

# Archaeological and chemical evidence for early salt production in China

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**Salt production and trade is thought to be critical to the development of all states and emergent empires. Until now, however, scientific evidence of early salt production has rarely been presented, and no studies of early Chinese salt production have provided unequivocal proof. Here, we report x-ray fluorescence, x-ray diffraction, and scanning electron microscopy (SEM) analyses that demonstrate that salt was the primary product during the first millennium before Christ (B.C.) at Zhongba in Central China. This work provides an early example of salt production discovered in China and presents a methodology for evaluating salt production sites in other regions.**

Chinese archaeology | scanning electron microscopy | x-ray fluorescence | x-ray diffraction | Three Gorges

The origins and development of salt production are important issues in human history. Salt is both necessary for many aspects of physiology (1–4) and crucial for cultural reasons (1, 3, 5–8). Salts are important dietary supplements and agents for preserving seasonal or geographically restricted meat sources (9–10). Salt production enables increased trade and population growth, opens regions to settlement, and permits diversification in cuisine that may mark ethnicity and class. For these reasons, salt is thought to be critical to the development of all complex societies, making its production significant to research on ancient society (9–12). We believe that no states are known to have developed without stable access to salt. In seeming contrast to this view, previous evidence has not demonstrated early salt production in inland China associated with early complex societies. Here, we report x-ray fluorescence, x-ray diffraction, and scanning electron microscopy (SEM) analyses that support our view by demonstrating that salt was the primary product during the first millennium before Christ (B.C.) at an early Chinese site called Zhongba. The data not only demonstrate salt production during the early stages of state development in inland China, they also provide a previously undescribed approach to studying ancient salt production in other contexts.

Despite its universal significance, salt production is often overlooked in studies of early civilization. Occasionally, studies have examined archaeological, iconographic, and historical evidence for early salt production (5, 9–12), but because of its impermanence, archaeologists frequently do not consider the vital role that salt may have played in ancient contexts. In China, although there is ample evidence for salt being an important commodity in later periods of Chinese history, after states were fully formed and had coalesced into an empire, archaeologists have likewise rarely considered the origins of salt production. This finding is true despite the fact that historical records show that salt and iron monopolies often provided the bulk of state revenue during the 22 centuries of

China's Imperial era [third century B.C. to *anno Domini* (A.D.) early 20th century], and salt remained important to state finance into the 20th century (13, 14). Historical accounts even suggest that inland salt sources may have played an important role in the unification of China by Qin in 221 B.C., but because of a lack of appropriate archaeological methodology, there has been no clear evidence of pre-Qin salt production in the Sichuan Basin. Likewise, hypotheses about salt's critical role in earlier Chinese states such as the Shang (*ca.* 1600–1050 B.C.) and subsequent Zhou (*ca.* 1050–221 B.C.) (15–17) have not yet been conclusively supported by unequivocal archaeological evidence of early salt production. Although we do not reject the hypotheses of Liu and Chen (15), Fang (16), and Li (17) that suggest salt production during the early Bronze Age in North China, these studies rely on circumstantial evidence. In fact, no reliable methods have been developed anywhere previously to identify salt production in archaeological contexts. Our study of salt production at the site of Zhongba addresses these major issues.

Zhongba is located in Zhong Xian County, Chongqing Municipality, ≈200 km down-river along the Yangzi from Chongqing City in central China (Fig. 1). The cultural remains at that site are concentrated on a small mound in the middle of the course of the Ganjing River, which enters the Yangzi 6 km further downstream in the Zhong Xian county seat. The mound comprises >12 m of anthropogenic deposits divided into 70 distinct strata. As discussed in recent Ph.D. theses by R.F. (18) and P.C. (19) and other recent publications (20), excavations lasted from 1997 through 2002 as part of the Three Gorges Dam Reservoir salvage project. The majority of the remains date to the period between 3000 and 200 B.C. (21). Based on dense pottery remains from the late Neolithic that increase in scale through the Bronze Age, it is clear that Zhongba was a large-scale production site during the pre-Qin era. Four lines of evidence demonstrate that the main product of the site was salt.

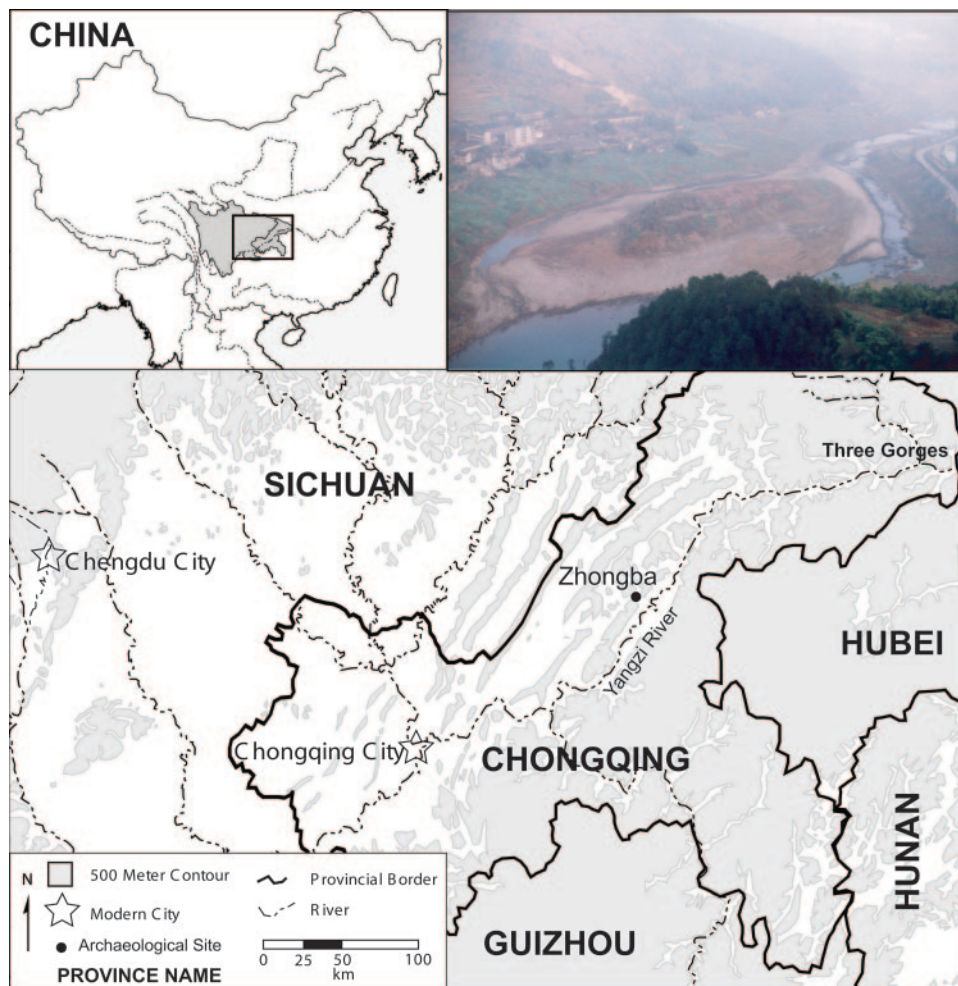
First, several lines of historical and cross-cultural analogy point to salt production. Zhongba is located in a well-documented place of historic salt production. Also, its ceramics and other features are similar in form and composition to salt production pottery (*briquetage*) from other regions of the world (22). Widespread ethnographic and historical examples of salt production involve a small number of optimum ceramic forms for *briquetage*. Each of three main phases of activity at

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Abbreviation: B.C., before Christ.

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**Fig. 1.** Location of Zhongba in Zhong Xian County on the eastern end of the Three Gorges in Chongqing Municipality, China. The inset photograph in *Upper Right* shows the site mound in the middle of the course of the Ganjing River, before the construction of the recently completed Three Gorges dam on the western side of the Three Gorges.

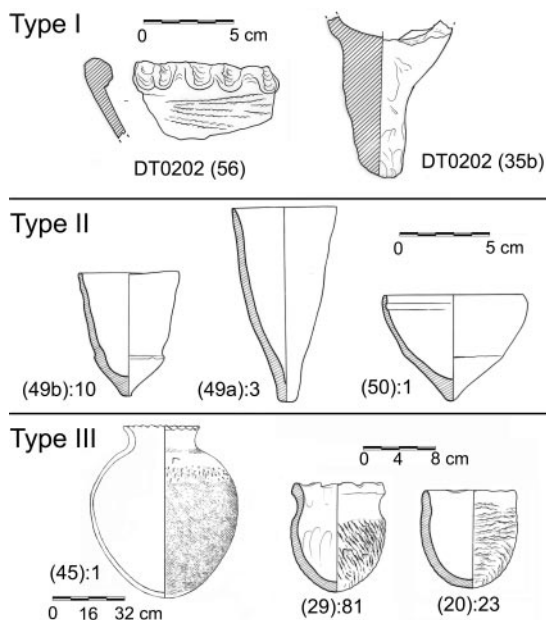
Zhongba is represented by one such vessel type (Fig. 2). In all three periods, the vessels were used in a process that involved boiling brine to crystallization, but each played a somewhat different role in this process. Large, pointed-bottom vats comprise the vast majority of vessels during the uppermost levels of the earliest phase (*ca.* 2000–1750 B.C.). Similar vessels were used in antiquity along the coast of Japan in salt production (23). At Zhongba, the vats may have been used for brine storage in conjunction with other, perishable production vessels. Alternatively, they may have been used directly in the evaporation process. It is also conceivable that they were used in the production of fish sauce or some sort of preserved food products.

The second phase (*ca.* 1630–1210 B.C.) contains pointed-bottom cups as the most common vessel type. These cups are similar to so-called “augets,” which are small cup-like vessels used in early Central European and Mesopotamian salt production (12, 24). The cups were small and were discovered in huge numbers. They were probably used as molds to dry wet salt and create relatively uniform cones of salt that could be traded easily. Rounded-bottom jarlets from Phase III (*ca.* 1100–200 B.C.) resemble *briquetage* from the coastal Maya region, the Shandong peninsula, the Philippines, and West Africa (refs. 16 and 25–27; A. Yankowski, personal communication). Among these analogues, ethnographic examples

from Niger (26) and the Philippines (A. Yankowski, personal communication) demonstrate that similar vessels were placed over fires and used to boil brine and produce large salt cakes. We suspect that the rounded-bottom jarlets also were used in this fashion, and experiments by the excavation team demonstrated that the vessels can be used effectively in this fashion.

In addition, the overall character of the pottery debris parallels known salt production sites and differs considerably from the debris found at pottery production sites. A large amount of pottery debris is found at both types of sites, but at salt production sites the assemblage is always extremely homogeneous. The Zhongba ceramic assemblage exhibits this sort of homogeneity. An analysis of 134,265 sherds collected from 35 successive levels in a single unit at the core of Zhongba shows that a single pottery type comprises  $\approx 90\%$  of the collection in almost all levels (see Fig. 3).

Archaeological features at Zhongba also parallel known salt production sites. Oval pits with thick clay lining are common throughout the Phase I. These pits are structurally similar to ethnographically and historically identified salt production facilities from Mexico, Africa, and elsewhere (11, 28). Although suggestive, these qualitative data do not unequivocally identify Zhongba as a salt production site. Most cases where salt production is identified archaeologically rely exclusively on such data. Here, we provide three additional lines of evidence.



**Fig. 2.** Principal vessel types in Zhongba assemblage. Type I are fragments of *jiandigang* pointed-bottom vats. Type II are *jiandibei* pointed-bottom cups. Type III are *huandiguan* rounded-bottom jarlets. Each type is analogous to salt-production pottery used in other contexts. Excavation contexts and artifact numbers are provided with each specimen.

Our second indicator is the similarity between the chemical composition of local brine and soil samples from archaeological features that are thought to be salt production facilities. These features and the local brine share certain elements not present in soil from nonfeatures or from features that were not associated with the production process. Chemical impurities are often the only trace of the brine or seawater that remain on production tools or facilities (29, 30). The major impurities in eastern Sichuan Basin salt and brine are magnesium, calcium, and potassium (31). X-ray fluorescence analysis of

**Table 1. Ca and Mg percentages in soil from various contexts based on x-ray fluorescence**

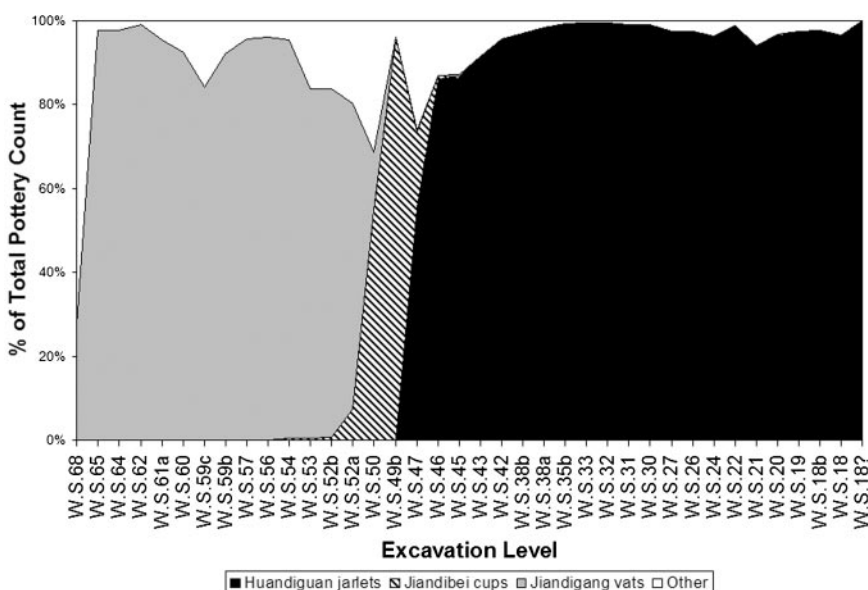
Component	Locus, %				
	F270	M75	F198	F226	Level 20
CaO	30.9	26.1	32.3	34.7	7.8
MgO	12.3	8.9	11.5	13.7	5.0

Calcium (Ca) (0.027 g/liter) and magnesium (Mg) (0.0073 g/liter) are significant impurities in the local brine. Ca and Mg were more highly concentrated in the soil from several Phase III features than in soil from the roughly contemporaneous Level 20. The features include a clay-lined pit (M75) and three workshop floors (F270, F198, and F226). The clay-lined pit was probably a brine-storage container, and the surfaces were the primary loci of salt production. The soil in level 20 would not have been exposed to brine as intensively as the features.

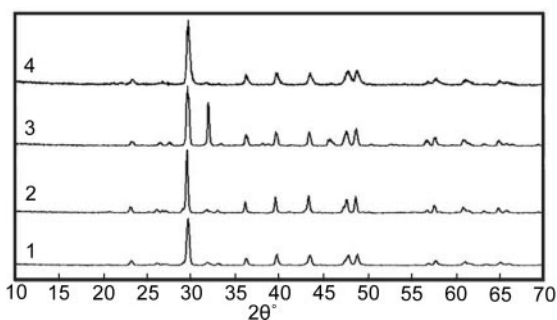
soil from production features (F270, M75, F198, F226)<sup>11f</sup> shows that they contain much higher levels of calcium and magnesium compared with soil from a nonfeature context (Level 20) (Table 1). These two compounds also are concentrated in the local brine (32). The high levels of calcium and magnesium in the surfaces and pits are the results of salt production.

A third data set that supports the salt production hypothesis comes from x-ray diffraction analysis of residues found on Phase III rounded-bottom pottery at Zhongba. The mineral compositions of these residues are consistent with those of residues found on a 2,000-year-old-era salt-boiling pan from Sichuan and of residues from a calcium oxide discard area collected at a modern salt production site in Yunyang, Chongqing, in 2002 (Fig. 4). In the modern case, calcium oxide is used to treat solvable impurities in the brine, and residues are disposed of in an area adjacent to the salt production furnaces. The dominant compound in all three samples is CaCO<sub>3</sub> with small amounts of SiO<sub>2</sub>. All of the diffraction peaks

<sup>11f</sup>F = Fangzi (house). Normally used to identify house foundations, at Zhongba, this designation was used for workshop floors. M = Muzang (burial). This designation, given to burial-shaped pits during excavation, also was used at Zhongba when numbering rectangular pits that turned out to be workshop features, most likely brine-storage pits. Level 20 is a deposition layer uncovered in DT0202, which was associated with salt production debris.



**Fig. 3.** Graph showing the relative frequencies of the three dominant vessel types in deposits excavated in Zhongba unit 99ZZDT0202. The levels listed at the left-hand side of the graph are earliest and date to the later third millennium B.C. In nearly every level the ceramic assemblage is extremely homogeneous.



**Fig. 4.** X-ray diffraction diffractograms from several samples of calcified residues thought to be associated with salt production. The y axis reflects x-ray intensity (i.e., counts for the number of x-rays diffracted at a given angle expressed as  $2\theta$ , or twice the angle of diffraction). Diffraction line 1 represents residue found on the inner surface of a rounded-bottom vessel from Zhongba pit H457. Line 2 represents residue found on the inner surface of a rounded bottom jarlet found in pit H509 at Zhongba. Line 3 represents residue collected in 2002 from a calcium oxide discard area at a modern salt production site in Yunyang County, Chongqing. Line 4 represents residue found on a Han era, iron salt-boiling pan (YG2) discovered in Zigong, Sichuan.

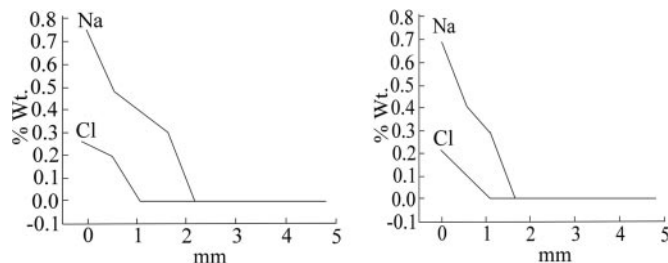
of  $\text{CaCO}_3$  are consistent with the values reported in the literature (Joint Committee on Powder Diffraction Standards File No. 70-0095). The Yunyang sample also has small amounts of  $\text{NaCl}$  (Joint Committee on Powder Diffraction Standards File No. 78-0751). This difference is explained by the fact that the salt is easily dissolved over time, but the other impurities remain. The  $\text{NaCl}$  crystals in the Zhongba and Zigong cases dissolved away in antiquity, whereas the crystals in the Yunyang case still remain because of the short duration of time since their deposition. In all cases, the other impurities in the brine formed a hard residue on the production tools.

Our fourth line of evidence is traces of sodium chloride on the interior surface of ceramic vessels. By using a scanning electron microscope with an energy dispersive spectrometer, we examined the salinity of the walls of suspected *briquetage*. The energy dispersive spectrometer analysis showed that both Na and Cl concentrations are highest on the interior surface of the ceramics and show a clear gradient toward lower concentrations toward the exterior of the sherd (Fig. 5). Spectrometry analyses of the exterior surface of the rounded-bottom jarlet sherds show an absence of both Na and Cl. The diminishing Na and Cl concentrations found on the inner surface are not due to the postdepositional conditions surrounding the sherds but rather relate to the use of these vessels for boiling brine. During the process of brine boiling, Na and Cl precipitate out of solution along with the salt and penetrate into the vessel wall, but different rates of diffusion lead to the different distributions of Na and Cl concentrations within the innermost 2.1 mm of the sherds.

We therefore can conclude that salt production was the most significant activity at Zhongba during the first millennium B.C. Furthermore, the homogeneity of the ceramic assemblage during Phases I and II suggests that salt production may already have been significant in this area throughout the second millennium B.C. The Zhongba data represent the oldest confirmed example of pottery-based salt production yet found in China. The first millennium B.C. dates alone confirm that salt production was established long before the Qin expansion into Sichuan in 316 B.C.

In fact, in southern China, salt from Zhongba was a vital component in the complex process of state formation. For example,

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**Fig. 5.** Scanning electron microscopic energy dispersive spectrometer analysis of two suspected *briquetage* sherds from Zhongba. (Left) A sherd from pit H457. (Right) A sherd from Unit DT0202. In both cases, after a depth of  $\approx 1.1$  mm, Cl is virtually absent. Na concentrations approach zero at depths of 2.1 and 1.7 mm from the interior surface of the sherds from H457 and DT0202, respectively.

the specialized production of surpluses of salt, and possibly salted products, and the trade of these commodities to regions outside the Three Gorges stimulated contacts between the upper and middle reaches of the Yangzi River. As coastal and inland lake-salt sources provided this crucial resource to emerging states in the Central Plains and Eastern China during their formative periods in the late second and early first millennium B.C. (15, 16), so, too, did the salt sources in the Sichuan Basin provide this dietary supplement, preserving agent, and industrial component to the emerging polities in the south. Although the Three Gorges remained a relatively peripheral area into the first millennium B.C., the establishment of trade networks based in large part on the exchange of surplus salt brought some elite practices into the region and stimulated the emergence of social differentiation in the area as elites in nearby polities such as Chu engaged in gift-giving and related practices in attempts to create ever-larger networks of political influence (33). At the same time, salt from the Three Gorges facilitated the development of more complex economic systems in these same nearby polities by providing a resource that was unavailable elsewhere in the middle reaches of the Yangzi River drainage. Eventually, salt became crucial to the provisioning of armies by expansive states such as Qin and Chu, polities that controlled areas adjacent to the Three Gorges region, and the existing networks of salt exchange became catalysts to the incorporation of this area into a unified Chinese empire.

The techniques used here can be used to study further salt exploitation in other contexts. As mentioned, the archaeology of salt production has been explored to varying degrees in Europe, Asia, Africa, Oceania, and the New World. The general topic continues to be an important issue in archaeological research, as recent scholarly and popular-history publications on the subject demonstrate (11, 25, 34, 35), because it is well known that salt has always been an important substance in human society. Nevertheless, archaeologists frequently struggle to find adequate methods for exploring this ephemeral product in ancient contexts. This work shows that new approaches to archaeological remains may bear fruit in the search for salt.

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