fire and linked to the waratah plant, *Telopea speciosissima*, a member of the Protea family, which is resistant to fire and whose brilliant red flowers seemed to the Aborigines like sparks from a fire. This was why, in the early years of white settlement, some Aborigines brought waratahs to the European blacksmiths: they identified the sparks from the anvil with the sparks from meteors and hence with the waratahs.

From this selection of star legends, it will be apparent that, with the possible exception of meteors (and even they can be regarded as recurrent events), the Aborigines' concern was not with extraordinary occurrences, but with the regular patterns of natural phenomena. The star legends served the purpose of integrating a potentially alien universe into the moral and social order of the tribe – by "humanizing" species and natural objects and ascribing to them behavior patterns and motivations which accorded with those of the tribal unit.

Such a philosophy serves a number of important social functions. In the first place it engenders a level of confidence about Man's place in the universe, not as a superior being but as an equal partner; in this it fulfils a role comparable to that of technology which also offers a level of some control over the environment. Secondly, this philosophy cultivates respect for the inanimate world as well as the animate since, through the indwelling power of the Ancestors, all creatures and things partake of the same spiritual identify as Man himself. Thirdly, the legends provide a justification for the customs, rites, and morality of the tribe, since these are reflected and enacted in the Sky-world.

The aboriginal myths are not fatalistic as astrology purports to be. Although they link certain natural events with a seasonal configuration of the sky, they make no deterministic predictions about individual lives; the moral values enshrined in the legends are held to be true for the *whole* tribe.

The most radical difference between the vitalistic beliefs which underlie these myths and the materialistic philosophy of western science concerns the relationship of the observer to the observed. In Newtonian science, the observer is assumed to be independent of, and distinct from, the object observed, which, in turn, is regarded as uninfluenced by the observer. Hence, the relationship between physical objects can be validly expressed in mathematical terms which remain true irrespective of the observer. The Aborigines, on the other hand, did not conceive of themselves as observers separated from an objectified Nature, but rather as an integral part of that Nature. The meaning of the celestial bodies, as of everything else in the environment, was neither self-evident nor independent of the observer; rather it depended on the degree of initiation into tribal lore which elucidated the links between tribal customs and natural phenomena. Without this knowledge the individual was disoriented and powerless in an alien universe.

See Also

► Environment and Nature: Australian Aboriginal People

References

Elkin, A. P. (1964). *The Australian aborigines*. Sydney, Australia: Angus and Robertson.

Haynes, R. D. (1990). The astronomy of the Australian aborigines. *The Astronomy Quarterly, 7*(4), 193–217.
Isaacs, J. (1980). *Australian dreaming: 40,000 years of aboriginal history*. Sydney, Australia: Lansdowne Press.
Mountford, C. P. (1956). *Art, myth and symbolism: Records of the American-Australian expedition to Arnhem Land* (Vol. 1). Melbourne, Australia: Melbourne University Press.
Mountford, C. P. (1976). *Nomads of the Australian desert*. Sydney, Australia: Rigby.
Norman, T. (1974). *Aboriginal tribes of Australia*. Canberra, Australia: Australian National University Press.

Astronomy of the Hebrews

Y. Tzvi Langermann

The Hebrew astronomical tradition that shall be surveyed in this essay is that tradition recorded in the Hebrew alphabet dealing with the motions of the heavenly bodies and the structure of the heavens. These writings utilize principally the Hebrew language, but include texts in languages such as Aramaic and Arabic that can be written out in Hebrew script. Topics of specifically Jewish interest, such as calendar computations and doctrinal matters, occupy only a minor portion of this literature. For the most part, the Hebrew astronomical tradition differs little from contemporary writings belonging to the traditions with which Jews found themselves in immediate contact at any given age and place. To the extent that these other traditions may be classified as non-Western, the Hebrew tradition may be by and large considered such.

The earliest substantive materials are found in the Talmud and Midrash. Most of the discussions center upon the structure and physics of the heavens. Of particular interest are several notices of disagreement between Jewish and non-Jewish experts, for example, on the question of whether it is the star itself, or the spherical shell within which the star was thought to be embedded, which moves around the earth. In other words, we have clear evidence that even at this early date Jewish scholars identified themselves with particular conceptions of the heavens. *Pirqei di-Rebbe Eliezer*, *Baraitha di-Mazalot*, and *Baraitha di-Shmuel* are three post-Talmudic writings whose precise dating is problematic but which certainly precede the flowering of the sciences under the Abbasids. The latter two are the earliest texts which preserve any mathematical astronomy, e.g., a computational scheme for shadows. In addition, al-Khwārizmī's treatise on the Jewish calendar, which belongs to the Arabic tradition but is almost certainly based on Jewish sources, exhibits positional data for the epoch of the Temple. All of this indicates that a Hebrew tradition, drawing upon Indian, Hellenistic, and other sources, had developed by the eighth century.

Without doubt the years spanning the ninth through sixteenth centuries were the most fecund for the Hebrew tradition. During this period, which is more or less commensurate with what Western historians have long called the medieval age, interest in astronomy was especially stimulated in Arabic speaking lands from Spain to Iraq. Contemporary Jewish writings consist for the most part of exposés or translations of the fruits of Arab science. Dozens of works were written, surviving in hundreds of manuscripts; only a few can be surveyed here. Abraham bar Ḥiyya created a Hebrew astronomical vocabulary that endured side by side with that developed by the Tibbons, the famous family of translators of Arabic literature. Abraham ibn Ezra's astrological writings were immensely popular both in the Hebrew original and in Latin translation. Both Abrahams utilize more ancient sources that are no longer extant. Isaac Israeli's *Yesod ʿOlam* is a thorough analysis of all of the astronomical and historical questions connected with the Jewish calendar; his book, written in 1310 in a polished Hebrew style, may be considered the pinnacle of the Spanish Hebrew tradition. All the same, Hispano-Jewish authors continued to produce treatises in Hebrew and Judeo-Arabic through the end of the fifteenth century. For instance, the work of Abraham Zacuto, so important for the Portuguese explorers, appeared around the time of the expulsion of Jews from Spain.

Southern France, Italy, and Byzantium were the other major centers of astronomical activity during this period. Emmanuel ben Jacob, Jacob Anatoli, and Mordecai Comtino are, respectively, perhaps the most important representatives of the Hebrew tradition in those lands. In those areas in particular, Jews drew upon Latin, Romance, and other literatures, as well as Arabic materials.

The two outstanding philosophers of this period, ► Moses Maimonides and Levi Gersonides, participated strongly in the Hebrew astronomical tradition. Maimonides' wrote a small work on the calendar, and he included in his great law code, the *Mishneh Torah*, a detailed scheme for computing the first visibility of the lunar crescent. However, Maimonides' weightiest contribution is the very high value which he placed on the study of astronomy within the context of his religious philosophy, something which encouraged many Jews to acquaint themselves with, at the very least, non-technical resumés of astronomical knowledge.

Levi Gersonides was without doubt the most creative representative of the Hebrew tradition, indeed one of the greatest scientists of his epoch. He too developed his astronomical views within the framework of a finely tuned and very comprehensive religious philosophy. Levi was both an observer and a theoretician, and, most notable, one of the rare breed who attempted to fit his own original theory, which had to answer to certain philosophical constraints, to his own observations. Among his other major achievements, Levi invented the Jacob's staff, a simple but accurate instrument for measuring the angular distances between stars; studied the errors involved in instrumental measurements; and arrived at a much greater (and hence more realistic) value for the distances of the stars than those accepted by his contemporaries.

Jews living in Islamic lands, most especially the Yemen, continued to study the ancient and medieval texts well into the twentieth century. In those countries the Hebrew tradition was maintained chiefly through the copying of manuscripts, often transcriptions of Arabic texts into the Hebrew alphabet. In European countries the study of Latin texts in Hebrew translation seems to have accelerated in the fifteenth and sixteenth centuries. Some three Hebrew translations of Georg Peurbach's *Theorica* were executed, and several Hebrew commentaries were written, *inter alia* by Moses Isserles of Cracow and Moses Almosnino of Salonika, both of whom were leading rabbis of their times.

There is little in the Hebrew tradition that reflects the great advances associated with the European scientific revolution. Joseph Delmedigo, a widely traveled Cretan who studied under Galileo, published the only lengthy and detailed Hebrew exposition of the new science. Other publications, such as Tuviah Cohen's *Maaseh Tuvia* (Tuvia's Opus), present the new science in somewhat abbreviated form; and yet other writings, such as Solomon Maimon's exposé of Newton's work, remain in manuscript. The Hebrew tradition revived during the nineteenth century, particularly due to the efforts of the *maskilim*, advocates for widening the intellectual horizons of Judaism, who published Hebrew scientific texts in a number of fields. With the re-establishment in the State of Israel of a native Hebrew speaking population, and, no less importantly, institutions interested in teaching and writing about astronomy in the Hebrew language, the quantity and scope of the Hebrew tradition have dramatically increased.

See Also

► Abraham Bar Ḥiyya (Savasorda)
► Abraham ibn Ezra
► Al-Khwārizmī
► Levi ben Gerson
► Zacut, Abraham

References

Beller, E. (1988). Ancient Jewish mathematical astronomy. *Archive for History of the Exact Sciences, 38*, 51–66.

Feldman, W. M. (1965). *Rabbinic astronomy and mathematics* (2nd ed.). New York: Hermon Press.

Gandz, S. (1970). In S. Sternberg (Ed.), *Studies in Hebrew astronomy and mathematics*. New York: Ktav.
Goldstein, B. R. (1979). The survival of Arabic astronomy in Hebrew. *Journal for the History of Arabic Science, 3*(1), 31–39.
Goldstein, B. R. (1981). The Hebrew astronomical tradition: New sources. *Isis, 72*, 237–251.
Goldstein, B. R. (1985a). Scientific traditions in Late Medieval Jewish communities. In G. Dahan (Ed.), *Les Juifs an regard de l'histoire. Mélanges en l'honneur de Bernhard Blumenkranz* (pp. 235–247). Paris: Picard.
Goldstein, B. R. (1985b). *The astronomy of Levi ben Gerson (1288–1344)*. New York: Springer.
Langermann, Y. T., Kuntizsch, P., & Fischer, K. A. F. (1989). The Hebrew astronomical codex Sassoon 823. *Jewish Quarterly Review, 78*(3/4), 253–292.

Astronomy: Indian Astronomy in China

Yukio Ōhashi

Chinese astronomy and Indian astronomy were originally independent. Both of them already had developed when Indian astronomy was introduced into China along with Buddhism. The exact date of the introduction of Buddhism into China is not known, but it can be said that Buddhism was gradually introduced at the beginning of the Later Han (Eastern Han) dynasty (AD 25–220) or so. According to my study, the earliest information on Indian astronomy reached China at the time of the Later Han.

During the Sanguo (Three Kingdoms) period (AD 220–265), some Buddhist works, where information of Indian astronomy was included, were translated into Chinese. At the time of the Tang dynasty (AD 618–907), some detailed monographs of Indian astronomy and astrology were composed in China. There were some astronomers who were well versed in both Chinese and Indian astronomy. Yixing was one of them.

It is not known whether Chinese astronomy was introduced into pre-modern India or not.

Indian Astronomy in the Later Han Dynasty

At the time of the Former Han (Western Han) dynasty (206 BCE–AD 23), there was no apparent foreign influence on Chinese astronomy. As Buddhism was already known at the time of the Later Han dynasty, there was a possibility that certain aspects of Indian culture, including astronomy, were also introduced into China.

According to my research, some fragments of information about the Indian calendar reached China at the time of the Later Han dynasty (Ōhashi, 1999). There are three reasons for my view:

1. When the Later Han *Sifen* calendar was compiled in AD 85, its first month was proposed to be large, although that was finally rejected. In the Chinese traditional calendar, the first month was small, because the first new moon occurs at the initial point of time, and the second new moon is included in the first day of the next month. To the contrary, the first month of the Indian traditional calendar was large, because the first new moon occurs at the initial point of time, and the second new moon is included in the last day of the same month. I suspect that the rejected proposal of the Later Han *Sifen* calendar might have been influenced by the Indian method.
2. The Later Han *Sifen* calendar has special days called *mori* and *mieri*, which did not exist in the Former Han dynasty. If 1 year is divided into 360 parts and 1 day is included within a part, the day is called *mori*. If the end of a day coincides with the boundaries of the parts, the day is called *mieri*. These days are of no use in Chinese traditional calendars, but they are similar to certain concepts of Indian traditional calendars, such as the method of intercalation in the *Arthaśāstra* (see the section on Yixing below; for details, see Ōhashi, 2001).
3. In Chinese traditional calendars, midnight is considered the beginning of a day. However, when the date of the half moon and full moon was calculated in the Later Han *Sifen* calendar, daybreak was considered to be the beginning of a day. In Indian traditional calendars,

sunrise is usually the beginning of a day. Therefore, the Chinese use of daybreak might have a connection with the Indian method.

From these three reasons, I suspect that certain information about the Indian calendar reached China. However, the information must have been fragmental, and did not influence the Chinese calendar very much.

Indian Astronomy in Chinese Buddhist Texts

The *Madengqie-jing*

At the time of the Sanguo (Three Kingdoms) period (mid-third century AD), a Buddhist text called *Śārdūlakarṇa-avadāna* in Sanskrit was translated into Chinese by Zhu Lüyan and Zhi Qian as the *Madengqie-jing*. This is the first Chinese text where Indian astronomy and astrology are explicitly mentioned. This text explains lunar mansions and the astrology based on them at length and also mentions some calendrical information.

The astronomical system of the *Śārdūlakarṇa-avadāna* is similar to *Vedāṅga* astronomy, which is one of the six branches of auxiliary learning for the *Veda*. According to my research, *Vedāṅga* astronomy was produced in North India sometime between the sixth and the fourth centuries BCE (Ōhashi, 1993). The description of astrology in the *Śārdūlakarṇa-avadāna* is also based on the Indian traditional system.

The original Sanskrit version of the *Śārdūlakarṇa-avadāna* has a description of the annual variation of the gnomon shadow, which is similar to that in *Vedāṅga* astronomy. The Chinese version, *Madengqie-jing*, also has a description of the annual variation of the gnomon shadow, but it is different from the Sanskrit original. Shinzō Shinjō, a pioneer of the study of the history of Eastern astronomy, pointed out that the description of the *Madengqie-jing* is based on the data around 43°N, and that the data might have been incorporated in Central Asia (Shinjō, 1928: pp., 217–218).

The *Śārdūlakarṇa-avadāna* was also translated into Chinese as the *Shetoujian-taizi ershiba-xiu jing* by Zhu Fahu at the time of Xi-Jin (Western Jin) dynasty (AD 265–316).

The *Daji-jing*

The *Daji-jing* (or *Dafangdeng-dajijing*) is a collection of *Mahāyāna* texts in Chinese. The *Yuecang-fen* (one text in the *Daji-jing*), which was translated by Narendrayaśa in AD 566, is the earliest Chinese text where zodiacal signs are mentioned.

The *Ricang-fen* (another text in the *Daji-jing*), which was translated by Narendrayaśa in AD 586, also mentions zodiacal signs. It is interesting to note that the annual variation of the length of daytime and that of the gnomon shadow, which are similar to those of the *Vedāṅga* astronomy, are mentioned there, but the position of the sun corresponding to their data is given with reference to zodiacal signs. This means that the system of *Vedāṅga* astronomy was still in use when Greek horoscopy reached India. *Vedāṅga* astronomy was widely used in India from sometime between the sixth and the fourth centuries BCE to sometime during the second and fourth centuries AD, and was mixed with the system of zodiacal signs which was introduced into India along with Greek horoscopy in the second or third century AD (Ōhashi, 2002).

The *Ricang-fen* of the *Daji-jing* is, therefore, an important source for studying the history of Indian astronomy. It says that the length of daytime and nighttime is 15 *shi* (which corresponds to Indian *muhūrta* or 1/30 of a day) in the months of Scorpio and Taurus, and that daytime is 12 *shi* (minimum) and nighttime is 18 *shi* (maximum) in the month of Aquarius, and daytime is 18 *shi* and nighttime is 12 *shi* in the month of Leo. The length of daytime and nighttime changes linearly. The above-mentioned data look strange at first sight. The relationship between the length of daytime and nighttime and the sign of zodiac differs by one. For example, the above data tell that the vernal equinox occurs in the month of Taurus, and not in the month of Aries. The only possible explanation of this difference is that the data of the length of daytime and nighttime is for the beginning of the month, and the sign of the zodiac is for the end of the month. The linear function of the length of daytime and nighttime is the same in *Vedāṅga* astronomy. My studies reveal that this function is not the result of interpolation from the observational data around the solstices, but the result of extrapolation from the observational data around the equinoxes in North India. The *Ricang-fen* also gives the length of the midday gnomon shadow, which is basically the same as in *Vedāṅga* astronomy, which is also based on observational data from North India. Here, we can see that *Vedāṅga* astronomy was still widely used even after Greek horoscopy was introduced into India (Ōhashi 2002).

Indian Astronomy During the Tang Dynasty

The *Jiuzhi-li*

One system of Hindu Classical Astronomy was introduced into China. It was recorded in Chinese as the *Jiuzhi-li* (AD 718) of Qutan Xida, which is included in his (*Da-*)*Tang Kaiyuan-zhanjing*. The author, Qutan Xida (probably a Chinese transliteration of his Indian name Gotama Siddha), belonged to a family of Indian astronomers in China and was the director of the national observatory. In the title *Jiuzhi-li*, *jiuzhi* corresponds to the Sanskrit word *navagraha* ["nine planets", i.e. sun (Ravi or Sūrya), moon (Candra), five planets – Mars (Maṅgala), Mercury (Budha), Jupiter (Bṛhaspati or Guru), Venus (Śukra) and Saturn (Śani), Rāhu (ascending node of the lunar orbit) and Ketu (usually considered to be the descending node of the lunar orbit)]; *li* means calendar. This work explains the method for calculating the sun's longitude, the moon's longitude, and solar and lunar eclipses, etc. This text also contains a sine table. The work also says that Indian numerals are mentioned, but the actual shape of the figure has not come down in extant texts.

Kiyosi Yabuuti pointed out that some astronomical constants of the *Jiuzhi-li* are similar to the *Sūryasiddhānta*, which was summarized in the *Pañcasiddhāntikā* of Varāhamihira (sixth century AD). This is a text of the *Ārdharātrika* school of Classical Hindu Astronomy (Yabuuti, 1944/1989, 1979; also see Yano, 1979).

It is interesting to note that the traditional calendars of mainland Southeast Asia (except for Vietnam) and also the classical astronomy of Tibet are related to the *Ārdharātrika* school. It may be that the *Ārdharātrika* school was quite popular among Buddhists. The *Jiuzhi-li* has never been used as an official calendar in China, because the tradition of Chinese original astronomy was so strong.

Yixing

There was also a famous monk, astronomer Yixing (AD 683–727), who knew about Indian astronomy. For example, he mentioned the Indian zodiac in his *Dayan* calendar. However, he made his *Dayan* calendar in a Chinese traditional way. There is only one thing which I suspect shows Indian influence in his *Dayan* calendar. It is the change of the meaning of *mieri*.

Yixing explained the method to calculate the *mieri* as follows:

> If the *xiaoyu* (time in terms of 1/3,040 day) of the mean new moon is less than *shuoxufen* (=1,427), subtract the *xiaoyu* from the *tongfa* (=3,040), and multiply the result by 30, and subtract the result from *miefa* (=91,200). Divide the result by *shuoxufen*. The result is the number of days. Count the days from the mean new moon day and take the day after the resultant day. It is the *mieri*.
>
> The meaning of this *mieri* is as follows. Let a synodic month be divided into 30 parts. Then, sometimes a part is included within a day. This kind of day is the *mieri* defined by Yixing. This *mieri* is similar to the "omitted *tithi*" in Indian calendars. In *Vedāṅga* astronomy, a *tithi* was a 1/30 part of a synodic month, where the equation of centre was not known. In Hindu Classical Astronomy, a *tithi* is a period of time during which the longitudinal difference of the sun and moon changes by 12°. If a *tithi* is included within a day, the *tithi* is called "omitted *tithi*". In Hindu traditional calendars, the name of a civil day is determined by the number of *tithi* at the beginning (sunrise) of the day. Therefore, the number of an omitted *tithi*, which does not include any sunrise, actually disappears from the calendar.

The significance of Yixing's definition is that when the sum of the *mori* (a day which is included within a segment of 1/360 of a tropical year) and *mieri* grows to 30, one intercalary month is produced. This way of thinking is similar to certain descriptions in Indian classics, such as the *Arthaśāstra*. A similar description is also found in a Chinese version of the Buddhist text *Lishi-apitan-lun*, translated by Zhendi at the middle of the sixth century AD.

I suspect that Yixing knew this Indian method, and changed the meaning of the *mieri* in order to make it meaningful in Indian calendrical context (Ōhashi, 2001).

Other Texts in the Tang Dynasty

In addition to the above-mentioned texts, the *Suyao-jing* is also famous. In the title, *su* means lunar mansions, *yao* means planets and *jing* means canonical scripture. It is an astrological work which was compiled by Amoghavajra in the middle of the eight century AD. It is based on Indian horoscopic astrology.

There is also an astrological work with planetary ephemerides entitled *Qiyao-rangzaijue*, compiled by Jin Juzha, who is said to have been a Brahman priest from Western India, in the early ninth century or so. In the title, *qiyao* means seven planets, and *rangzaijue* means formulae to avoid disasters (caused by planets). This work is a kind of mixture of Indian astrology and Chinese astronomy. It includes the ephemerides of the five planets, Rāhu, Ketu and the sun. In Indian astronomy, Ketu usually means the descending node, or comets. However, Ketu in the *Qiyao-rangzaijue* is, according to Michio Yano's study, the apogee of the lunar orbit. This is a special feature of this work (Yano, 1986).

We have seen some records of Indian astronomy in Chinese sources. We have to keep in mind that Indian influence on Chinese astronomy was very small. The tradition of Chinese original astronomy was very strong, and it seldom accepted foreign influence. However, we can find some exceptional influences in Chinese sources, and these exceptions draw attention to researchers.

References

Ōhashi, Y. (1993). Development of astronomical observation in Vedic and post-Vedic India. *Indian Journal of History of Science, 28*(3), 185–251.

Ōhashi, Y. (1999). Historical significance of mathematical astronomy in Later-Han China. In Y. S. Kim & B. Francesca (Eds.), *Current perspectives in the history of science in east Asia* (pp. 259–263). Seoul, South Korea: Seoul National University Press.

Ōhashi, Y. (2001). Preliminary remarks on the origin of "Mori" and "Mieri" in Chinese calendars. In K. Tatsuhiko et al. (Eds.), *Proceedings of the fourth international symposium on the history of mathematics and mathematical education using Chinese characters, Maebashi, 1999* (pp. 97–102). Maebashi, Japan: Maebashi Institute of Technology.

Ōhashi, Y. (2002). The legends of Vasiṣṭha – a note on the Vedāṅga astronomy. In S. M. Razaullah Ansari (Ed.), *History of oriental astronomy* (pp. 75–82). Dordrecht, Netherlands: Kluwer Academic Publishers.

Shinjō, S. (1928). *Tōyō tenmongaku-shi kenkyū (A study of the history of astronomy in the east, in Japanese).* Kyoto, Japan: Kōbundō. Rpt. Kyoto: Rinsen-shoten, 1989.

Yabuuti, K. (1944). *Zuitō rekihō-shi no kenkyū (A study of the history of calendars during Sui and Tang dynasties, in Japanese)*. Tokyo, Japan: Sanseidō. Revised ed. Kyoto: Rinsen-shoten, 1989.

Yabuuti, K. (1979). Researches on the *Chiu-chih li* – Indian astronomy under the T'ang dynasty. *Acta Asiatica, 36*, 7–48.

Yano, M. (1979). The *Chiuchih-li* and the *Ārdharātrika-pakṣa* on the true daily motion of the moon. *Indogaku-bukkyōgaku-kenkyū (Journal of Indian and Buddhist Studies), 27*, 6–9.

Yano, M. (1986). The *Ch'i-yao jang-tsai-chüeh* and its ephemerides. *Centaurus, 29*, 28–35.

Atomism in Islamic Thought

Alnoor Dhanani

Atomism, the view that there are discrete irreducible elements of finite spatial or temporal space, played a significant role in Islamic intellectual history. It was upheld by most practitioners of the uniquely Islamic discipline of kalām. However, some practitioners of *kalām* (i.e., *mutakallimūn*) as well as all but one of the practitioners of *falsafa* (i.e., *falāsifa* – those engaged in the Neoplatonized Peripatetic philosophy of medieval Islam) were antiatomists. There was thus a lively debate between atomists and antiatomists, regarding not only matter theory, but also other areas of natural philosophy and cosmology, particularly theories of space, time, void, motion, and causality.

Kalām has no counterpart in the Western tradition. Even though primarily theological in orientation, it is not equivalent to theology. The subject matter of *kalām* includes not only theological topics, e.g., the nature and attributes of God, prophecy, and revelation, but also philosophical problems of cosmology, logic, anthropology, psychology, etc. The origins of *kalām* are obscure and a subject of debate. Suffice it to say that *kalām* arose in the mid-eighth century, and that during the later half of that century, questions about the nature and attributes of objects were being discussed. In their discussion of such questions among themselves and with others from the various religious and intellectual traditions of the Hellenized Near East, the *mutakallimūn* had access to views and theories propounded by the intellectual, doctrinal, and sectarian movements of Late Antiquity: Neoplatonism, Stoicism, Manicheanism, Dualism, Bārdaiṣānism, etc. Little is known about the *mutakallimūn*'s manner of access to these views. It was probably oral and through personal contact. Such a transmission is in sharp contrast with the large-scale translation of Greek philosophical and scientific texts during the late eighth and ninth centuries which gave rise to *falsafa*.

The *mutakallimūn* of the late eighth century held three theories of matter and its attributes. In the first, bodies are the only constituents of the world. All secondary qualities like sound, taste, color, etc. are thus corporeal. It follows that perceptible objects consist of several interpenetrating bodies. This view, whose origins are Stoic, was held by some Dualists. Its early *kalām* subscribers were ḥishām ibn al-ḥakam (d. ca. 795), and al-Aṣamm (d. 815). Later, the antiatomist Ibrāhīm ibn Sayyār al-NaẒẒām (d. 835–845) advocated it, albeit holding that motion was the sole accident.

In the second theory, unextended accidents are the only constituents of the world. Extended bodies result from a combination of accidents, namely, color, taste, hot/cold, rough/smooth. The origins of this view lie in Neoplatonism and Christian theology. Its *kalām* subscribers were ḍirār ibn ʿAmr (d. 815), ḥafṣ al-Fard (fl. 810), and ḥusayn al-Najjār (d. ca. 835–845).

The third theory holds that accidents and bodies constitute the world, and that bodies are constituted from atoms. This view had its partisans among the Dualists and the Bārdaiṣānites. It was appropriated into *kalām* by Abū al-Hudhayl al-ʿAllāf (d. 841) of the Basrian Muʿtazilī school of *kalām*; the Baghdadī Muʿtazilī Bishr ibn al-Muʿtamir (d. 825–840); and Muʿammar ► ibn ʿAbbād al-Sulamī (d. 830). Towards the mid-ninth century, the atomic theory displaced its rivals to become the dominant physical theory of kalām. Atomism was upheld by the Ashʿarī *kalām* school formed in the tenth century in opposition to Muʿtazilīs, particularly regarding questions of man's free will and God's absolute power. However, atomism was attacked by the *falāsifa* who upheld Aristotelian arguments. In the eleventh century, the Basrian Muʿtazilī Abū al-ḥusayn al-Baṣrī (d. 1044) embraced *falsafa* physical theory and abandoned atomism. Atomism declined further in the twelfth and later centuries with the growing influence of Ibn Sīnā's (d. 1037) philosophy. Even though atomism was never actually abandoned, it was no longer central to post-twelfth century *kalām*.

As none of the writings on physical theory of the eighth and ninth century *mutakallimūn* has survived, their theories must be reconstructed from extant fragments. The principal source has been the doxography, *Maqālāt al-islāmīyīn* (The Doctrines of Muslims) by the former Muʿtazilī and founder of Ashʿarī *kalām*, Abū al-ḥasan al-Ashʿarī (d. 935). The following account of early atomism may be drawn: early *kalām* atomists distinguished between the atom (denoted by *jawhar* (atom), *juz*ʾ (part), *al-juzʾalladhī lā yatajazza*ʾ (the indivisible part)) and the body. The body has length, breadth, and depth, while the atom lacks these dimensions (however al-ṣāliḥī [fl. end of ninth/early tenth century] held that the atom was a body). Rather, they believed that dimensions are produced by combinations of atoms. Hence, a minimal length arises when two atoms combine (or, in the formulation of the *mutakallimūn*, a line is formed by the combination of two atoms). There were different views on the minimal number of atoms which constitute a body having length, breadth, and depth: Abū al-Hudhayl held that it was six; Muʿammar held that eight were required; and Abū al-Qāsim al-Balkhī (d. 931) held that four sufficed.

There are obvious parallels between *kalām* and Greek atomism regarding proofs for the existence of atoms, as well as terms which denote the atom. Yet the concept of dimensionless atoms combining to form bodies with dimension is unique to *kalām*. New light has been shed on this puzzling view, and on *kalām* physical theory in general, by the rediscovery of eleventh century sources. Of particular importance are the Basrian Muʿtazilī texts of Ibn Mattawayh and Abū Rashīd al-Nīsābūrī (both fl. first half of eleventh century), as well as Ashʿarī texts by Abū al-Maʿalī al-Juwaynī (d. 1085) and Ibn Fūrak (d. 1015). These sources reveal that, in his reformulation of *kalām*, the Basrian Muʿtazilī Abū Hāshim al-Jubbā'ī (d. 933) had redefined the atom as "that which occupies space (*mutaḥayyiz*)," a designation which was also applied to the body. From this designation, as well as arguments advanced in support of the theses that the atom has magnitude (*miṣāḥa*) and its shape resembles a cube, it is clear that the atom must somehow be extended (the Ashʿarī *mutakallim* Abū Bakr al-Fūrakī (d. 1085) states: the atom is the smallest of what is small with respect to volume). Paradoxically, these *mutakallimūn* insisted that despite its magnitude the atom lacked length, breadth, and depth. Like their earlier colleagues, they continued to hold that dimensions were produced by combinations of atoms. Moreover, they considered any difference between their view of the atom and the earlier view as marginal; it was partially conceptual but partially a result of the manner of expression.

These texts suggest the interpretation that a geometry of discrete space underlies kalām atomism (as in Epicurean atomism). In ancient and medieval thought, any distinction between geometrical and physical space was inconceivable. If physical space was continuous, then so was geometrical space. Likewise, discrete physical space meant discrete geometrical space. Hence, *kalām* formulations of "indivisible," "dimension," "magnitude," and "body" need to be analyzed within discrete geometry. Here, a point, which is defined as that which has no parts, is equivalent to the indivisible magnitude (i.e., atom). Next, a line, which is terminated by two end points, must consist of at least two indivisibles. It follows that two indivisibles constitute the least line and are the least to constitute the dimension of length. The *kalām* atom cannot, thus, have length, breadth, or depth, but it has magnitude for it is an indivisible of discrete (and not continuous) geometry. The combination of atoms to form linear dimensions is no longer problematical; unlike points of continuous geometry which lack both dimension and magnitude, atoms/indivisibles of discrete geometry have minimal magnitude yet lack dimension. Such atoms combine to form objects with larger magnitudes and dimension. In a discrete geometry whose indivisibles are square-shaped (as seen from a continuous geometry, for the *mutakallimūn* state that the atom *resembles* a square; having no dimensions it cannot be a square!), one may configure minimal bodies from four, six, or eight atoms.

In his critique of atomism, Aristotle argued that atomism entails indivisible parts of space, time, and motion. Accordingly, most eighth and ninth century atomist *mutakallimūn*, and many later *mutakallimūn* upheld the minimal parts of space, time, and motion. In the tenth century, Abū Hāshim al-Jubbā'ī abandoned the minimal parts of space (and consequently minimal parts of time and motion) in response to difficulties raised by antiatomists. His successors did not all adopt this view; some continued to say that space, time, motion, and matter were constituted out of indivisibles. We may also note that the atomist *mutakallimūn* upheld the existence of void spaces.

Atomism posed several conceptual and geometrical difficulties, some of which are traceable to Aristotelian arguments against atomism. It may be relevant to mention some Islamic contributions. One argument formulated by Abū al-Hudhayl, which is based on Zeno's dichotomy paradox, was the ant and sandal argument. Imagine an ant creeping over a sandal. In order to traverse the sandal, the ant must first traverse half the sandal; but to traverse half, the ant must first traverse half of this, and so on. Hence the traversal cannot commence unless the division terminates at an indivisible (i.e., atom). Abū al-Hudhayl's student, the antiatomist al-NaẒẒām, responded with his theory of leap (*ṭafra*), saying the ant does not traverse through all points on the path of traversal, but it traverses through some and leaps over others. Hence, al-NaẒẒām claimed, one may traverse from one location to another without traversing all intervening points. The theory of leaps played an important role in discussions of physical theory, if only to illustrate the absurdity of the actually infinite division of matter which was attributed to al-NaẒẒām. Al-NaẒẒām also formulated a clever argument against atomism. Imagine a rotating millstone. Since both an inner circle and the millstone's circumference must complete a rotation in equal time, when an inner circle is ten atoms in length, and the circumference is a hundred atoms, for each unit of space traversed by an atom on the inner circle, an atom on the circumference would have to traverse ten units. Explaining this, al-NaẒẒām resorted to his theory of leaps: when an atom on the inner circle moves one unit, an atom on the circumference moves one unit and leaps nine units. Abū al-Hudhayl, however, responded that the atom on the inner circle moves for one time unit and rests for nine units, while the atom on the circumference moves for all ten units. Al-NaẒẒām objected that this entails that particles of a solid body cannot adhere to each other but must be set loose to allow for such moments of motion and rest. Hence, a rotating solid body must disintegrate (*tafakkuk*) and its internal configuration of atoms be modified. The atomist *mutakallimūn*, unable to answer al-NaẒẒām's challenge, accepted the internal disintegration of a rotating body. However, they considered it to be analogous to a salt shaker where salt particles move freely within the confines of the shaker.

Why did the *mutakallimūn* embrace atomism? This question has puzzled researchers, particularly given the difficulties atomism raised. The thesis that atomism was theologically more acceptable than the continuously divisible matter theory of the *falāsifa* has been widely accepted. Continuous divisibility raises problems of infinity, and the *mutakallimūn* were mindful of the relationship between ending infinite regress in the argument for the temporal creation of the world and the argument for the divisibility of matter. Yet the question still remains as to why three theories of matter were considered theologically sound in early kalām, and why early atomists did not claim that their theory was, theologically, the most sound. The assertion that antiatomists were heretics is only found after the tenth century when atomism had triumphed. The question of the affinity of atomism to occasionalism has also been raised, but this needs to be reexamined in the light of new sources.

Atomism was also upheld by the famous physician and *faylasūf* Abū Bakr Muḥammad ibn Zakariyāʾ ► al-Rāzī (d. 925). However, surviving accounts are scanty. We only know that his atoms were extended (like Democritus' atoms). Atomism is part of al-Rāzī's cosmology of the five eternals: God, Soul, Space, Time, and Matter upheld by the ṣābians of ḥarrān. Some of al-Rāzī's views may derive from Irānshahrī (fl. late ninth century) about whom very little is known.

See Also

► al-Rāzī
► Ibn Sīnā (Avicenna)

References

Baffioni, C. (1982). *Atomismo e Antiatomismo nel Pensiero Islamico*. Naples, Italy: Instituto Universitario Orientale.

Dhanani, A. (1994). *The physical theory of Kalām: Atoms, space, and void in Basrian Muʿtazilī cosmology*. Leiden, Netherlands: Brill.

Frank, R. (1984). Bodies and atoms: The Ashʿarite analysis. In M. E. Marmura (Ed.), *Islamic theology and philosophy: Studies in honor of George F. Hourani* (pp. 39–53). Albany, NY: State University of New York Press.

Pines, S. (1936). *Beitrāge zur islamischen Atomenlehre*. Berlin, Germany: Heine.
Sorabji, R. (1983). *Time, creation, and the continuum: Theories in antiquity and the early middle ages*. Ithaca, NY: Cornell University Press.
Sorabji, R. (1988). *Matter, space, and motion: Theories in antiquity and their sequel*. Ithaca, NY: Cornell University Press.
van Ess, J. (1978). *Theology and science: The case of Abū Isḥāq al-NaẒẒām*. Ann Arbor, MI: Center for Near Eastern and North African Studies, University of Michigan.
van Ess, J. (1991). *Theologie und Gesellschaft im 2. und 3. Jahrhundert Hidschra*. Berlin, Germany: Walter De Gruyter. 6 vols to date.
White, M. (1992). *The continuous and the discrete: Ancient physical theories from a contemporary perspective*. Oxford, UK: Oxford University Press.
Wolfson, H. A. (1977). *The philosophy of the Kalam*. Cambridge, MA: Harvard University Press.

Ātreya

Guy Mazars

Ātreya or Punarvasu Ātreya was probably the physician of an ancient king of Gāndhāra. The name Ātreya implies that he was either a descendant or a disciple of Atri, a sage mentioned in the *Veda*. The date of Ātreya may be fixed before the grammarian ► Pāṇini (seventh century BCE) and after the *Atharvaveda* (1200 BCE), ca. 1000 BCE.

On the basis of his teachings, six of his disciples composed medical treatises. One of them, Agniveśa, wrote the *Agniveśatantra* or 'System of Agniveśa', which became known as the *Carakasaṃhitā* after its revision by ► Caraka. Another disciple, Bhela, wrote the *Bhelasaṃhitā*, which has fragmentarily been preserved in a single manuscript. Unfortunately, the text is mutilated and full of scribe's errors. Some scholars are of the opinion that the *Bhelasaṃhitā* may be older than the *Carakasaṃhitā*. The *Hārītasaṃhitā* is ascribed to a third disciple, also called *Ātreyasaṃhitā*. But the text that has come down to us is regarded as a relatively late work of an apocryphal nature, though parts of it might be old.

As to the treatises composed by the other three disciples of Ātreya, they have not been preserved. But quotations from their works occur in many commentaries. Two other Ātreya, Kṛṣṇātreya and Bhikṣu Ātreya, are mentioned in the *Carakasaṃhitā*. According to the *Mahābhārata*, the 'Great Epic of India', Kṛṣṇātreya was the founder of a medical school. There is mention of another Ātreya connected with the Buddhist University of Takṣaśilā. He was the teacher of a contemporary of Buddha (fifth century BCE), the famous surgeon Jīvaka to whom tradition attributes extraordinary operations.

References

Meulenbeld, G. J. (1974). *The Mādhavanidāna and its chief commentary, chapters 1–10, introduction, translation and notes*. Leiden: E. J. Brill.
Mukhopadhyaya, G. (1922–1929 [1974]) *History of Indian medicine: Containing notices, biographical and bibliographical, of the Ayurvedic physicians and their works on medicine, from the earliest ages to the present time* (2nd ed., 3 vols.). Calcutta: University of Calcutta, New Delhi: Oriental Books Reprint Corporation.
Raison, A. (1974). *La Hārītasaṃhitā. Texte médical sanskrit avec un index de nomenclature āyurvédique*. Pondicherry, India: Institut Français d'Indologie.
Sharma, P. V. (Ed.). (1992). *History of medicine in India from antiquity to 1000 A.D*. New Delhi, India: Indian National Science Academy.

Aztec Science

Frances Berdan
California State University San Bernardino,
San Bernardino, CA, USA

The name Aztec most commonly refers to Nahuatl-speaking people who dominated the Basin of Mexico, and indeed much of central and southern Mexico, in the fifteenth and early sixteenth centuries. The most prominent of these people called themselves Mexica. They settled their island city of Tenochtitlan (today Mexico City) in AD 1325, in the midst of a large number of well-established cities. The Mexica, as hunter and gatherer immigrants from the northern Mexican deserts, were latecomers to the Basin of Mexico and combined their nomadic-style culture with the ways of life of long-settled villagers and urban dwellers. In the fifteenth and early sixteenth centuries, numerous different ethnic groups coexisted in the Basin of Mexico; these groups were politically organized in city-states and exhibited visible emblems of their specific cultural identities (such as patron gods, clothing styles, and distinctive languages and dialects). Three of these groups, the Mexica of Tenochtitlan, the Acolhua of Texcoco, and the Tepaneca of Tlacopan, joined in a military alliance in AD 1430, creating the Aztec empire which subsequently conquered much of Mexico. The empire was short-lived; Tenochtitlan was conquered in AD 1521 by Spanish forces.

The Mexica were the last of a long succession of complex states and civilizations in pre-Hispanic central Mexico. As such, they inherited many cultural traditions from prior civilizations, including much in the scientific realm. The Mexica were devout admirers of their predecessors, the Toltecs (ca. AD 950–1150), to whom they attributed much of their scientific knowledge. This included medicine, geology and mining, astronomy and calendrics, architecture, and fine technical arts (especially featherworking, metal-working, and stone-working). While the Mexica honored the Toltecs with these inventions, most of these skills and surely much of this knowledge clearly predated the rise of the Toltec civilization in central Mexico.

Mexica society was hierarchical and highly specialized. In general, pronounced distinctions between nobles and commoners, between different occupational specialists, and between members of different ethnic groups also meant differences in access to certain scientific knowledge and specialized training. Noble boys were educated in priestly schools where the curriculum included literacy skills, astronomically based calendrics, and the learning of histories, orations, and songs. Some highly placed individuals actively pursued scientific knowledge and were renowned as great thinkers or philosophers. Medicinal knowledge and skills were in the hands of highly trained physicians, who appear in the documents as men or women skilled in herbal remedies and treatments of injuries and afflictions. Midwives also applied their extensive medical knowledge to the curing enterprise. Specific forms of scientific knowledge, embedded in industrial arts such as stone- or feather-working, were typically the province of exclusive occupational (and sometimes ethnic) groups, who passed on their craft from parent to child. Engineering and architecture (manifest, for instance, in the construction of buildings, dikes, and elaborate irrigation works) would have required special training, perhaps in an apprentice-style setting. Unfortunately, the documents are silent on this. Much knowledge of agronomics, as in genetic engineering of food crops, was probably developed by farmers themselves, who slowly but persistently developed increasingly productive strains of maize and other crops. While documentary evidence is uneven and inconclusive, it appears that some scientific knowledge was developed and passed on in a formal, literary context while other knowledge (such as seed selection and midwifery) was maintained in a more informal folk realm.

Mexica scientific understandings were empirically based, but also closely linked to religious beliefs. To the Mexica and their neighbors, the natural and supernatural worlds shaded into one another, and their practical scientific inquiries cannot be understood apart from their religious concepts and abstract symbolism. So, for example, empirical astronomy was intertwined with astrology and predictions of human fates. The involved system of calendrics was largely based on prolonged astronomical observations, but the calendars themselves were applied to godly demands and ritual as well as practical ends. Medicine combined pragmatic remedies with shamanism, divination, and magical cures. Glyphic writing, sculpture, architecture, and the luxury crafts of stone-, feather-, and metal-working all relied on sophisticated and well-honed practical technologies; the resulting works served secular goals and/or displayed essentials of Aztec religious symbolism. Animals and plants resided in the everyday, visible natural world, but also carried a heavy load of abstract meaning in the less tangible world of mythology and cosmic forces. To the Mexica and their neighbors, then, an empirical, scientific realm of understanding and inquiry was intricately intertwined with a more abstract, religious realm.

Mexica scientific concepts and knowledge are understood only imperfectly today, mainly due to the paucity of primary source materials on the subject. The ancient peoples of central Mexico, including the Mexica, maintained extensive libraries of pictorial books (codices), but almost all of these were destroyed during or shortly after the Spanish conquest in 1521. An Aztec exception is the *Matrícula de Tributos* (1980) which contains numerous illustrations of plants and animals embedded in place name glyphs, as well as indications of geographical sources of certain raw materials (such as jaguar pelts, precious stones, gold, woods, birds, and feathers). Some of the information contained in pre-Columbian books (such as the *Matrícula* and others now lost) was reproduced or reconstructed following the Spanish conquest and set down in written and/or pictorial form, usually under the supervision of Spanish friars. The most famous of these, and one which includes considerable textual and pictorial information on astronomical knowledge, natural history, and medicinal practices, is *Historia general de las cosas de Nueva España* [General History of the Things of New Spain (Florentine Codex)]. This compendium relied on native informants and was compiled in the Nahuatl (Aztec) language by the Franciscan friar Bernardino de Sahagún (1950–1982).

Additional early colonial codices contain interesting scientific details, such as the images of plants and animals in place name glyphs and a star-gazing priest in the Codex Mendoza (Berdan & Anawalt, 1992) or the several herbal remedies pictured and described in the Cruz-Badiano herbal (Bye & Linares, 2013). Also available, and providing variable enlightenment on native scientific concepts, are Spanish-language histories and descriptions of the Mexica and their neighbors by Spanish secular and religious officials. Among the most revealing of these are the natural histories of Francisco Hernández (1959) and Gonzalo Fernandez de Oviedo y Valdés (1959), although the latter focuses primarily on areas to the south and east of the Aztec imperial domain. These postconquest sources blend native concepts and information with European understandings and conventions and must be read in that light.

Written sources are augmented by the material remains of the people themselves, discovered and interpreted archaeologically. The remains of structures provide clues to architectural and engineering skills; urban layouts suggest detailed understandings of the movements of celestial bodies; artifacts in metal, stone, and feathers (and the tools that produced them) reveal sophisticated industrial technologies; and ancient food remnants, such as corncobs, demonstrate a steady enhancement of crop productivity through hybridization and selective breeding. In addition, human physical remains have left clues to Aztec health, nutrition, and medical practices.

A closer look at astronomy, natural history, and medicine is presented below to illustrate the nature, extent, and goals of Mexica scientific inquiry.

Cosmology, Astronomy, and Astrology

Like their forebears and contemporary neighbors, the Mexica were sophisticated observers of astronomical phenomena. Systematic celestial observations and studies were reportedly the domain of the elite. Imperial rulers such as Motecuhzoma Xocoyotzin (r. Tenochtitlan 1502–1520) had duties which included observing star groups in the night sky, as well as carefully following the morning star, Venus. Nezahualpilli, early sixteenth-century ruler of neighboring Texcoco, spent endless nocturnal hours observing and recording the movements of celestial bodies from the roof of his royal palace. This "observatory" was structured so a man could lie down and contemplate the night sky through small perforations through which were placed lances with cotton spheres atop. While this description of observing techniques is vague and not entirely clear, it does indicate that careful, rigorous, naked-eye techniques were employed to follow changes in the celestial realm.

Although rulers may have spent some of their nighttime hours studying the heavens, this activity was more commonly performed by priests, who spent many waking hours at night. The Codex Mendoza shows one such priest engaged in observing the heavens for the purpose of marking the passage of time. Some temples may have served as "sighting stations" or observatories, from which pairs of crossed sticks were aligned to gain accurate lines-of-sight to celestial phenomena. Lines-of-sight were also established between temples and recognizable points on the horizon and between specific urban structures. The passage of the sun through the seasons could be readily charted in this fashion, with solstices and equinoxes especially marked. For instance, in Tenochtitlan the spring equinox was marked by the passage of the sun directly through an opening between the twin shrines of the Great Temple. This was extremely important to the Mexica; reportedly the emperor Motecuhzoma, micro-managing new construction of the temple, ordered imprecise work torn down and rebuilt to assure the temple conformed to its spring equinox alignment (Motolinia, 1971). This emphasis on precision, along with the various observational devices and techniques, also allowed the ancient Mexicans to track the phases of the moon, record the arrangements of star groups (constellations), follow the movements of the Pleiades, calculate the revolution of Venus, and predict eclipses. They also attended to other celestial phenomena such as meteor showers and comets. Their eyes and minds were glued to the heavens (Aveni, 2001, 2012).

The movements of the sun, stars, moon, and planets had important practical and ritual applications for the Mexica and their neighbors. They were especially concerned with the passage of time and developed complex and accurate calendars of 365 and 260 days. The former was a solar calendar especially used in seasonal agricultural and state-ceremonial planning; the latter, approximating periods of human gestation and the agricultural cycle, was the basis for divination and astrological determinations. Combined, these two calendars yielded a 52-year cycle which carried a heavy load of complex symbolism and obligatory rituals. To the Mexica, time was cyclical and repetitive, and much as the individual seasons and years came and went with marked similarity, so also did the 52-year "centuries." The fate-oriented Mexica also saw cycles in the creation and destruction of the universe. Legends told of four prior worlds and their destructions, with the Mexica living in the "fifth sun." A great deal of carefully prescribed ritual and human sacrifice was required of the central Mexicans to assure the maintenance of this world, whose continuance was especially vulnerable at the closing of each 52-year unit. Thus, a great deal of cultural interpretation was lent to the systematic visual astronomical observations of priests and rulers.

The Mexica conception of the universe and its heavenly bodies was a combination of scientific observations and ideological constructs. Celestial and terrestrial space was united in a hierarchical scheme containing thirteen heavenly layers and nine layers of the underworld. Heavens and underworld were linked by the earth's surface, which was counted in each. The world above the earth combined visible phenomena with invisible gods and goddesses; for instance, the moon occupied the layer above the earth, followed by the clouds in the next tier, then the sun, Venus, and the Fire Sticks constellation (possibly the belt and sword of Orion) in successive levels. It should be kept in mind that certain celestial bodies, especially the sun, moon, and Venus, were not only visible phenomena but were also accorded divine status. Heavenly layers contained invisible deities, with the male/female creator god at the apex. This whole, integrated arrangement is quite different from the heliocentric (sun-centered) and geocentric (earth-centered) concepts developed in the Eastern Hemisphere.

The linking of heavens and earth is manifest in much of central Mexico's urban planning. Some scholarly arguments favor the position that cities and temples conform to astronomically significant alignments. The orientation of Teotihuacan (ca. AD 1–650/750), for instance, may have been associated with the movements of the Pleiades (Aveni, 2012), and we have already seen the spring equinox orientation of Tenochtitlan's Great Temple. At least some astronomically based alignments directed city planning, although its extent is currently debated (see Smith, 2008). In those cases where the ancient Mexicans oriented their centers and temples along astronomically meaningful lines, the human, sacred, and scientific were meshed into a single cultural realm.

Natural History and Ecology

Like the celestial bodies above the earth, the natural phenomena on and in the earth were viewed both scientifically and symbolically. In this close perceived link between natural and supernatural, the creatures of the earth performed a variety of functions in both visible and invisible cultural realms. Birds and beasts were valued as providers of food, fur, and feathers, but were also frequent subjects of metaphors and players in myths and legends. The concrete and abstract were linked: the roles that creatures played in myths, the meanings they carried in the ritual calendar, and the messages they conveyed in metaphors were based on empirical observations of behavior, life cycles, and anatomy (see Berdan, 2014). For example, a human fugitive was likened to a fleet deer, the patting of tortillas compared to the flapping wings of a butterfly, and an eavesdropper described as the little mouse that inhabited every nook and cranny of a house. Close, systematic observations also led to an understanding of the transformations of the hummingbird, which seemingly died during nighttime or winter months and came to life in the warmth of day or springtime. Not surprisingly, hummingbirds were associated with human life-death transformations.

Much of the study of wild creatures undoubtedly took place in the animals' natural habitat, so that, for instance, the wily hunting techniques of the bobcat, the reproduction of locusts underground, and the nesting of certain birds in "inaccessible places" are recorded. However, the Mexica also maintained a large zoo and aviary in the city of Tenochtitlan, and such a setting would have provided ample opportunity for some degree of observation and study. This was particularly significant for understanding birds and beasts from distant parts of the empire; these were especially valued for their fine feathers or precious pelts.

Habitats of various creatures were meticulously recorded, surely from direct attention to nature: the gray fox was a cave dweller, the tadpole lived in freshwater among algae and water lilies, the raccoon preferred forests and crags, and so on. The many parts of nature were perceived as interconnected: the American Bittern's enthusiastic nighttime singing predicted heavy rains and abundant lacustrine fish; the Ruddy Duck's evening antics signaled rain at dawn; the song of yet another bird heralded the onset of frost.

The Mexica readily understood relationships among the various creatures themselves, including humans. Human involvement in ecological dynamics at times had significant consequences. The Mexica were aware of the rarity of certain creatures, such as the wood ibis or certain serpents; indeed, they considered it a bad omen to catch the wood ibis, a cultural constraint which would have served to preserve this rare avian. In another example, the Mexica king Ahuitzotl (r. 1486–1502) was reportedly responsible for bringing great-tailed grackles to Tenochtitlan from eastern lands and ordering their protection. Unexpectedly, these birds thrived to such an extent that they became an ecological burden, understandably losing their popularity. In these examples, the Mexica were active participants in a continuous ecological drama, engineering changes with often-unanticipated consequences.

Medicine and Health

The Mexica were scientific and empirical in their discovery and use of medical cures for a large number of illnesses and injuries. The specialized doctor, or *ticitl*, used practical approaches to his/her profession, examining and diagnosing physical problems and prescribing appropriate cures. Physicians could call upon a large pharmacopoeia derived from herbs, roots, animals, and minerals to relieve symptoms, heal injuries, and restore health. They were skilled in soothing burns, setting broken bones, and suturing lacerations, many of these latter injuries undoubtedly suffered in the frequent battles fought in this militaristic society. Midwives also entered the curative arena, being skilled in herbal remedies as well as childbirth processes.

Medical procedures could be multi-staged and quite complicated. Broken bones, for instance, were first set and then splinted with poultices of specified ground roots or herbs. There was some variety in these usages, as the curative ground roots or herbs could be spread on the injury, drunk with pulque, or enjoyed in a bath. A bitten tongue was first subjected to a mixture of chili cooked with salt, followed by a more comforting application of bee or maguey honey. The Mexica considered at least 132 herbs to have curative properties, and these were applied to at least 40 ailments other than injuries. Curable ailments included nosebleed, pimples, headache, diarrhea, fatigue, coughs, chest pains, nausea, difficult childbirth, and many fevers and infections. Other medical issues (some more serious than others) included compromised mental states, arthritis, tuberculosis, insomnia, and hair loss. Some individual infirmities could be served by a variety of cures – for instance, 45 different herbs could be used to relieve fevers and 18 could be applied to festered skin. On the other hand, some remedies had multiple uses – one herb, for instance, could reportedly slow bleeding, inhibit vomiting, relieve side and chest pains, and in general restore a person's strength. The effectiveness of some of these natural remedies has been verified scientifically. In one study, of 118 plants used by the Mexica for curing, 85 % were shown to contain medicinal components recognized in the twentieth century (Bye & Linares, 1999, p. 5). For instance, the Mexica used the sap of maguey leaves to heal festering wounds; today's studies indicate that the same sap inhibits the growth of various bacteria associated with wounds. In another example, the Mexica used white sapote as an effective sleep aid, and modern medicine reveals that the seeds of this fruit indeed contain sedative components (de Montellano, Bernard 1990, pp. 182–185).

There was some geographic variation in the incidence of medical problems: respiratory and gastrointestinal afflictions were especially prevalent in the highlands, while parasites were particularly problematic in lowland settings. Age was also a factor: rheumatism and arthritis troubled people over the age of 30–35, young children most often suffered from diarrhea and dysentery, and some children also experienced iron-deficiency anemia (Berdan, 2014, pp. 247, 250).

Medicinal aids were often mixed into complex curative potions. Additionally, cures were at times combined with other types of remedies. One of the most popular of these adjuncts was the sweatbath, often recommended as helpful in childbirth problems, skin festering, and traumas. Practical remedies were also at times joined with divinatory and magical cures; magic and divination were used in both diagnosis and curing of certain illnesses. The Mexica believed that some illnesses could have supernatural causes; these included soul loss and the intrusion of unpleasant supernatural substances.

A preventive element is also evident in Mexica medicine. A generally adequate diet contributed to relatively low incidences of chronic diseases such as cancer and heart disease (de Montellano, Bernard, 1990, p. 121). The Mexica also put a premium on hygiene, although a good diet and/or hygiene was not always followed; malnutrition and illnesses have been detected in some skeletal and dental remains of both children and adults (Berdan, 2014, p. 250). Some specific behaviors and natural materials were earmarked for illness prevention and the maintenance of good health. For instance, one designated herb was said to aid digestion and prevent fevers, a nursing mother could prevent diarrhea in her infant by shunning avocados, hair loss could be arrested by avocado seeds, and stammering or lisping could be avoided by weaning children at a young age. In another vein, some illnesses required adherence to strict taboos: a patient with a fever was not to eat hot tortillas or chilies, and one with a head wound was to refrain from eating fish or meat. Thus, medicine and the maintenance of health in Mexica society were complex matters, relying on a blending of scientific knowledge, behavioral conventions, and strong religious beliefs.

Applications of Mexica Science

What did the Mexica do with the vast amount of knowledge they and their forebears had acquired about the world around them? What was the purpose of the many systematic and rigorous studies they made of the heavens and the earth?

While some priests and rulers may have enjoyed the process of discovery for its own sake, it is clear that scientific knowledge among the Mexica was preeminently geared toward practical and religious applications. Long-term, rigorous observations of the heavens, and the recording of celestial movements, furnished the Mexica with temporal order. These scientific inquiries provided the basis for a sophisticated calendrical system, the ability to make appropriate seasonal preparations, and the capacity to predict and prepare for extraordinary and sometimes fearful events (such as eclipses).

The Mexica were hunter-gatherers long before they entered the Basin of Mexico and adopted a well-developed agrarian lifestyle. Bolstered by both of these traditions, the Mexica were keen observers of nature and its processes. They understood the anatomy, behavior, life cycles, and ecology of wild plants and animals. They also had a sophisticated knowledge of cultigens and drew on a long agrarian tradition of seed selection, agricultural technology, and even the ability to predict certain pertinent weather conditions from animal behavior. They applied this extensive and varied knowledge first and foremost to increase and protect their food supply. However, natural resources also enhanced their life conditions by providing fibers, furs, and feathers for clothing and adornment; building materials for domestic and godly shelter; and precious stones and metals for ostentatious displays of social status.

Nature also provided a wealth of medicinal cures, discovered, combined, and applied successfully by specialized physicians. Administering the proper remedy to the specific ailment undoubtedly required considerable experimentation, but unfortunately the documents are silent on this process.

We therefore have quite a bit of information on the Mexica's scientific results, but little understanding of their methods. Those methods, such as rigorous naked-eye astronomy, repeated observations of earthly phenomena, and centuries-long seed selection, yielded a significant body of sophisticated scientific knowledge, applied by the Mexica to practical ends. The Mexica also consistently linked the scientific realm to the religious and utilized empirical discoveries to enhance and embellish their everyday lives on more abstract and supernatural levels.

References

Aveni, A. (2012). Mesoamerican calendars and archaeoastronomy. In D. L. Nichols & C. A. Pool (Eds.), *The Oxford handbook of mesoamerican archaeology* (pp. 787–794). Oxford: Oxford University Press.

Aveni, A. (2001). *Skywatchers of ancient Mexico* (2nd ed.). Austin: University of Texas Press.

Berdan, F. (2014). *Aztec archaeology and ethnohistory*. Cambridge: Cambridge University Press.

Berdan, F., & Anawalt, P. (1992). *The Codex Mendoza* (Vol. 4). Berkeley: University of California Press.

Bye, R., & Linares, E. (1999). Plantas medicinales de México prehispánico. *Arqueología Mexicana, VII*(39), 4–13.

Bye, R., & Linares, E. (2013). Códice de la Cruz-Badiano. Introducción. *Codice de la Cruz-Badiano, Arqueología Mexicana edición especial, 50*, 8–14.

Hernández, F. (1959). *Historia natural de Nueva España* (Vol. 2). Mexico City: Universidad Nacional de México.

Oviedo y Valdés, Gonzalo Fernández de. (1959). *Natural history of the West Indies*. Trans. and

Ed. S.A. Stoudemire. Chapel Hill: The University of North Carolina Press.
de Montellano, O., & Bernard, R. (1990). *Aztec medicine, health, and nutrition*. New Brunswick: Rutgers University Press.
Motolinia, or Fray Toribio de Benavente. (1971). *Memoriales o libro de las cosas de la Nueva España y de los naturales de ella*. Mexico City: Universidad Nacional Autónoma de México, Instituto de Investigaciones Históricas.
de Sahagun, B. (1950–1982). Florentine Codex: General history of the things of new Spain (Vol. 12). Trans. and Eds. A. J. O. Anderson and C. E. Dibble. Salt Lake City: University of Utah Press.
Smith, M. E. (2008). *Aztec city-state capitals*. Gainesville: The University Press of Florida.
de Tributos, M. (1980). *Matrícula de Tributos, Museo de Antropología (Col. 35–52)*. Graz: Akademische Druck-u. Verlagsanstalt.

A