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Edited by
Paolo Forti

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Foreword

Vulcanospeleology is a far younger science and activity than speleology and karstology: in fact only in the sixties systematic exploration of lava tubes started, while the 1st International Symposium on Vulcanospeleology was held in the United States in 1972.

Nevertheless in these few years vulcanospeleology was able to achieve an important position amongst the caving activities. Day by day longer, deeper and more complex volcanic caves have been discovered and explored all over the world and cavers started to understand the spelogenetic mechanisms ruling the evolution of these cavities.

The International Union of Speleology acknowledged the relevance of Vulcanospeleology by establishing a new Study Group on this topic, which was recently transformed into an official UIS Commission.

The 8th International Symposium on Vulcanospeleology was the first official meeting of the UIS held in Africa and, despite the scarce attendance from abroad, it was a success from the scientific point of view. In fact, during the Symposium in Nairobi, 16 contributions have been presented, most of which of good or even outstanding level and the field excursions allowed the participants to have useful discussion on several topics related to volcanic caves while visiting the most important vulcanospeleological features of Kenya.

Due to the relevance of the scientific achieved results in vulcanospeleology in the last few years, it's really time for this discipline to become better known among the scientific community. Moreover the volcanic caves of Kenya, despite their beauty and widespread scientific interests, have been only marginally presented in the international literature and presently they are still practically ignored by far the majority of the cavers.

For these reasons it was decided to print the Proceedings of this Symposium on the International Journal of Speleology.

14 of the contributes presented during the Symposium have been submitted and accepted for this publication. Beside them, 2 papers have been added in order to make this volume more complete and interesting: the first is a short report on the Symposium, while the second is an overview on the most important volcanic caves of the East Africa.

The volume have been arranged in two sections: the first one with the papers dealing with the Symposium and with the East Africa and the second one containing the contributes from all the rest of the World.

The editor and contributors hope that this publication will give some important insights to the understanding of volcanspeleology and encourage further studies on this topic.

Paolo Forti

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Int. J. Speleol., 27 B (1/4), (1998): 9-10.

OVERVIEW OF THE 8th INTERNATIONAL SYMPOSIUM ON VULCANOSPELEOLOGY

William R. Halliday *

ABSTRACT

In February 1998 the 8th International Symposium on Vulcanospeleology was hosted by CEGEA (Cave Exploration Group of East Africa) in Nairobi, Kenya: it was attended by 16 scientists coming from 4 continents. Pre- and Post- Symposium excursions allowed the participants to have an overview on the most important and famous volcanic cave of that area.

Keywords: vulcanospeleology, symposium, Kenya

Despite record-breaking floods, sporadic intertribal warfare (grossly distorted by the media), a false rumor of massacre of British Museum scientists and true threats of a paralyzing nationwide bank strike, 16 vulcanospeleologists attended the 8th Symposium in Kenya in February 1998. Included were participants from Australia, Great Britain, Italy, Japan, Kenya, Netherlands, Norway, and the United States. Host organization was the venerable Cave Exploration Group of East Africa; the International Union of Speleology was a co-sponsor. At the meeting of the IUS Commission on Volcanic Caves, Jan Paul van der Pas took over as President.

The overwhelming success of the meeting was a personal triumph for Jim Simons, Hon. Chairman of CEGEA, who had been urging such a meeting in Nairobi for a quarter of a century, and served as its organizer and Chairman.

In addition to a remarkable overview of vulcanospeleology of East Africa by Jim Simons, notable papers in the East Africa session included a report on high-elevation caves of Kilimanjaro by Clive Wood, and reports on lava tube caves of Grand Comoro Island and of Mauritius, by Tasmanian Greg Middleton, session Chairman.

Ron Greeley of Arizona State University chaired a session on vulcanospeleogenesis, including his own paper on California's Giant Crater lava tube system (where there is definite evidence of erosion into pre-flow country rock). Kevin Allred's paper (in absentia) on supposed "Lava Tube Remelt by Radiant Heat and Burning Gases" was read by Dave Womack of CEGEA. I presented papers on hollow tumulus caves and sheet flow caves of Kilauea Caldera, Hawaii.

IUS past president Paolo Forti chaired a session on speleothems of lava tube caves and presented a paper (with several co-authors) on "Chemical Deposits in Volcanic Caves of Argentina", contrasting occurrences in Cueva del Tigre (ions from weathering of lava) with phosphates in a nearby tectonic cave, resulting from interaction of bird guano and volcanic rock. Gordon Davies reported unique rope-like meters-long speleothems in a hollow half-cone in carbonatite in the caldera of Tanzania's 01 Doinyo Lengai. This was a short-lived hyperthermal cave with speleothems presumably of sodi-

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um carbonates (and possibly also NaCl), primarily in the form of long, thin uniform stalactitic columns. Tourism has arrived here, but requires a 1800-m ascent using ropes and crampons to reach the caldera at 3100 m. Ron Greeley commented that carbonatite lava is the only type in which downcutting by flowing lava actually has been observed. Also, Kevin and Carlene Allred (in absentia) reported on filter-pressed segregation as the cause of tubular lava stalactites and related forms, and Jim Simons, on guano-mining in Kenya lava tube caves.

Jan Paul van der Pas chaired a session on miscellaneous topics. Included were an archaeological report on an important Kenya lava tube cave, a report by Bob Davies on roofed tectonic caves in the Solai area of Kenya, and my paper on speleological aspects of pit craters and certain open vertical volcanic conduits, with special reference to definitions in the 1997 4th Edition of Glossary of Geology.

Floods in the Leviathan Cave area forced long detours and caused major changes in the Chyulu Hills field excursions. Only the central section of 10.5 km Leviathan Cave could be reached in the time available. However, fascinating Mathioni Cave and Shetani Cave at the north and south ends of the Chyulus were reached without difficulty. An especially notable feature of the former is a 5m lava stalagmite formed by invasion through a round 1 m defect in the ceiling high overhead. A 1/2-day excursion from Nairobi also visited two of the puzzling Gigglers Caves: intricate networks of small passages in tuff in the Ndarugu River Gorge, with what appear to be karstic features.

After the sessions, several lava tube caves in the intricate Mt.Suswa network were visited. These contain extensive secondary deposits of SiO2 and other minerals in addition to a magnificent dislay of enormous hollow pahoehoe ropes and other notable primary features. Some overnighted in "The Ballroom", frustrating a prowling hyena that wanted to nibble somebody. Most continued north to Mt. Elgon on the Uganda border, for "dread" Kitum Cave, supposedly the lair of the Ebola virus and other caves in a peculiar, partially soluble complex of agglomerates, tuffs, and lake bed deposits. The entrance of Makningen Cave is 60 m wide and 20 m high; its entrance room is some 200 m long and contains numerous features characteristic of karstic caves. The 1973 published map labelled Makningen Cave actually is of Kitum Cave where speleogenesis is partially obscured by more extensive breakdown. The caves have been enlarged by primitive mining of the salty bedrock and by their use as salt licks by domestic and wild animals (including elephants) but most of their volume clearly is due to geologic processes

Extra copies of the symposium guidebook are available from the Cave Exploration Group of East Africa (P.O. Box 47363, Nairobi, Kenya).

Int. J. Speleol., 27 B (1/4), (1998): 11-20.

VOLCANIC CAVES OF EAST AFRICA - AN OVERVIEW

Jim W. Simons *

ABSTRACT

Numerous Tertiary to recent volcanoes are located in East Africa. Thus, much of the region is made up by volcanic rock, which hosts the largest and greatest variety of East Africa's caves. Exploration of volcanic caves has preoccupied members of Cave Exploration Group of East Africa (CEGEA) for the past 30 years. The various publications edited by CEGEA are in this respect a treasure troves of speleological information. In the present paper an overview on the most important volcanic caves and areas are shortly reported.

Keywords: vulcanospeleology, lava tubes, East Africa

INTRODUCTION

From the viewpoint of speleology. East Africa includes a vast area extending from the Indian Ocean to eastern Zaire, and north to south from the Sudan to southern Tanzania, unmatched in its variety of caves and in the magnificence of their settings. Included are: (1) dissolution caves in limestones ranging from recently elevated coral reefs to dense marbles and possibly also in partially soluble agglomerates and tuffs; (2) world-class lava tube caves, some unitary and others strongly braided, with remarkable sequences of unusual primary and secondary features; (3) volcanic pits much like those in limestone, unrelated to lava tubes; (4) extensive roofed tectonic caves; (5) a few inland "sea caves" formed by wave action of large lakes; (6) a unique pit cave in carbonatite lava described elsewhere in this volume; and (7) some which are difficult to classify.

In East Africa, great upheavals in comparatively recent time have produced great rift valleys running north-south through Kenya, Tanzania and Ethiopia, and along the eastern border of Zaire. These upheavals resulted in the building of numerous Tertiary to Recent volcanic's either within the troughs or along related lateral fault systems. Thus, much of the region is made up of volcanic rocks. Contrary to other regions where limestone is more common, in these volcanic rocks are the largest and the greatest variety of East Africa's caves. Especially in Kenya, exploration of caves in these rugged, scenically spectacular volcanic areas has preoccupied members of the Cave Exploration Group of East Africa (CEGEA) for the past 30 years. The caves of central Kenya thus are known much better than those elsewhere in the region. In the volcanic areas along the eastern Zaire border, speleologists from several other nations have added important contributions. A large literature exists, with one bibliography now quite obsolete (Mills, 1977). The various publications of CEGEA are veritable treasure troves of speleological information, now supplemented by this volume and the field guide for this symposium.

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LAVA TUBE CAVES OF FAST AFRICA

The largest and most important caves of East Africa are lava tube caves. All known examples are in Quaternary or Recent flows, although a report of holes seen from the air at the southern tip of Kenya's Tertiary 250 km long Yatta Plateau is intriguing. In the volcanics on both sides of the eastern border of Zaire (along the Rwanda-Uganda boundaries) Ubuvomo bwa Musanze in Rwanda has a length of 4.56 km and a vertical extent of 210 m. Nearby Ubuvomo bwa Nyrabadogo is about 1.5 km long. Total length of the Musanze system is about 5.1 km (Montserrat i Nebot, 1978). Garama Cave in the nearby Kigesi Diestrict of Uganda is 342 m long (Schomer and Randall, 1994). Among several in eastern Zaire, a cave along the Kakomeru climbing route of Mt. Nyamulagira is especially impressive (Simons, 1972; Glaser, 1989). In Tanzania, small examples reported elsewhere in this volume are located on Kilimanjaro and others probably exist. Those of Ethiopia are less investigated. A 70 m lava tube cave has been recorded south-east of Addis Ababa and a smaller example on K'one Volcano (Morton, 1976).

LAVA TUBE CAVES OF KENYA

Kenya's largest lava tube caves are scattered through the Chyulu range of volcanoes located between Nairobi and Mombasa (Simons, 1998). Nearly 100 caves have been recorded in this area, and dense vegetation undoubtedly hides many others. On its eastern flank is the Leviathan Cave System (Fig. 1, 2), including the country's longest and deepest cave. Leviathan Cave proper is 10.5 km long. The CEGEA working map is several meters long and a few cm wide, and has not been published. This great cave was discovered through study of aerial photographs. It was first entered by CEGEA in September 1975. Most of its passages were surveyed in a 10-day expedition in April 1976. Scaling poles were needed in later mop-up work. In the north Cbyulu area, more than 20 caves are known. The principal caves here occur in two adjacent groups along a single unitary tube in a flow of olivine basalt more than 20 km long. The groups are about 1 km apart. They consist of Hells Teeth and Kimakia Caves (upslope) and Mathioni and Skull Caves (downslope). Kimakia Cave is a two-level cave, and has about 1.4 km of passages. Its main entrance segments its upper level. The upslope section of the cave is notable for consistently large dimensions and for unusual ruby-red secondary stalactites derived from guano minerals. Downslope beyond a second collapse orifice and a series of notable flow ledges, the tube has the form of a canyon passage 20 m high at a lavafall 10 m high. Local collapse of accreted wall linings reveals loose pyroclastics, demonstrating downcutting into earlier materials. Deep guano deposited by the Giant Free-tailed Bat (Otomops martiensenni) in this part of the cave formerly was mined commercially. At that time the cave was known as the Ithundu Mine. An extensive guano-based fauna is present. On one occasion a civet cat was observed eating low-hanging bats here. Several short segments of the master tube exist about 250 m upslope.

Mathioni Cave (Fig. 3) also has two levels. It has about 1.9 km of passages, 1.4 km in the main line. Like Kimakia Cave, its main entrance segments its upper level. Its upslope 600 m passage was briefly developed as a tourist attraction in 1972, with pathways and wooden staircases (now rotting). Attractive chocolate-colored stalactites and flowstone are present. Near the entrance, a pit with accreted surfaces leads down to a major level, through a lavaball complex where the tube was almost completely obstructed while still conducting lava. Beyond, much of the cave exceeds 20 m in height and width. Its cross-section is high and narrow, then a flat rectangle. Three "burial cairns"

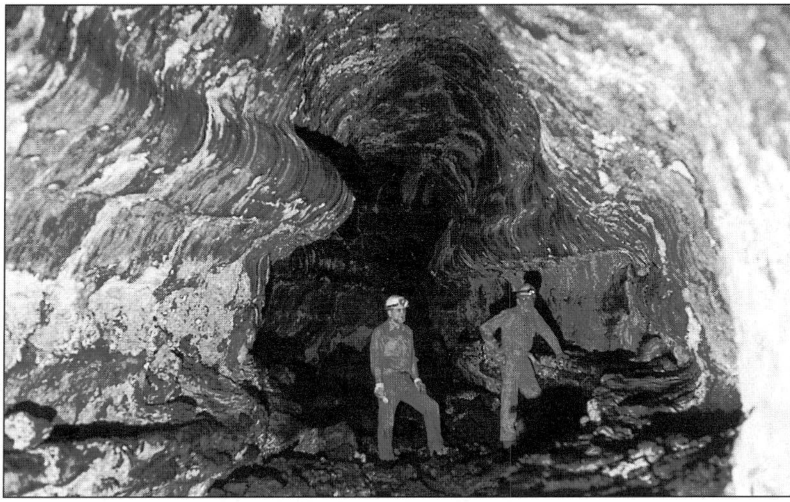

Figure 1. Leviathan Cave, near Discovery Entrance. WRH photo.

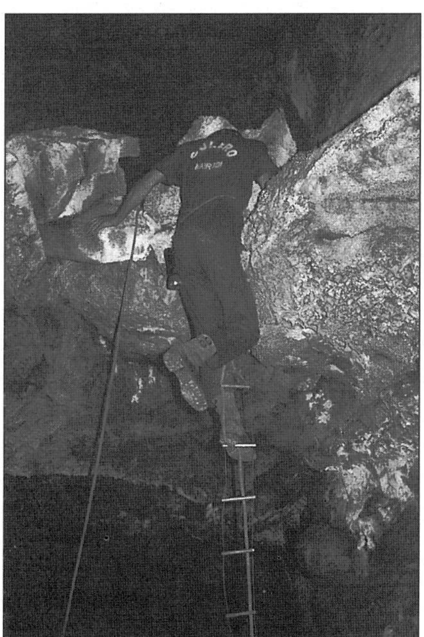

Figure 2. Use of "maypole" to reach The Attic in Leviathan Cave. JWS photo.

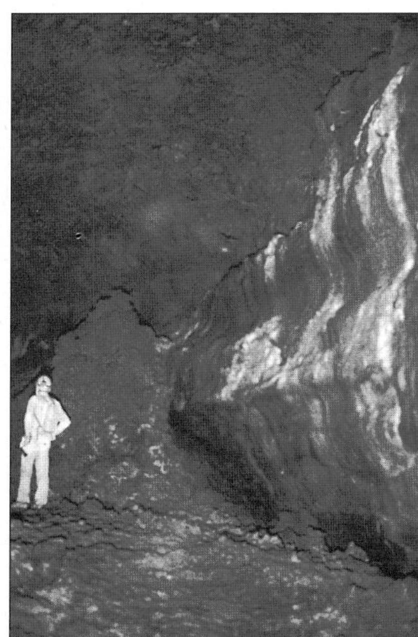

Figure 3. Large conical lava stalagmite in Mathioni Cave. WRH photo.

are present here, but have not been disturbed to determine what (if anything) lies within. The writer contends that the builders of these cairns must have entered the cave through an upslope entrance closed by invasion of later lava. One such flow of pasty lava obviously entered the cave through a 1-m hole in the ceiling, producing a conical stalagmite about 4 m high. Another flow blocks the upslope end of the cave. Downslope from this cave are small additional segments of the system. One contains two oxbows.

Mount Suswa is the second major lava tube area known in Kenya. In an area 3 km square, phonolitic basalt flows extruded after formation of the caldera contain the greatest concentration of lava tube caves in East Africa (Fig. 4). Here some 40 caves are segments of a very complex braided tube system with up to three levels of passages. 67 entrances are recorded. Estimated total passage length is over 11 km. A few of the entrances are recent artificial excavations but most are large roof collapses. 26 caves have a single entrance; the remainder have at least two.

Figure 4. Typical cave entrance, Mt. Suswa. WRH photo.

Three distinct levels of passage exist here. The uppermost lies just below the lava crust and the lowest are 20-35 m below the surface. Superimposition of passage levels is common. Cross-sections of totally infilled tubes seen in cave walls show that the network originally was even more extensive. Passage size varies greatly. Those in the largest systems are consistently 6 to 10 m in diameter, reaching 20 to 30 m where breakdown has occurred. Individual passage segments leading off from and between collapses are 10 m to more than 1/2 km long. What constitutes the overall length of a single cave depends on interpretation of the dripline of collapse holes.

Much exploration remains to be done here, and full plan and profile surveys of known caves in the Main Cave Area remain to be completed. The chance discovery of "Hole in the Floor Tube" in the 23 Series demonstrates the existence of largely unknown extensive lower levels. More detailed surface exploration and "digs" in obvious gaps undoubtedly will yield additional caves.

Unusual treacly lava stalactites are a special feature of Mount Suswa caves (Fig. 5).

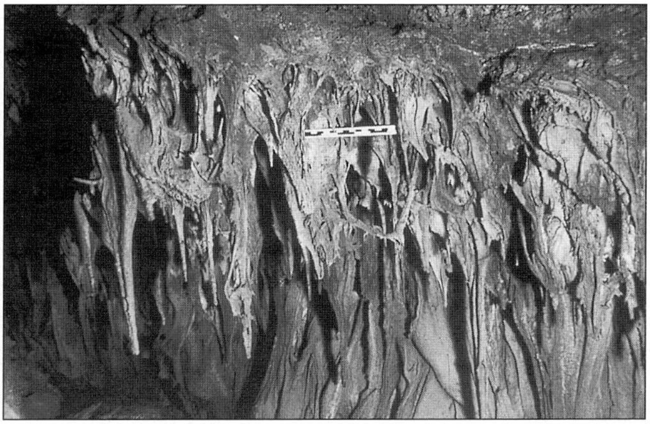

Figure 5. Wind-blown lava stalactites, Mt. Suswa. JWS photo.

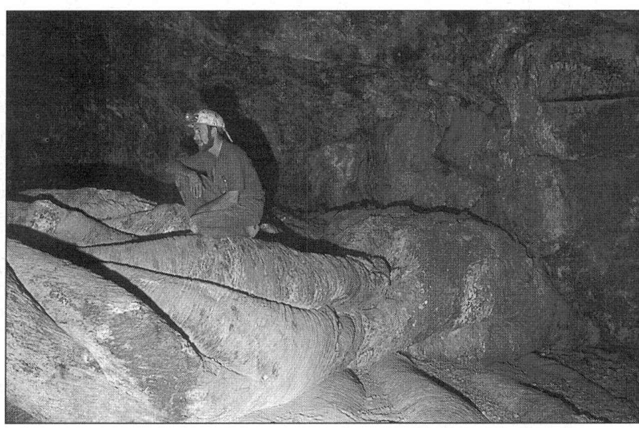

Figure 6. Giant hollow pahoehoe ropes, Mt. Suswa. WRH photo.

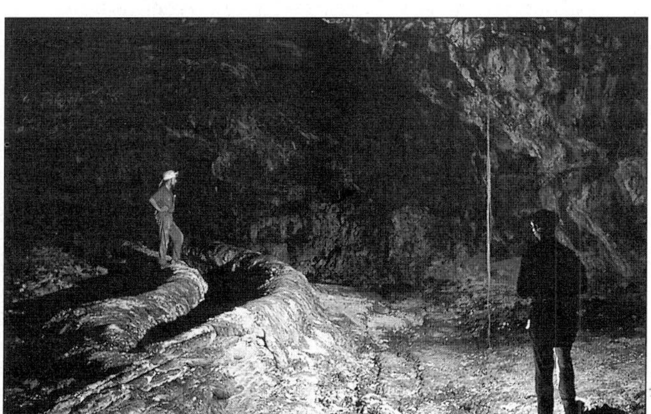

Figure 7. Open channel leading to tube-in-tube, Mt. Suswa. WRH photo.

Some have the form of wind-blown complexes. Cave 12 contains some especially interesting features. With a few unsurveyed sections, it has a length of a little over 600 m, of which 400 m is the "Master Tunnel", a tube locally as much as 15 m wide, with both upper and lower level segments. The northern entrance passages contain some fine lava ropes (Fig. 6) and a corner wall where "dragged lava" forms a notable feature called The Wedding Cake. In the downslope segment of the Master Tunnel one can see a successive series of open channels (Fig. 7), wall benches and tubes attesting to the flow of lava at varying levels. In its uppermost passage, a part of another channel is defined by a raised lip 1 m high, formed by individual paps of viscous lava congealed one above the other to resemble a man-made wall. Farther along the passage is a magnificent cascade of huge lava ropes. In a nearby side passage leading to a 5 m pitch into a closed chamber is an array of lava stalactites and small secondary speleothems of mendozite. The unusual form of successively thin to bulbous shapes of the latter suggest that their deposition may be linked to seasonal rainfall. The choked, 160 m long upslope section of the Master Tunnel also contains a shallow open channel as well as the only example of a lava stalagmite yet found in any Suswa cave. Also present are gutters, wall benches and lava tongues with web-like surfaces. Humid tunnels commonly contain secondary silica-based dripstone and flowstone (Fig. 8). Some has a porcellaneous appearance. Transient precipitates or efflorescences of white salts coat some cave walls after rains.

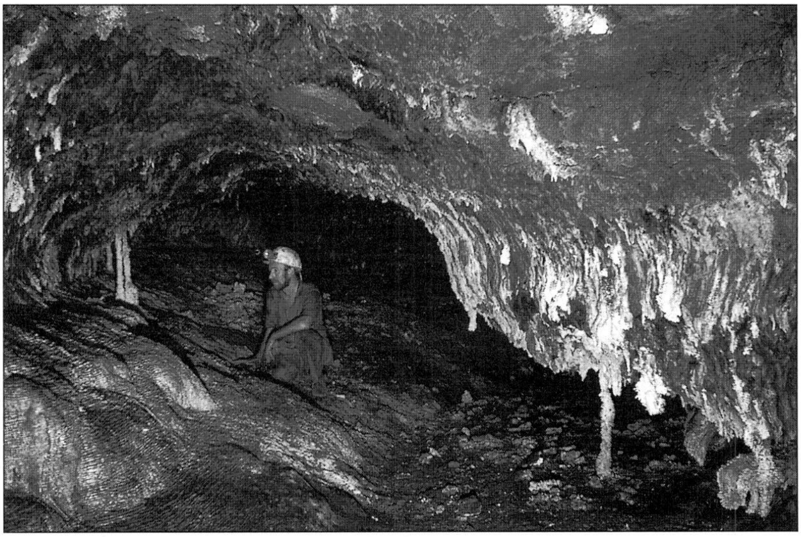

Figure 8. Si02 flowstone and microgours, Mt. Suswa. WRH photo.

Occupation by man in late prehistoric times is shown by obsidian artifacts and the former presence of stone bowls in some caves. During "The Emergency" in the 1950's Mau Mau Freedom Fighters are said to have left certain stone circles with brush enclosures (now largely disintegrated), pottery, and food debris. The present Maasai inhabitants of the mountain do not generally venture far into the caves but do collect honey from beehives in collapse entrances. Some caves have been used as lairs by hyaena and porcupine; both bring in animal bones. Leopards formerly inhabited a number of passages where baboons utilized collapse entrances to feed or to lie up on ledges at night.

When the caves were first explored in the mid-1960's, remains of the baboons caught by the leopards littered several lairs. Smaller mammals also use the caves, including at least four species of insectivorous bats. Locally, their long habitation gave rise to deep guano deposits which were mined as a source of agricultural fertilizer. A microfauna of several species of beetles is found in the guano tunnels, together with cave crickets, pedipulpids, mites and fleas.

Elsewhere in Kenya, several small caves have been examined in the Elmenteita Badlands north of Mt. Eburru, while a single vent-like cave occurs on the west flank of Menegai Caldera.

The nearby Kilombe Caldera and Loldiani Volcano have yet to be investigated speleologically. In the area around seasonal Lake Tillam, near Korosi Volcano, several lava tube caves are known, while others are reported on nearby Mt. Paka. Many occur on Mt. Silali, north of Lake Baringo, and a major 3 km cave rivalling those of Mt. Suswa in size has been partially explored here. More lava tube caves are known to occur in the Kabernet region and elsewhere around Lake Baringo, on Emurangogolak Volcano and probably also around Teliki's Volcano on the volcanic barrier between Lake Turkana and the Suguta Valley. Two small, caves have been investigated high in the Nyambeni Mountains near Maua, and other caves are said to exist here. It also is reported that large collapses with caves occur in lava fields surrounding Mt. Marsabit, and cavities often are encountered when digging wells in the Hurri Hills.

CAVES IN TUFF AND AGGLOMERATE

A great part of central Kenya is an up-domed region of lavas, tuffs, and agglomerates of Tertiary age. Caverns in these tuffs and agglomerates and related lake bed deposits currently comprise almost a third of the caves known in Kenyan volcanic rocks (2596 of all known caves in Kenya). They vary greatly in size and geomorphology. Beneath waterfalls or in valley sides, simple chambers with limited passage development are known along many rivers on both sides of the Rift Valley while on Mt. Elgon, some caves have great breakdown chambers up to 100 m wide. Elsewhere are small, intricate systems of passages which provide good sport caving. Due to their number and complexity, those along the Ndarugu River (Fig. 9) are especially important. As in the case of other Kenyan caves mentioned in this report, maps and sketches of these caves appear in the symposium guidebook. Similar caves are located near Machakos where Kangundo Cave has more than 300 m of passage, and on Kilamasimba (Lion Hill) south of Oldonyo Sabuk is a shorter and lower series of stoopways.

On Mt. Elgon (the remnant of a huge Tertiary volcano) are numerous large cave chambers including world-famous Kitum Cave. Their origins are obscured by excavations of salty rock by elephants and other large animals, and by man. A similar situation exists in the caves or "mines" of the Kericho (Lumbwa) area. Here there is a seemingly natural cave below a waterfall of the Jamji River. It provides the novel experience of visiting a streamway while being directly beneath a river. An underwater cave exists in Lake Chala, on the Kenya-Tanzania boundary (Davies, 1972). Caves on the Aberdare Mountains and on Mt. Kenya were used as refuges by the Kikuyu during tribal warfare and the Mau Mau insurgency, as near Maro Moru. Some along the Myamindi, Nithi and Mara Rivers have been reported to be large and extensive. At the northern end of the main Ethiopian Rift, "blister caves" in ignimbrite on Mt. Fantale have been reported in some detail (Gibson, 1974). Two to several dozen meters in diameter and up to 7 m high, they contain extensive deposits of mammalian bones (Morris, 1974). Shallow littoral "bat caves" as much as 8 m high have been reported in cliffs of Lake Rudolph.

At Mt. Elgon, the bedrock is especially rich in soluble salts. Ollier and Harrop (1958) have described some of the caves on the Uganda side of the volcano. Those on the Kenya side, however, now are much better known. Many, but not all of them, have been extensively enlarged by native tribes over a long period of time. Pick marks are locally abundant, and some walls and great fallen blocks have been strangely sculptured. Complex mazes of roof-supporting pillars remain. Some of the pillars are so slender as to seem incapable of supporting any considerable weight or roof span. Indeed, there are legends of miners having been buried under rock falls. Artifacts of this mining remain in some of the caves. Elephant, buffalo, bush buck, and large domestic animals also contribute to enlargement of some of these caves, including Kitum Cave (Fig. 10).

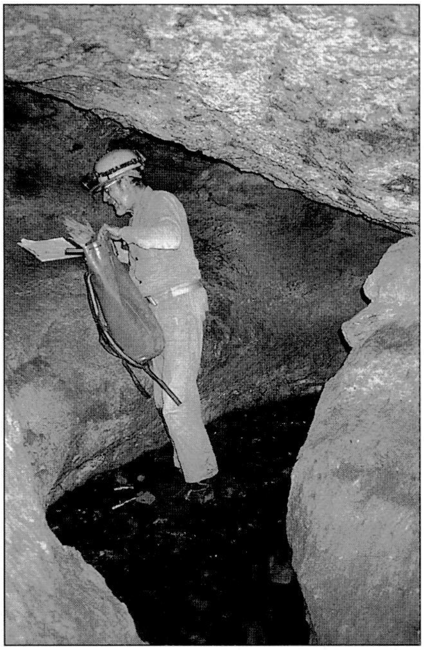

Figure 9. Intermittent stream passage, Ndarugu River cave. WRH photo.

Figure 10. Tusk marks, Kitum Cave. WRH photo.

Toroton Cave is Mt. Elgon's largest cave. More than 1/2 km of chambers and galleries of this type link two entrances. An intervening chamber with a huge roof span is partially supported by seemingly artificial pillars. Between the two entrances but seemingly an independent cave, is Stone Axe Cave. On the opposite bank of the river, at the foot of a waterfall, is Water Cave. Here, part of the river passes into the cave, floods an excavated area, and exits through another large natural portal. Two other caves at the foot of another waterfall on the main Kapkulkul River appear to have been largely excavated by man.

Kimothon Cave (also known as Tweedie's Cave and likely Lindblom's Cave #1) is at about 2,600 m in the cliffs of a conspicuous bluff near the Khybe Sawmills on a route from Endebess. It consists of a wide chamber visited by elephant and mined galleries leading to a higher chamber with great fallen rocks.

This section formerly was inhabited. The walls were greatly hewn by man, and the cave contains numerous bored stones. Increasingly indistinct crude rock-paintings of animals and a "bowman", are present in a rockshelter outside this cave. Other, better-preserved multicolored hunting scenes exist in Kakapeli Cave elsewhere on this side of the mountain.

The best-known and most visited caves of Mt. Elgon, however, are Kitum Cave, Makningen Cave, and the Chepyanili Caves. All are located near a popular 4x4 track in Mt. Elgon National Park. Kitum and Makingnen Cave are described in detail in the guidebook of this symposium (Simons, 1998). Petrified vegetable material and possibly some animal remains are seen in the ceiling walls of these and some other Mt. Elgon caves. Some contain sizeable vugs. The published map of Kitum Cave (Sutcliffe, 1967) was mislabelled Makingnen Cave which is north of Kitum Cave, along the same escarpment. Waterfalls tumble over the mouths of both caves. Makingnen Cave has a huge, high-vaulted entrance. The cave extends northward for about 125 m. The first 60 m is very wide, flat, dusty, and relatively free of boulders. On its left side is a large, smooth-sided dome which has the appearance of a solutional feature. Near the midpoint of the cave is a large rockfall dividing the cave into two chambers. Many elephant and buffalo footprints and droppings usually are seen in the vast entrance chamber. These animals seem to confine their salt-mining to an excavated alcove on the right side of this chamber. Although droppings have been found on the rockpile, it appears that elephants do not cross it into the back of the cave. The latter is more than 100 m wide and is occupied by a great central pile of fallen roof slabs up to 8 m high. Here there are several small pools of water, and a colony of fruit bats.

With so much non-geologic enlargement of these caves, their origin is unclear. More than 30 years ago (Sutcliffe, 1967) it was suggested that their origin was solutional, with later enlargement by mining by man and animals. Small solutional tubes are present at the entrance of Kitum Cave, and smooth roofs and domes in Makingnen Caves suggest that ground water in the partially soluble pyroclastics played an initial part. Many of the caves are associated with river valleys and waterfalls, and it is possible that early ground water cavities were broken into and subsequently enlarged by rivers. Water Cave clearly is undergoing such action at the present time, by a tributary of the Kapkulkul River. Although much of the great size of Toroton Cave is clearly the result of human mining, it is difficult to attribute the great size of some of the underground chambers to the hand of man with simple tools, short of creation of huge rock falls by mining activity. Despite all the evidence of mining by man and wild and domestic animals, the writer agrees that these caves are mostly natural, with chance discoveries of salty rock leading to mining by animals and humans.

Finally, it should be noted that early reports of the Mt. Elgon caves and cave-dwellers gave inspiration to the novelist H. Rider Haggard (who visited the coast of Kenya) for his famous book King Solomon's Mines.

TECTONIC RIFTS IN VOLCANIC ROCKS

Some rifts in granitic rocks have been descended in Kenya. However, open or roofed rifts are more commonly associated with movements of graben blocks along the edges of or within the Rift Valley and on individual volcanos. Most have been revealed and/or enlarged through their taking surface water. Such caves no doubt undergo repeated change with monsoons. In the Nakuru area near Menengai Caldera, rifts continually appear during the rains. A 1928 earthquake measuring 7.0 on the Richter Scale, resulted in movement of blocks of relatively hard tuffs, forming escarpments 10 m high and many fissures. It also diverted the Subukia River underground. Fissures on the former Milton's and Reynold's Farms, near Solai, have been descended by CEGEA members to depths of around 30 m. The Main Rift on Rey- nold's Farm clearly showed enlargement at depth by the passage of water. It was followed laterally for over 130 m before it became too narrow to continue. At the bottom of several such rifts are dehydrated carcasses of domestic animals.

Other kinds of rifts are known in very loose pyroclastics or „earths" which perhaps form an overburden conceiling deepseated faults. Kilimabogo Pot, a 60 m shaft broken into two pitches, is one of Kenya's deepest caves. It is on the north side of Mt. Eburru. At the southern foot of the same volcano is "The River Sink", a deep open rift which forms a sheer end-wall to a river valley. A seasonal river flows off the mountain and disappears into the rift at the foot of the wall. It is choked with silt and boulders. West of Lake Naivasha, on the Mau Escarpment, Merrick's Pot is another earth rift, 25 m deep. Mummut N'gei (Maasai for "The Cave of God") on the Ndabibi Plains at the foot of the scarp is clearly on a fault line within old lake sediments and interbedded pumices. It has been enlarged into a cave with 196 m of passages, mostly walkable.

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REFERENCES

DAVIES, G. 1972. Caves, crabs, and crocodiles. CEGEA Bulletin 3, p. 9.

GIBSON, I.L. 1974. Blister caves associated with an Ethiopian ash-flow tuff. Stud. Speleol. Vol. 2, part 6, p. 225.

GLASER, S. 1989. Dachungel, vulkane und - eine Höhle. Der Schlaz, no. 58, June, p. 32.

MILLS, M.T. 1977. The subterreanean wonders of Kenya. Shepton Mallet Caving Club (U.K.) Occ. Publ. no. 8, Spring, 19 p.

MONTSERRAT I NEBOT, A. 1979. Rwanda 77. Espeleoleg no. XXVIII, March p. 536.

MORRIS, P. 1974. The mammal fauna of the ash-flow tuff blisters of Fantale, Ethiopia. Stud. Speleol. Vol. 2, part 6, p. 233.

MORTON B. (attributed) 1976. New cave discoveries in Ethiopia. CEGEA News l. Nov.-Dec. p. 1.

OLLIER, C.D. AND J.F. HARROP. 1958. The caves of Mt. Elgon. Uganda Jour., Vol. 22, no. 2, Sept., p. 158.

SCHOMER, B. AND B. RANDALL. 1994. Garama Cave, Mgahinga Gorilla National Park, Kisoro, Kigesi District, Uganda. Unpublished report and map, Feb.

SIMONS, J.W.E. 1972. Lava tunnel on Nyamulagira, Zaire. CEGEA Bulletin 3, p. 19.

SIMONS, J.W.E. 1998. Guidebook of the 8th International Symposium on Vulcanospeleology. Privately published. Feb.

SUTCLIFFE, A. 1967. A caving expedition to East Africa. Wm. Pengelly Cave Studies Assn. Newsl. no. 9, Sept., p. 17

SUTCLIFFE, A. 1973. Caves of the East African Rift Valley. Cave Rsch. Group Trans. Vol. 15, no. 1, Feb., p. 41.

Int. J. Speleol., 27 B (1/4), (1998): 21-31.

THE CAVE EXPLORATION GROUP OF EAST AFRICA AND VOLCANIC CAVES IN KENYA

Michael Declan Kennedy

ABSTRACT

This paper looks at the history of the Cave Exploration Group of East Africa with special reference to the exploration of volcanic caves. It demonstrates that the group has concentrated on two main areas, the Chyulu Hills and Mt. Suswa, although other areas have also been studied. The Cave Exploration Group of East Africa has had to cope with various problems. The most important of which are related to the socio-economic conditions of a developing country. These problems have not prevented the group from making a valuable contribution to vulcanospeleology.

Keywords: Caving Club, vulcanospeleology, Kenya

FORMATION OF THE CAVE EXPLORATION GROUP OF EAST AFRICA

The history of cave exploration in Kenya goes back at least 5,000 years. Dr. L.S.B. Leakey found evidence of human habitation at Gamble's Cave at Elmentaita. This dated from the Upper Kenya Capsian period (5,000-10,000 b.p.) (Clarke, 1996). Various Kenyan communities used caves as refuges, burial centres, for minerals and as religious centres (Mwaniki, 1973). The first published account of caves in Kenya is Joseph Thomson's account of the Mt. Elgon caves, although he mistakenly decided that these were formed by an ancient superior civilization mining for "precious stones or possible some precious metal" (Thomson, 1885). The caves are formed by water erosion in soluble pyroclastics, but have been extended by mining (Bristow, 1961).

Although the Cave Exploration Group of East Africa was formed during April and May 1964, its origins lie slightly earlier. Dr. P.E. Glover, of the Dept. of Veterinary Service and Dr. Guest, of the Mines and Geological Dept., accompanied by their families, paid a visit to Mt. Suswa. They were guided by Mr. D. Hobden, also of the Mines and Geological Dept., who had been carrying out geothermal investigations in the area. Dr. Glover had noticed holes in the lava flow on Mt. Suswa from the air, but had not been able to get access to them until Mr. Hobden had made a track up the mountain. The weekend visit confirmed Dr. Glover's suspicions that these holes gave access to lava tubes (Glover, 1965).

Dr. Glover found evidence that primitive man had visited the caves. This took the form of obsidian artefacts and stone tools. The local Maasai confirmed that the caves had been visited by Wandorobo (now more commonly called Okiek) hunter gatherers. The caves were used during the Emergency (1952-60) by Mau Mau freedom fighters as refuges. The Maasai themselves were reluctant to venture beyond the day-lit entrances of the caves (Glover, 1965). Dr. Glover began a scientific study of the caves. In company with other interested parties, he began the initial mapping of the area and began to survey caves. Studies were also carried out on the geology and ecology of the area.

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Mr. Hobden's road gave easier access to the lava flows and the number of visitors increased. Many of these visitors came for scientific studies, but others did not share their respect for caves. Specimens were damaged and artefacts, including bones, were removed. To protect the Mt. Suswa caves, a conference was held during April and May 1964 amongst interested parties with a view to conserving the caves and to encourage their scientific exploration. These conferences took place at the National Museum of Kenya and resulted in the formation of the Cave Exploration Group of East Africa, with Dr. Glover as the first president of the Society.

CAVING AREAS

During the first year and a half of the existence of the Cave Exploration Group of East Africa, Mt. Suswa was the main area of exploration. Forty per cent of all caving trips were to Mt. Suswa. These expeditions concentrated on surveying known caves, searching for new caves, the geological structure of the caves and the fauna and flora of the caves and the surrounding area. This seeming overconcentration on one area is justified in that it is one of the most complicated areas of lava tubes in the world. In 1971, four new caves were discovered on Suswa (Davis, 1971a, King, 1971). Indeed in 1973 a whole new area of lava tubes was discovered and explored by Arkle, Davis, Mason, Shuttleworth and Simons. This was near the moat and a good distance from navigable roads. A new tube entrance was found about 200m from the well visited entrance, Collapse 12. Other areas visited in this period included Mt. Elgon and the rediscovery of the Cave of God (Ngumut Ngai in the Maasai language, Maa), which was described by Gregory in his account of his journey through the Rift Valley (Simons, 1969). Simons identified 39 known caves or collapses with the potential for extension via digging or pushing (Simons, 1979). The sheer number of tubes in the lava flow and the complicated arrangement makes it well worthy of study. In the main cave area there are 69 known entrances with some 40 cave series totally over 11km of passage (Simons, 1998).

As the Cave Exploration Group of East Africa gained new information more cave areas were added to our knowledge. Erosional caves in the Kiambu and Thika regions were explored. These caves were popular as they close to Nairobi and quite sporting. The badlands area around Mt. Eburru and the Rift Valley north of Nakuru were also popular (Davis, 1971b). Small caves were also explored on the Delamere Estate near Lake Elmentaita. This period also saw the initial exploration of the Chyulu Hills that was to become a major focus of future study.

The Chyulu Hills area was known to have caves. Shaitani Cave had been fitted with ladders to allow tourists to the Mzima Springs camps to visit about 200m of passage. In 1969 new passages were found in the area running from collapse holes (Simons, 1971). The Chyulu's, being a comparatively young chain, had many areas of fresh lava flows. These had every indication of cave bearing potential. The North Chyulu area has many fine tubes, some of which appear to be part of a blocked linear tube (Simons, 1972b). The Mathioni Cave was mined for bat guano and opened as a show cave (Simons, 1972c). Other caves and trenches are found all along the Chyulu's, but there has been little exploration of the Western side of the range. Currently ninety different cave structures have been located in the Chyulu's (Simons, 1998).

In 1974 CEGEA had a major change of direction. Aerial photos had shown what appeared to be more entrance holes in the Chyulu Hills, in a lava flow running down to the Kibwezi area. Upon investigation the following year - they went. The first reports indicated a half kilometre of tube on either side of the entrance. This gradually got longer and longer on each visit. It was announced that Leviathan existed (Simons, 1976). This was like a drug. Every other two weeks there was a trip to extend this monster. We were going to get the longest lava tube in the world. The thing was immense and it had levels that seemed to breed new levels. Hard core members such as Dave Womack and John Arkle gave up weekends of their lives moving the maypole, digging, pushing and surveying to do justice to one of the greatest underground systems known to human kind. We ended up with over twelve kilometres of cave and are still digging at the Top Choke in hope of extending it further. Leviathan saw the most intensive effort ever on the part of the Cave Exploration Group of East Africa when 19 people descended on the site from the 10th to the 19th April 1976 to survey the monster. The first transit was made in 1985. This involved teams on the surface waiting to service the underground team. To everyone's surprise the underground team made much better progress than the support team which had to batter its way across the bush to various entrances. Several other caves, such as ABC and Pango ya Moshi (Smoke Cave) were found in the vicinity of Leviathan, but were found to be separate systems. There was a decline in activity in Leviathan during the late 1970's and early 1980's. The newsletter expresses surprise at this, but in retrospect it can be explained in economic terms. In the early 1970's Kenya went through recession caused by the effects of the oil price shock after the Yom Kippur war of 1973. Between 1976 and 1978 there was the 'coffee boom'. The economic chaos in Uganda under Idi Amin Dada led to massive smuggling of Ugandan coffee through Kenya. This coincided with a world coffee shortage and consequent high prices. The ouster of Amin and the decline of coffee prices in the face of the world recession after the second OPEC price hike of 1979 hit the Kenyan economy badly. Cavers could not afford the long travel needed to spend a weekend at Leviathan and they tended to concentrate on the nearer Mt. Suswa.

As the economy began to recover there were massive efforts to study and survey the upper levels. The Cave Exploration Group of East Africa logbook is full of entries that say "moved the maypole". Currently Leviathan stands at 14km of surveyed passage, with digging continuing at the Top Choke in hope of finding an extension. Even when we were gripped with excitement about Leviathan visits were still made to our old haunts. In 1976 Mathioni was extended by another 100m via a crawl which had been attempted but not pushed before. John Arkle pushed cave 12 on Mt. Suswa as well as spending a lot of time and effort on Leviathan. His efforts made 12 the longest system on Mt. Suswa, which was an added bonus, as it was one of the most interesting caves with some of the most magnificent flow patterns we had seen. In 1977 Simons and Timberlake found a new tube of about 100m length leading out from the first collapse in the lava flow. Further discoveries were made in 1984. This find shows the potential of even such a widely visited area as Mt. Suswa to yield new finds. Naturally the logbook shows the shift in emphasis from Suswa to Leviathan. While there were nearly as many trips to Mt. Suswa as before, in terms of days spent in caves Leviathan was far ahead. The effort to push and survey Leviathan led to a neglect of surveying in other known caves. As a result some of the caves on Mt. Suswa have not been properly surveyed to date.

Mt. Elgon has always been a major attraction. This necessitated a four or more day expedition, due to the distance from Nairobi. While there were members elsewhere, especially Nakuru, they had to join up with the majority from Nairobi to make a worthwhile party. While local farmers knew of the cave entrances, and in many cases had explored them, and poachers certainly knew of them and used them as hideouts, CEGEA was the first group to seriously survey such caves as Kitum and Hampton

Court. The latter was a particular favourite as a testing ground for novice cavers. Its maze-like nature made it a hilarious examination of navigation and surveying skills (Davis, 1972). In January 1980 Kitum cave was identified as a primary vector in a suspected case of Marburg Virus (Preston, 1995). Cave Exploration Group of East Africa members co-operated with the Centres for Disease Control and the Kenya Medical Research Laboratories in donating blood samples for analysis and guiding research parties to the cave. CEGEA members showed no traces of the virus although they were frequent visitors to the cave. Indeed CEGEA members wore ordinary caving gear while leading the researchers dressed in full biological protection suits into the cave. Nevertheless, many members were reluctant to venture onto Mt. Elgon for some time, there being no trips between 1981 and 1989.

Mt. Elgon was never as widely visited as the Chyulu Hills and Mt. Suswa. The distance meant that a long weekend, such as Christmas, Easter or one of our public holidays, was needed to gain enough free time to reach the caves. Other interests such as Leviathan, Silali and combining the limestone of the Coast with a weekend on the beach also contested this time.

The new area of study seems to be Mt. Silali. This is at the border of Baringo and Turkana districts and was reported to us by geologists doing geothermal surveys for the Government of Kenya and the Overseas Development Association. The main tube that has been entered here almost defies description. It has the potential to surpass Leviathan. The exploration of Mt. Silali has been intermittent. This is due partly to periods of insecurity. The distance and inaccessibility means that a five-day expedition will yield one day of caving with the risk of either not reaching the cave or being cut off for some time by the sudden and unpredictable rains which flood the rivers and luggas (dry river beds). There are other potential cave areas in Kenya. The Yatta Plateau, a 300km long lava flow appears to have entrance holes when seen from the air. This plateau appears to have been formed from lava flowing down a river valley, the sides of which subsequently eroded leaving the plateau standing alone (Nyamweru, 1980). There are known to be caves in lava in Turkana district. Again this area is very far from Nairobi and the harsh climate is a further barrier to successful exploration.

As the Cave Exploration Group of East Africa we have also been active in our neighbouring countries. Expeditions have gone to Tanzania, although mainly to limestone areas. Clive Ward has found some fascinating tubes on Kilimanjaro and Arkle investigated blisters on Mt. Meru. Jim Simons has also investigated a lava tube on Mt. Nyamulagira in the Democratic Republic of Congo (then Zaire) in 1972 (Simons, 1972a). Mt. Nyamulagira erupted the following year but it has not been possible to return for further investigation. The continuing insecurity rules out a visit for some time. We have members in Uganda although we have not had much news. Somalia has limestone caves but we have not heard of any caving activity from there for a while.

CAVING ACTIVITIES

Cave conservation was one of the reasons why the Cave Exploration Group of East Africa was formed. CEGEA continues to exercise this policy. The Mt. Elgon caves are well known and attract a number of tourists who have seen wildlife films on the elephants in the caves. Other caves are less well known but are also visited by non-CEGEA members. Cave 18 on Mt. Suswa was used during the making of the film Sheena Queen of the Jungle. After the film crew departed, CEGEA members removed the debris that they had left behind. Crystal Cave on Mt. Suswa has extremely delicate and beautiful speleothems. The location of this cave has not been revealed to prevent unnecessary damage to the formations. CEGEA members have not visited the cave since its initial survey (Simons, 1974).

Like many other caving groups of this period the Cave Exploration Group of East Africa made much of its equipment, such as ladders from nylon rope and podo wood for the rungs (Mason, 1965). There was an extra incentive in Kenya. The government promoted a policy of import substitution to encourage the growth of local industry and to reduce its dependence on the export of primary agricultural products (Ogonda, 1994). This policy severely limited the amount of foreign exchange available for the import of luxury items, of which caving equipment was considered an example. As well as making its own equipment, the Cave Exploration Group of East Africa members resorted to various subterfuges of differing degrees of legality to obtain equipment from overseas. One favoured method was to persuade visitors to bring in equipment; another was to request visiting cavers to donate some of their equipment when they left.

Over the years the Cave Exploration Group of East Africa has often expressed doubts about its direction and viability, "We are still alive". This is because we go through periods where members leave and are not replaced, or when the existing membership seems to lapse into a state of inactivity. These periods are then followed by expressions like "well, we actually had a good year with lots of trips" or the infusion of new members. The areas of study also represent the interests of the membership.

Part of our worry has come about because of the changing socio-economic climate in Kenya. Most members cannot afford to spend as much time caving as they did in the 1960's because they cannot afford it financially. As well as the general expense of caving, there is also the expense of running repairs on vehicles caused by the damage inflicted by getting to the caves. In Kenya the biggest potholes are the obstacles to be overcome before you even get to a cave. Although the extent of sealed and graded roads has greatly increased since independence it still does not reach the major caving areas. For example the amount of tarmac had increased from around 2000 to 9000 kilometres between 1964 and 1989 (Central Bank of Kenya, 1981). The economic problems caused by the effects of world recession, climatic problems and IMF-World Bank Structural Adjustment Programs have led to a slow-down in this expansion (Government of Kenya, 1996). Lack of resources for maintenance has caused deterioration in the existing transport infrastructure. By 1988 only 34% of the paved roads were in "good condition" (World Bank, 1995). The unprecedented rains linked to the 1997-8 El Niño phenomenon have worsened the state of the roads. The dangerous state of the road network in Kenya contributed to a serious accident in 1986. Jim Simons and Bill Tanner were seriously injured in a head-on collision with a vehicle attempting to overtake a slow-moving vehicle. They had to be evacuated to Nairobi by the Flying Doctor service.

In the early days of the Cave Exploration Group of East Africa we used to have many active members from the university and government departments such as geology. These members were able to combine their professional interests and research with their caving. Today we have very few such members. Civil service and university salaries are so low that most lecturers spend their spare time on paid consultancies in order to make ends meet. The Ndegwa Commission of 1967 that permitted civil servants to engage in business while still performing their government duties encouraged this policy. This policy permitted the government to give small pay increments while encouraging civil servants to find other sources of income generation (Leys, 1994). They have little time for other activities. This is one of the sad facts of life involving caving in a developing country.

A related problem is specific to Kenya. This is product of the local education system.

Before Independence the colonial government employed Africans only in the lower levels of the civil service. Appointments were determined by educational attainment. At Independence education was reinforced as the key to advancement due to the Africanisation of the civil service. As a result a lot of stress was spent on passing exams (Berman 1990). Once exams had been passed and a position obtained then there was no further incentive to read any further to keep up to date in one's chosen subject or to pursue any research which did not bring any obvious financial benefit (Chakava, 196). This attitude has helped to hinder the spread of caving beyond a wider section of the populace. Sheer poverty is a further hindrance to widening the popularity of caving. A nation with a per capita income of under US$ 300 will see caving as a luxury when basic needs are not yet met.

Specific problems in Kenya are tribal clashes and rustling. Rustling has been a traditional part of pastoralist life since time immemorial as different communities have myths in which God gave all the cattle in the world to them. Rustling was always carried out with an element of cultural ritual, discipline and traditional weaponry. The insecurity in neighbouring states led to an influx of modern weapons such as the AK 47 and rustling has turned into clashes between heavily armed bands (Karimi and Ochieng, 1980). During the 1992-3 period it was not safe to go to Mt. Elgon, due to clashes in that area, apparently generated by political tensions during and after the transition to multi-party politics (Troup and Hornsby, 1998). This area is safe now. Mt. Silali on the Pokot-Turkana border was also ruled out for some time due to rustling.

We have also come across caves being used by poachers, especially in the Chyulu's and Mt. Elgon area but luckily have had little trouble with them. It has been impossible to ignore their effects. The wildlife in these areas is much less prolific than when we first started visiting these areas, as can be seen by comparing entries in the Logbook from the 1960's and 1970's with more recent entries. We have, however, had some problems of access to caves. This is a universal phenomenon but has specific local ingredients. In 1974 a visit to a cave in the Nyambeni Hills that was used for circumcision ceremonies by the Meru people led to arguments about payment to the locals. The guide showing us the cave solved this problem. As an elder his words settled the matter. The Mt. Suswa caves lie on a Maasai group ranch and we have at times been asked to pay for access. We have not felt that this was justified as the local community has done nothing to help to maintain the access and the route up has continued to deteriorate.

Theft from vehicles while a caving party is underground seems to be a universal problem for cavers. This has necessitated the use of camp guards who are left behind to take care of the vehicles and equipment at all sites. There have been problems with security on Mt. Suswa. In 1974 a vehicle was broken into and camera equipment taken. The cavers who had suffered the loss had noticed two Maasai herdsboys who had been watching them earlier but who were now at a far distance, and who would not come closer when called. The two intrepid cavers took one of the cows from the herd and took it to a local police post. The police were able to prevail upon the Maasai to return the camera equipment in exchange for their cow (CEGEA Newsletter, March 1974). This was shrewd psychology on the part of the cavers as the cow is wealth to the Maasai. It also indicates the transitional nature of Kenyan society. The traditional respect for the cow as source of wealth co-exists with the knowledge of the monetary value which the camera equipment could obtain. The equipment would probably have been sold and the money gained used to buy more livestock.

Generally we have been more fortunate in our relationships with the local population. On Mt. Suswa Mzee Sulatun has been a great help to us in passing on information about the location of entrances (Womack, 1998). On the Chyulu's Julius Ngeka Kyule was also a great help as were many of his neighbours who found it fascinating that outsiders would be interested in their local holes and would even wish to enter them. This assistance is reflected in the came given to one tube Twende Mwende ("Let's go Mwende"), named after the young girl, Mwende, who told us about the entrance and after the invitation Twende Mwende, actually led us there. These local people have now been moved away to preserve the Chyulu Hills Nature Reserve as a National Park. This has led to tracks becoming overgrown and the vegetation to bloom with the absence of grazing animals. This has made access to some of the caves more difficult and much time has to be spent hacking (or thrutching in Cave Exploration Group of East Africa speak) through the bush to reach the cave. A lot of time is also spent looking for cave entrances, as the landscape can often be quite unrecognisable with a profusion of bush. The Kenya Wildlife Service now in charge of the Park has been very co-operative. They have waived camp entrance fees for caving expeditions and have also granted us permission to camp outside the designated campsites to allow us to be nearer the caves.

The Cave Exploration Group of East Africa has also maintained relationships with other sections of society. Thus we have led tours for members of other societies, such as the Geological Society, East African Wildlife Society amongst others to the cave areas of Mt. Suswa. We also have cordial relationships with the Mountain Club of Kenya of which many of our members are also members. Joint weekends have been quite useful. Visiting cavers and other interested parties have also been welcomed. For instance, in 1974, Dr. Bill Halliday paid us one of his many visits and discussed the possibility of holding the symposium in Nairobi (Halliday 1975). Visitors from the Society of Lancaster University Graduate Speleologists helped us push a new section in Leviathan, which was named S.L.U.G.S. in their honour. At this time we also received an offer of assistance from CROSA (The Cave Research Organisation of South Africa) in our exploration of the then newly discovered Leviathan (CEGEA Newsletter Jan-April 1977 p.7). Unfortunately this offer could not be taken up due to the political situation at the time. South Africa was boycotted by the member states of the Organisation of African Unity and South African citizens were not allowed to enter Kenya (Orwa, 1994). The politics of the nation also affected us in a small way. When Kenya gained its independence in December 1963, Mzee Kenyatta was Prime Minister with a Governor-General representing the Queen as head of state. In December 1964 Kenya became a republic with Mzee Kenyatta as president. Out of respect for Mzee a law was introduced which made it illegal for any organisation or person to use the title president, except the head of state. The Cave Exploration Group of East Africa had to change its president to chairman. President's Pot at Thika, consequently had to be changed to Chairman's Pot. In December 1997 the ruling party KANU (The Kenya African National Union) finally got around to changing its constitution so that the head of state became the chairman rather than the president of the party.

The society has also prepared work for publication. Articles by members have appeared in journals such as the Shepton Mallet Caving Club Journal (Mills, 1980), the BCRA Bulletin (Simons, 1976b) and the NSS News (Simons, 1975b). Local publications have also featured some of our activities. The most extensive coverage being the first transit of Leviathan in 1976. This had received sponsorship from several local firms and they advertised in a supplement published in the Nation newspaper. We also have our own publications. The newsletter for members often has reviews and news of past trips and new discoveries. The Newsletter has changed format several times, between monthly, quarterly and, very occasional. Our Bulletin, renamed Speleophant in 1973, has become somewhat erratic. This is partly because of pressures of time also with the difficulties of outdated equipment. We have had to choose, in these economically testing times, between publishing and Leviathan. Leviathan won hands down.

In these days of Desktop Publishing the standard of most caving publications have improved out of all recognition. However to use DTP you need access to the equipment that can run it. Until recently most of us have been stuck with out-dated, under-powered and incompatible equipment. This is partly a result of economic factors beyond our control. Import duties and taxes make new equipment prohibitively expensive. The computers that were being imported were often out of date equipment that was being replaced by the next generation in the developed world. As it could no longer be sold there, it was possible to dump such equipment here where it still had a market. Reconditioned 486 computers are currently available here for US$ 700 plus VAT while a lower range new Pentium would cost at least twice as much. Cave Exploration Group of East Africa members have now managed to replace their CP/M machines and we intend to resume publishing Speleophant this year. We have reached a peak of fame of sorts. In January 1998 on Cartoon Network the famous Tazmania met a genie who set him three tasks, the third of which was to retrieve the famous ball of thread from the famous Leviathan Cave in Kenya. We expect an influx of juvenile cavers immediately.

We have also taken part in symposia. Our Chairman has represented us at previous meetings of the International Vulcanospeleological society. In 1974 The 4th International Bat Research Conference was held in Nairobi. We had a stand and Dieter Kock and Issa Aggundey presented papers (Hillman, A.K.K., 1975).

Cave biology has been a part of the Cave Exploration Group of East Africa interests, from the earliest days (Glover, 1966). We have a close relationship with the National Museum to whom we send species for identification. J. A. McFarlane published his work on the carnivorous beetles of Ithunda in the early 1970's (McFarlane, 1972). When the Hillman's were in Kenya and were active members of the Cave Exploration Group of East Africa there was a lot of work on cave biology. This was partly caused by the fact that Chris Hillman was working for his doctorate in biology. This resulted in the discovery of new species and of others that were identified in Kenya for the first time. The Hillman's also educated us in what was important for the study of cave biology, e.g. in which zone of the cave was the insect found, the temperature and relative humidity etc (Hillman, 1975). Thus a new species of pyrogoniscus lanceolotus was found and identified in 1977. As well as insects, we have also studied bats. The largest bat colony of Otomops martiensseni is found on Mt. Suswa and the extremely rare Hipposideros megalotis is also found (Kock et al. 1975). Fleas were found in Kiboko cave, which is rare in Kenya. Hillman also found a new cavernicole cockroach in Leviathan. Timberlake also explained what was needed in a bat survey (Timberlake, 1976).

One of the hazards that we face is that of finding animals in caves. The famous elephants of Mt. Elgon are probably the best known. Hyenas and leopards use caves as lairs. That is why you will find Cave Exploration Group of East Africa members making lots of noise before entering certain caves. It is not that they are trying to raise their spirits sufficiently to face the unknown darkness, rather they want any creature inside to come out or to roar to let us know that it is not safe to enter. Although this can be embarrassing, it is a lot safer than entering a narrow entrance to meet an angry leopard coming out. The first examination of a new cave in the Chyulu's was abandoned when it was noticed that lion tracks entered the cave but did not exit (Simons, 1975a, p.2). Other animals are also found in caves. The Cave Exploration Group of East Africa helped with the 1980 Operation Drake. This was a British project where groups of school children joined the round-the-world expedition for short periods of time. When the project was in Kenya Cave Exploration Group of East Africa members assisted in the exploration of Mt. Suswa caves while the army assisted with a bridge across the trench. In his account of the expedition,Lieutenant Colonel John Blashford-Snell, the leader of Operation Drake, describes a journey in one of the lava tubes on Mt. Suswa. While crawling along, he came to a chamber that had a small opening in the roof. In the pool of sunlight which this let in, lay a python sleeping soundly. The intrepid explorer and his companion tiptoed around the sleeping creature and proceeded to crawl along the next part of the tube. When this closed down, they retreated. On coming to the chamber they found that the python had woken up and taken off. They then had to exit the cave knowing that there was a python somewhere ahead of them. When being informed of this account our Chairman denies that this happened to Blashford-Snell, but in fact happened to two Cave Exploration Group of East Africa members. On another occasion Jim Simons reached out to grab a tempting tree root only to discover that it was a spitting cobra. Hence the name Cobra Cavern (Davies, 1974).

Besides subterranean hazards, we face problems of disease. Marbug's Fever has been mentioned, and hystoplasmosis is an enemy of all cavers, but malaria is also endemic in low-lying caving areas. Tick fever has also curtailed some expeditions.

Animals regularly fall into caves. This includes both domestic and wild animals (Hillman, 1975, Simons, 1982). In the early days of the Cave Exploration Group of East Africa, we were often invited to investigate fault caves into which animals had fallen. This was not a pleasant task as the atmosphere of decomposing animals was often overpowering. Bob Davis has a beautiful description of one such exploration, where the rift was actually as deep as it was rumoured to be (Davis, 1971). Animals falling into bat caves are often mummified by the dehydrating action of the guano. We have found many interesting specimens, ranging in size from civet cat to cow and kongoni. Mummies have been found in Suswa, Elmentaita and the Chyulu's (Simons, 1982).

The study of cave biology has also been linked to cave archaeology. Jim Simons did a lot of work on hyena and leopard lairs for Professor Glynn Isaac. The object of the study was to find what type of animals, scavengers took into the caves and what type of damage occurred to the bones. This was to help to identify which archaeological sites represented the homes of early hominids and which were of scavengers. It was also to study the differences between human and animal scavengers. This study involved collecting the bones from the hyena and leopard middens in the lava tubes and identifying and counting them (Simons, 1966).

Cave Exploration Group of East Africa members have been involved in other archaeological activities. Pottery shards have been discovered in the Tandala trench on the Chyulu's. These have been photographed and measured but have been left in situ so that they may be properly analysed at a later date (Soper, 1975). The rock cairns in Mathioni also in the Chyulu's have been left untouched but have been photographed and measured. These cairns are quite mysterious as their purpose is not yet known and they are deep within the dark part of the tube, which is very unusual for human artefacts in this country (Simons, 1972c). Simons has noted a cairn in Kimakia Cave also in the Chyulu's.

Cave Exploration Group of East Africa members have also been engaged in cave photography. Some of this has been in co-operation with professionals such as a Japanese television crew who filmed on Suswa with Dick Fordyce and Bill Tanner for a programme on the Rift Valley. Members have also made their own equipment. This has included filming with delayed flash release so as to paint the cave. The most home made effort involved the use of a car battery as a power point and aluminium foil covering a piece of cardboard as a reflector. This proved surprisingly effective and is another example of improvisation to compensate for lack of imported equipment.

All members of Cave Exploration Group of East Africa are active botanists. This is because while searching for entrances we have all learned to identify certain signs that a depression might be a collapse and then might be a cave entrance. If we see a fig tree (Ficus sp.) or a Dracaena sp. then we head in that direction and hope to hear the cries or "it goes".

The Cave Exploration Group of East Africa has always seen itself as a serious caving group. In 1965 we organised the first serious cave rescue group in Africa. If there was a problem in a cave all one had to do was to telephone the police who had the contact numbers of all the active cavers in the country and help would be on its way. This has fallen into disuse with the general decline of the national infrastructure. Frequently the police are unable to respond to emergency calls as their vehicles are grounded for lack of spare parts or fuel. In 1974 we practised a cave rescue on Mt. Suswa and were favourably impressed with our performance. Although the victim, who was nicely trussed up to simulate leg injuries, complained about rescuers knocking dust into her eyes.

When new techniques are developed we are also interested in learning. This even including a successful attempt at divining for caves using a forked stick (Watts, 1974). Lukenya, near Nairobi, and anybody's back garden that had a tree were favourite places for learning SRT. As we all know this gave massive grounds for hilarity even without trying to set records for prussiking up a tree. Cave diving was also introduced to East Africa (Davies, 1972). Gordon Davies introduced this in Lake Jipe and Cobra Cavern, but due to lack of backup this was never really followed up. Possibly because most other cave-divers fail to see the attraction of caving with crocodiles. Although the cave entrances on Mt. Suswa had been noticed from the air, and other entrances identified from aerial photographs of the Chyulu's, Gordon deliberately set out to be a sky caver. His pilot's licence was put to good use in over flights of the Chyulu Hills searching for surface holes that might give access to underground. Other members had also spotted apparent entrances while flying on wildlife surveys.

CONCLUSION

The Cave Exploration Group of East Africa has made a major contribution to vulcanospeleology in East Africa and the World. Despite limited resources and and being a mostly amateur group, i.e. none of the members are professionally involved in related fields such as geology, it has managed to push the boundaries of speleology in the region. This has been despite the socio-economic restrictions that are a fact of life in a developing country. CEGEA members have contributed a great deal to vulcanospeleology using their own resources in a hostile environment. Since the discovery of the great Leviathan system, CEGEA members have concentrated on this, almost to the exclusion of anything else. The region has an enormous potential given the amount of unexplored prospective cave area. The Cave Exploration Group of East Africa has never hesitated to welcome outsiders and to share its knowledge and to encourage others. With the proper resources, Kenya has the potential to contribute even more to vulcanospeleology.

REFERENCES

BERMAN, B. 1990. Control and Crisis in Colonial Kenya: The Dialectic of Domination, Nairobi. East African Educational Publishers

BRISTOW, C. 1961. The Mystery Caves of Elgon in East African Annual, 1960-61

CENTRAL BANK OF KENYA. 1991. Kenya: Land of Opportunity, Nairobi: Central Bank of Kenya

CHAKAVA, H. 1996. Publishing in Africa: One Man's Perspective, Nairobi. East African Educational Publishers

CLARKE, R.J. 1996. Introductory Notes on the Use and Habitation of Caves by Man South of the Sahara. CEGEA Bulletin, Vol. 1, March, pp. 70-114.
DAVIES, G. 1972. Caves, Crabs and Crocodiles. CEGEA Bulletin, Vol. 3, pp. 10-12.
DAVIES, G. 1974. Scuba in Cobra. CEGEA Bulletin, Vol. 4, pp. 13-15.
DAVIS, B. 1971a. Recent Discoveries on Mt. Suswa. CEGEA Bulletin, Vol. 2, pp. 5-6.
DAVIS, B. 1971b. Kenya Rift Caves. CEGEA Bulletin, Vol. 2, pp. 30-34.
DAVIS, B. 1972. Elgon Adventure. CEGEA Bulletin, Vol. 3, 1 pp. 23-25.
GLOVER, P.E. 1965. First Presidential Address. CEGEA Newsletter No. 1, Feb. pp. 2-4.
GLOVER, P.E. 1966. A List of Plants Associated with the Lava Caves of Suswa Mountain. CEGEA Bulletin, Vol. 1, March, pp .28-50
HALLIDAY, W.R. 1975. Impressions of a Visiting American. CEGEA Bulletin, Vol. 5, pp. 25-27.
HILLMAN, A.K.K. 1975. The Fourth International Bat Research Conference, Nairobi September 1975. CEGEA Bulletin, Vol. 5, pp. 28-29.
HILLMAN, C. 1973. East African Cave Fauna and Flora. CEGEA Bulletin, Vol. 3, p.14.
HILLMAN, C. 1975. Tandala Trench: an Open Lava Tube in the Chyulus. CEGEA Bulletin, Vol. 5, 1975, pp. 9-13.
KARIMI, J. and P. OCHIENG. 1980. The Kenyatta Succession, Nairobi, Transafrica Distributers.
KING, C. 1971. Original Exploration of Cave 6A. CEGEA Bulletin, Vol. 2, pp.6-7.
KOCK, D., J.C. HILLMAN and A.K.K. HILLMAN. 1975. A Colony of a Rare Bat Discovered. CEGEA Bulletin, Vol. 5, pp. 30-31.
LEYS, C. 1994. Underdevelopment in Kenya, Nairobi. East African Educational Publishers
MASON, E.I. 1965. Construction and Use of the Group's Ladders. CEGEA Newsletter No. 1, Feb. pp. 35-37.
MCFARLANE, J.A. 1971. The Carnivorous Beetles of the Ithunda Caves, Kenya. Studies in Speleology, Vol 2 (for 1970-71), pp. 149-158.
MILLS, M.T. 1980. An Outline History of Vulcanospeleology. Journal of the Shepton Mallet Caving Club, Series 6, No. 10, Autumn, pp. 13-26.
MWANIKI, H.S.K. 1973. The Living History of Embu and Mbeere, Nairobi: Kenya Literature Bureau
NYAMWERU, C. 1980. Rifts and Volcanoes, Nairobi. Thomas Nelson
OGONDA, R.T. 1992. Kenya's Industrial Progress in the Post-Independence Era: An Overview of Kenya's Industrial Performance up to 1980. OCHIENG, W.R. and R.M. MAXON. An Economic History of Kenya, Nairobi: East African Educational Publishers, pp. 297-311.
ORWA, D.K. 1994. Continuity and Change: Kenya's Foreign Policy from Kenyatta to Moi. OYUGI, W.O. Politics and Administration in East Africa. Nairobi. East African Educational Publishers. pp. 297-330.
PRESTON, R. 1995. The Hot Zone, London: Corgi
SIMONS, J.W. 1966. The Presence of Leopard and a Study of the Food Debris in the Leopard Lairs of the Mount Suswa Caves, Kenya. CEGEA Bulletin, Vol. 1, pp. 51-69.
SIMONS, J.W. 1969. The Rediscovery of the Cave of God. CEGEA Newsletter No. 5, June, pp. 10-12.
SIMONS, J.W. 1971. New Caves in the Chyulu Hills, Kenya. CEGEA Bulletin, Vol. 2, pp.33-38.
SIMONS, J.W. 1972a. Notes on a Lava Tunnel on Nyamulagira Volcano, Zaire. CEGEA Bulletin, Vol. 3, pp. 19-21.
SIMONS, J.W. 1972b. More Collapse Holes and Caves in the Chyulu Hills, Kenya. CEGEA Bulletin, Vol. 3, pp.29-34.
SIMONS, J.W. 1972c. The Mathioni Series, North Chyulu Hills, Kiboko, Kenya. CEGEA Bulletin, Vol. 3, pp. 40-50.
SIMONS, J.W. 1974. Yet More Caves on Suswa Main Flow. CEGEA Bulletin, Vol. 4, pp. 2-6.
SIMONS, J.W. 1975a. Lava Caves in the Virunga Mountains in NSS News, Vol. 33, No. 10, Oct, p.163.
SIMONS, J.W. 1975b. Notes on New Lava Tubes in the Chyulu Hills. CEGEA Bulletin, Vol. 5, pp. 2-5.
SIMONS, J.W. 1979. Extending the Suswa Main Flow Caves. CEGEA Newsletter, No. 1, Jan-Mar, pp. 3-6.
SIMONS, J.W. 1982. Kenya Cave Mummies. CEGEA Bulletin, Vol. 6, pp. 32-37.
SIMONS, J.W. 1976. Leviathan Cave - A Major Lava Tube in Kenya in BCRA Bulletin No. 14, Nov. pp. 23-25.
SIMONS, J.W. 1998. Volcanic Caves of Kenya, Nairobi. privately published.
SOPER, R. 1975. Pottery Sites in Tandala Trench, Chyulu Hills. CEGEA Bulletin, Vol. 5, pp. 15-16.
THOMSON, J. 1885. Journey Through Masailand, London
THROUP, D. AND C. HORNSBY. 1998. Multiparty Politics in Kenya, Nairobi. East African Educational Publishers.
TIMBERLAKE, J. 1977. Bat Survey. CEGEA Newsletter, Nos. 3&4, July-Dec, pp. 6-9.
WATTS, C. 1974. Cave Divining - Suswa. CEGEA Bulletin, Vol. 4, pp. 1-2.
WOMACK, D. 1998. Saturday Night, Sunday Morning. CEGEA Bulletin, forthcoming.
WORLD BANK. 1995. World Development Report 1995, New York. Oxford University Press.

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GUANO MINING IN KENYAN LAVA TUNNEL CAVES

Jim W. Simons *

ABSTRACT

Commercial mining of bat guano for agricultural fertilizer only became possible in Kenya through discovery of major deposits in the lava tunnel caves of Mt.Suswa and the North Chyulu Hills in the early 1960's. This paper provides historical information leading up to the guano mining, describes the cave deposits, outlines the mining under-takings, and provides information on the guano producing bats and insect faunas. The results of guano analyses, details of the the tonnages extracted and sold to recipients between 1966 to 1984, and some benefits which resulted from its use on crops are given. A brief outline of attempts to conserve the areas and caves is also included.

Keywords: guano, history of Speleology, Kenya

HISTORICAL INTRODUCTION

More usually associated with caves in limestone, bat guano has long been recognised worldwide as a source of fertilizer. It has also been mined for less peaceful purposes, as in the U.S.A. where it was dug out of caves to extract nitrates for the manufacture of gun-powder as early as the 1780's, and was in demand for the war of 1812 and for the American Civil War in the 1860's (Halliday, 1966).

In Tanzania, guano was extracted from limestone caves along the Songwe River, near Mbeya (Teale & Oates, 1935). Here, no less than 2,500 tons of high phosphate material was sold to local agriculture between 1934-1962 (Source - Annual Reports of the Mines Division, Tanganyika). A scamble to obtain the rights over guano in the Machinga Caves of Kilwa, along the Tanzanian coastline, also led to a "Guano Rush" (Bulpin, 1962).

Guano was first extracted in Kenya sometime in the 1930's or 1940's for personal farm use by an enterprising European settler, the late Renshaw Mitford-Barberton, from several caves on the slopes of Mt.Elgon. It was not, however, until exploration in the lava tubes of Mt.Suswa from 1963, and of the northern Chyulu Hills from 1965 onwards (Fig. 1), was it discovered that Kenya possessed substantial guano deposits of value.

Recognising their potential, and that it would not be too long before the accumulations attracted the attention of miners with little or no knowledge of caves and their conservation, three of the original cave explorers registered a company, Kenya Guano Ltd., and made plans for extraction and sale of the deposits while hoping to otherwise minimise damage to the caves and afford them some protection until they could be conserved within National Parks.

As bat guano was then unknown to Kenya's agriculture, and by its nature was a variable product, the new venture had a high investment risk. However, initial laboratory analyses indicated that the deposits were rich in organic matter and contained N.P.K. elements of sufficient percentages that might be sold to Kenya farmers and save on the

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then scarce foreign exchange needed for the import of chemical fertilizers. It was considered that a ready market could be established with coffee estates north of Nairobi which were convenient to the rail network.

To be able to commercially extract the deposits under the Mining Act (Laws of Kenya-CAP.306), it first became necessary through the Mines and Geology Department, for guano to be gazetted as a new Kenya mineral based upon its phosphate content, and to obtain a Prospecting Licence. A Consent to Prospect and Mine from Provincial Commissioners and the local district councils was followed by the pegging of Lode Claims, regist-ration of Locations, and authority to proceed to production. The caves were collectively to become refered to as the Kiboko and Mt.Suswa Mines. The company was also obliged to follow the Mining Regulations and file monthly and bi-annual returns of ore produced and sold, its value, and a breakdown of labour and other costs.

At each cave "mine", surveys of the tunnels and the guanos were under-taken. To arrive at estimates of available tonnage, many hundreds of auger-drill holes were laboriously hand-bored into the guano accumulations and samples taken for analyses.

THE LAVA TUNNEL CAVES AND GUANO DEPOSITS

Lava tunnel caves of international significance were first reported in Kenya on Mt.Suswa Volcano in the Rift Valley in 1963 (Williams, 1963; Glover et. al., 1964). This promoted the formation of the Cave Exploration Group of East Africa in 1964 (Simons, 1964), which led to further studies of that complex system and a search for caves in the Chyulu Hills volcanoes, near Tsavo National Park, where large tubes were soon located in the northern part of the hills (Simons, 1965A, 1972, 1974).

North Chyulu Caves

Clusters of steep-sided ash cones of the Tindima-Migululu and Kimabui Hills (1,400-1,500 m. a.s.l.), form a lower extension of the main Chyulu range of volcanoes, 160 km. south-east of Nairobi. In the pahoehoe lava flows of this northern outlier lie a series of lava tunnel caves which are south-north trending segments of what was originally a long single tube in a flow which originated from the Makukani Pit Crater in the central cone cluster (Simons, 1974, 1998). Three widely seperated caves were found to contain bat bat guano deposits of significance (Fig. 2).

Kimakia Cave (Ithundu Mine-Locations 130/1 & 155/1)

At an altitude of 1,120 m., at the foot of the Kimabui Hills near to the Ithundu Cone, Kimakia Cave was one of the first major lava tubes to be found in the Chyulu Hills in November, 1965 (NGR-415563). Although it has a total of 1.4 km. of passages, the cave is mainly composed of a 1,100 m. long main tunnel which is blocked at both ends. Generally 10 m.across, the tube is frequently "canyon-like" in cross section with roof heights reaching between 12 and 15 m. In the central sector there are three tubes levels, one above the other, with several collapse holes into the upper part. The largest entrance conveniently divides the cave into a 500 m. long northern segment (Imperial Canyon) and a 600 m. long southern segment with a great guano accumulation and was named New Maxwell House from the strong aroma of ammonia.

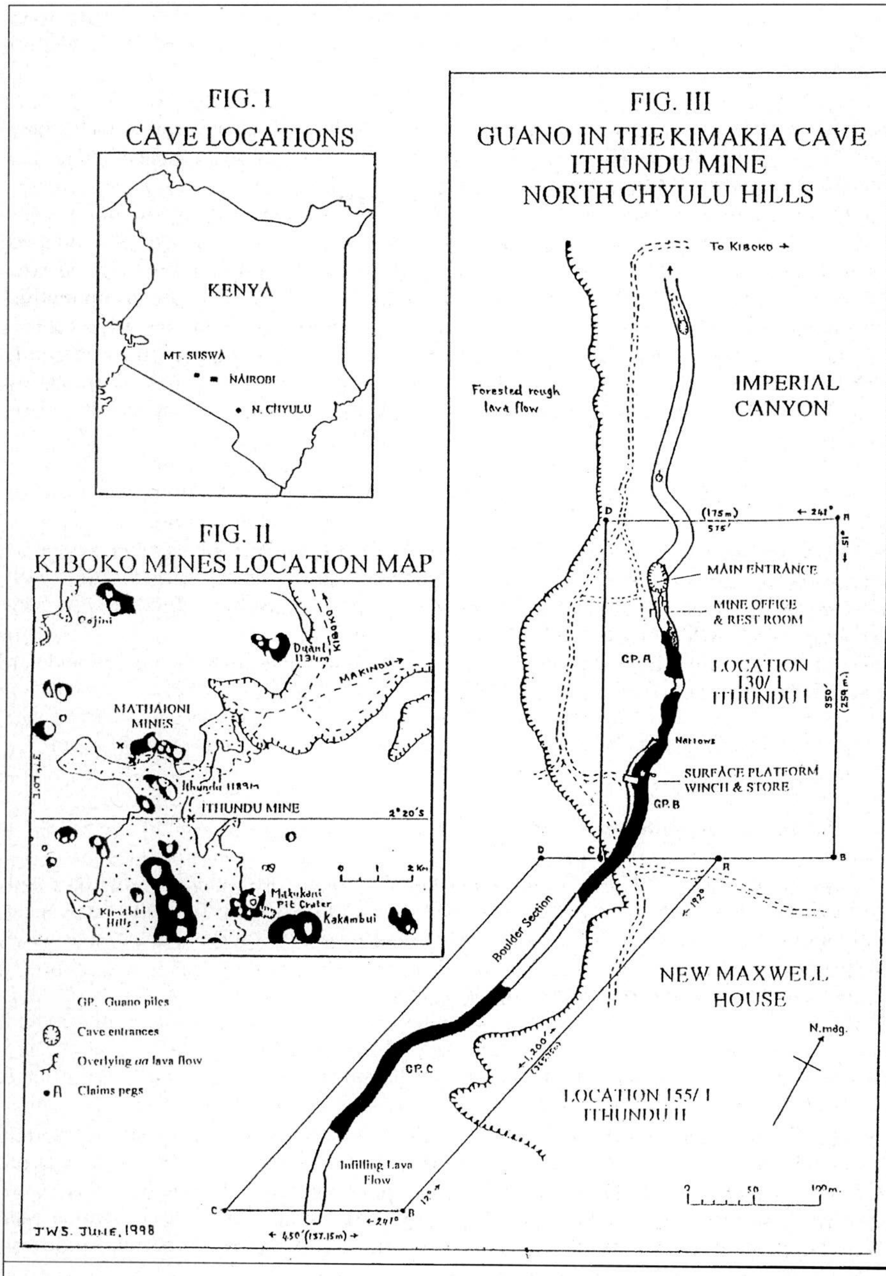


Fig. 1 - Cave locations.
Fig. 2 - Kiboko Mines location map.
Fig. 3 - Guano in the Kimakia Cave Ithundu Mine, North Chyulu hills.

Claims over the guano were registered in April, 1966 and May, 1968. There were three dusty guano sectors, seperated by boulder piles, which were found to be deepest under the principal bat roosts (Fig. 3):

A) - A short guano sector started 30 m.in from the Main Entrance and extended 35m. to a roof dome just at the limits of daylight, where there was a mjor bat roost, and reached 1m.in depth.

B) - The largest accumulation occured between 80-270 m. along the tunnel. Initially, the depth increased inwards from more than 1m., to 2m. at the narrows, and attained a maximum depth of 4m. where the tube widened and formed a 15m.high domed area and the principal roosting place for thousands of *Otomops* bats. Here, the accumulation covered a hill of breakdown and then sloped steeply down to continue inwards as a 1m. deep accumulation before being replaced by a long boulder section occupying the mid-tunnel area. Before the narrows, a 1.4m. section of the guano showed some stratification with an 0.8m. basal layer composed of comparatively loose guano pellets. Conversely, at the deepest level below the dome where there was a small roof hole allowing the ingress of water, the guano formed a wet, grey, clay-like layer of similar thickness. When first augured-into, this released the very pungent odour of sulphuretted hydrogen! Two minerals with probable guano origins were collected. Radiating crystals from the wet clay-like layer were tentively identified by the Late Professor Igor Loupekine as Bobierrite - Mg .P 0 .8H 0. A delicate and almost transparent stalactite, filled with blood red liquid, was found at an overhang under a guano-covered ledge and was considered to be a calcium phosphate (Simons, 1974).

C) - A 120m.long boulder section, which had small guano patches up to 1m.deep, was followed by a 135m. long sector of guano ending at 525m.in from the entrance where rough lava forms an invading flow. Bats have a series of roosts along this fine part of the tunnel and guano varied between 0.3m to 1.2m. deep, with an average of 0.6m.

Mathaioni Cave (Mathaioni I - Location 360/1-4)

Mining of the Kimakia Cave guano deposits was already underway when other nearby guano tubes were discovered in July, 1966, 2 km.to the north at the foot of the Mathaioni Cone (Simons, 1972). These deposits were held in reserve and extraction did not take place until 1974.

Mathaioni Cave (NGR-436547) is an extension of Kimkaia Cave, the two being seperated by a gap of roughly 1km. The cave has around 1.9 km. of passages distributed along a main-line length of 1.4 km. There are also several tube levels one above the other, with three entrances providing entry into the uppermost level. The Main Entrance collapse divides the cave into a 600m. long southern section (Cairn Passage), which was opened as an attraction in 1974, and an 800 m.long northern section (Boulder Passage). Part way along this segment lies a smaller collapse into a short upper level (Mathaioni Upper), while half-way along there is a depression which was cleared to reveal an 8m. pitch into the last part of the cave (Exit Pitch). Small insectivorous bats and rather damp guanos were found in humid sections of the cave over which a block of four claims were registered in July, 1974 (Fig. 4):

From "The Pit", roughly a third of the way along the southern tube, a 280 m. long lower tunnel runs beneath Cairn Passage and under the main entrance collapse for 65m.into the northern tube section. Three guano piles occured:

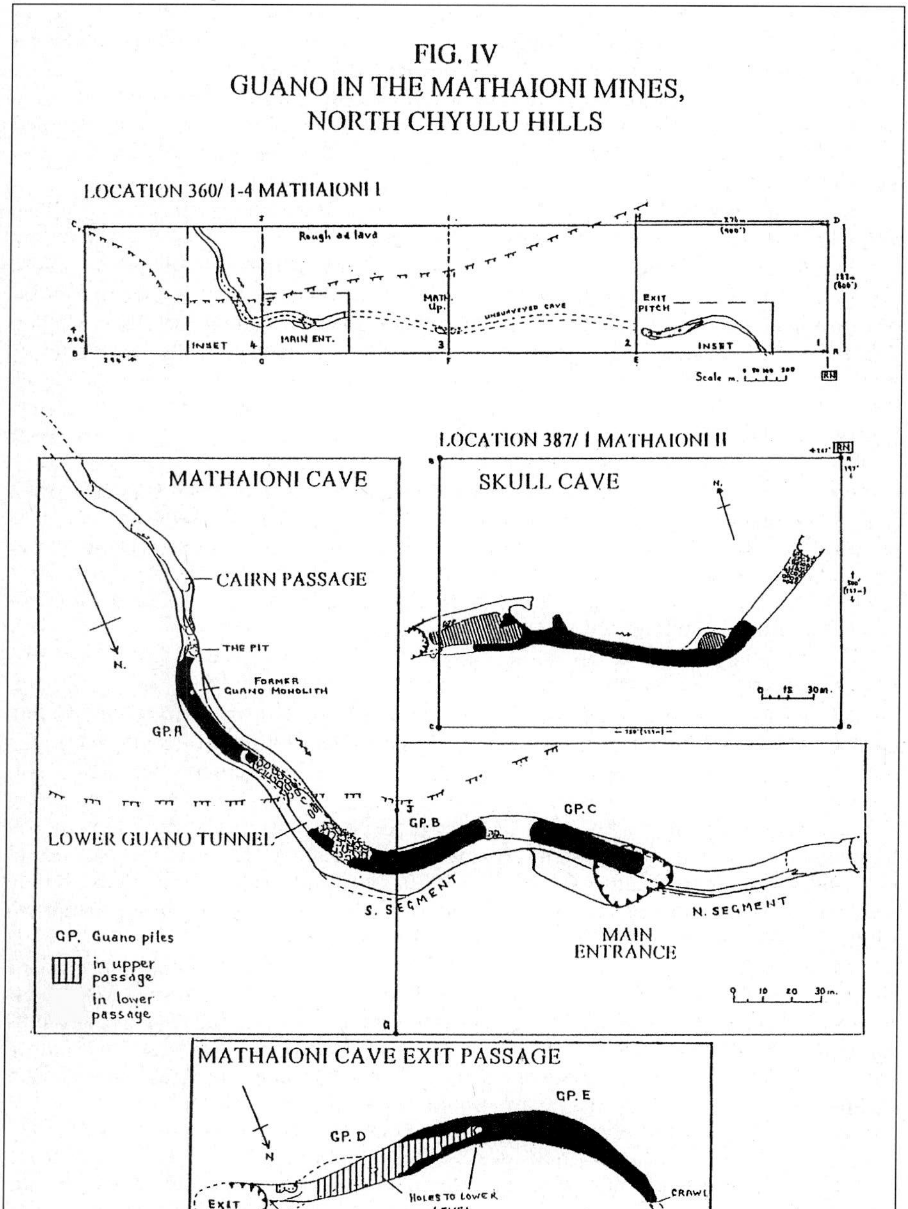


Fig. 4 - Guano in the Mathaioni Mines, North Chyulu hills.

A) - The first pile commenced at the foot of "The Pit", formed a distinct mound, and ran for 30m.to peter out at a 2.4m.drop. It was a little over 2m. deep and excavation revealed an alternative crawlway into the downstream continuation of the tunnel. A monolith of the guano hill was left standing for further scientific research and as a demonstration section for planned tourist visits into the cave. It remained undisturbed for many years, but in the early 1990's the entire section was regretably stolen by persons unknown and its value to science and posterity forever lost!

B-C)-Roughly mid-way along the lower tunnel were two, rather wet, 1m. deep piles, with B) being 60m. and C) nearly 40m. long.

D-E)-The Exit Pitch led to a 75m.long upper level floored with guano 15-60 cms.deep (D) and below into the 290 m.long final segment of the cave. Damp guano (E), locally up to 1m.deep, covered a long boulder breakdown, ending as a deep sloping pile. Removal of this opened up a low crawlway into a 130m. extension of the tunnel.

Skull Cave (Mathaioni II-Location 327/1)

On a lower plain, 1 km. north of Mathaioni Cave, are two collapses between which is a 250m.long passage making up the bulk of Skull Cave. Much of this 10m. wide tunnel was covered with dry guano up to 60 cms. deep over which a single claim was registered in May, 1976 (Fig. 4).

Mt.Suswa Caves

Mt.Suswa is a shield volcano situated in the middle of the Great Rift Valley, 50 km. north-west of Nairobi. Centrally within its caldera is an impressive collapse graben forming a moat surrounding an "island" block which is unique among the world's volcanoes (McCall & Bristow, 1965).

In a lava flow which spewed out of the caldera on the eastern flanks of the volcano lie a braided and multi-level system of tunnels which were already well known prior to the commencement of guano extraction in 1970. Nearly 70 collapse entrances provide access to some 40 seperate caves which represent segments of what was a mammoth system totalling more than 11km.of passages (Simons, 1998).

Principal among the tunnels, is the 14-18 Series or Grand Central System. This complex of 10-20m diameter tubes, totals around 3.4km. of passages and has no less than 8 entrances, several of which segment the system. The series has two upper tunnel sections, those off the 14A-14C collapses and that connecting the 18A-18D and 28 entrances, and a lower level which connects the 14 and 18 upper passages by means of several pitches. Guano deposits of various sizes occured in the tubes (Fig. 5).

18 Upper Series (Suswa I - Location 155/1)

Guano in the 18 Upper Series was located in two parallel tunnels and a single claim over them was registered in January, 1967:

A) - Many thousands of bats reside in Otomops Passage and, 100m.in from the 18C collapse, dry guano formed a 140m.long pile at a bend in the tunnel to end just before a low crawl near a small roof hole (No.28). In places between boulders, it reached depths of more than 2.4m. One 3m.deep trench was dug into the south side of the pile by the

FIG. V
GUANO IN THE 14-18 SERIES, MT. SUSWA MINES, RIFT VALLEY

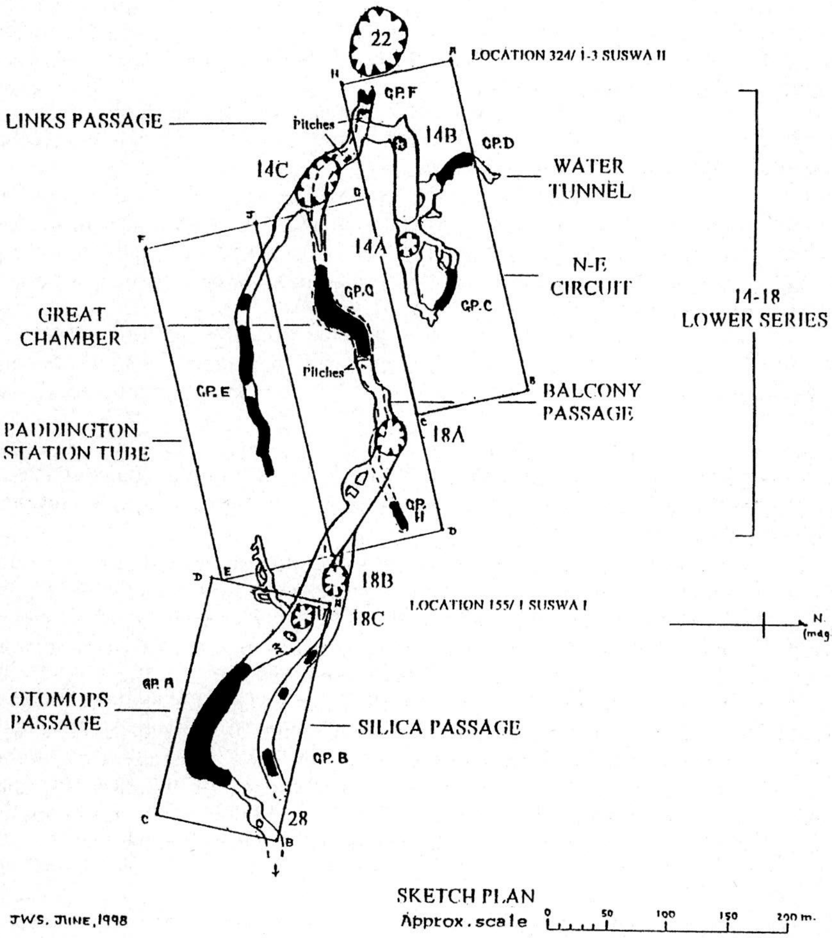


Fig. 5 - Guano in the 14-18 series, Mt. Suswa Mines, Rift Valley.

author and Dr.P.S.Martin in January, 1966, and samples were collected at every 20cms. for pollen analyses and some went to Geochron Laboratories of Tuscon, USA, for possible C14 dating. Unfortunately, no feedback on the samples was ever received.

B) - Entered through boulders off the 18B collapse, Silica Passage is a long and rather humid tube which had several small and damp guano piles and colony of hundreds of small insectivorous bats.

14A-C & 14-18 Lower Series (Suswa II-Location 324/1-3)

Three upper level tube segments contained various guano areas worthy of extraction, with that in a lower level being significant. A block of three claims over the deposits was registered in September, 1972:

C) - One of the 14A N-E Circuit tunnels contained small insectivorous bats and a 30m.long area of guano with an average depth of little more than 35 cm. and reached a maximum of 0.5m.in depth.

D) - The 14A-14B Water Tunnel is the seasonal roost of many small insectivorous bats and contained a 75m.long section of dry guano which increased in thickness inwards from 10cms. up to a maximum depth of 1.3m. where it formed a hill over the last 30m. Beyond, a thin and "caked" guano layer had been deposited in what had formerly been a water pool in the mid-1960's.

E) - The 365m.long Paddington Station passage has *Otomops* bats and had three areas of damp guano supporting a fairly prolific beetle population. Guano commenced 105m.in from the 14C entrance and made up 17m., 97m.and 77m.long sectors with depths reaching 0.75-0.80m.

Ladder pitches from Links Passage in the 14 Series or from the "Balcony Passage" off 18A entrance provide access to the 700m.long 14-18 Lower Series which had several guano sectors:

F) - A small area beneath the pitch in "Links Passage" had dry guano inbetween boulders from which mummified carcasses of Hyaena, Civet Cat, Rock Hyrax and a rat were recovered (Simons, 1982).

G) - Extensive areas lay mid-way along the passage, either side of a massive boulder fall in the 25m. wide "Great Chamber" where there is a large colony of *Otomops* bats. On the west side it formed a steep dusty hill covering rocks to an average depth of 1m. over a 30m. distance and reached 1.5m. deep in places. Lower down on the east side, was a 40m.long by 12m. wide area where guano covered the floor to a general depth of 0.7m. and reached a maximum of 1.4m. deep. A nearby 10m. wide bench had guano averaging 0.6m.deep, while a gully below was filled to a depth of over 1m. A small 10m.pile, up to 0.75m.deep, also lay almost directly beneath a hole in the floor of the higher level Balcony Passage.

H) - At the very end of the 14-18 Lower tunnel, was a 40m.long accumulation with an average depth of 0.5m.

GUANO EXTRACTION

Although each site or cave presented its own problems, mining of the accumulations was basically similar. The guano was first shovelled into sacks (Fig. 6A), moved

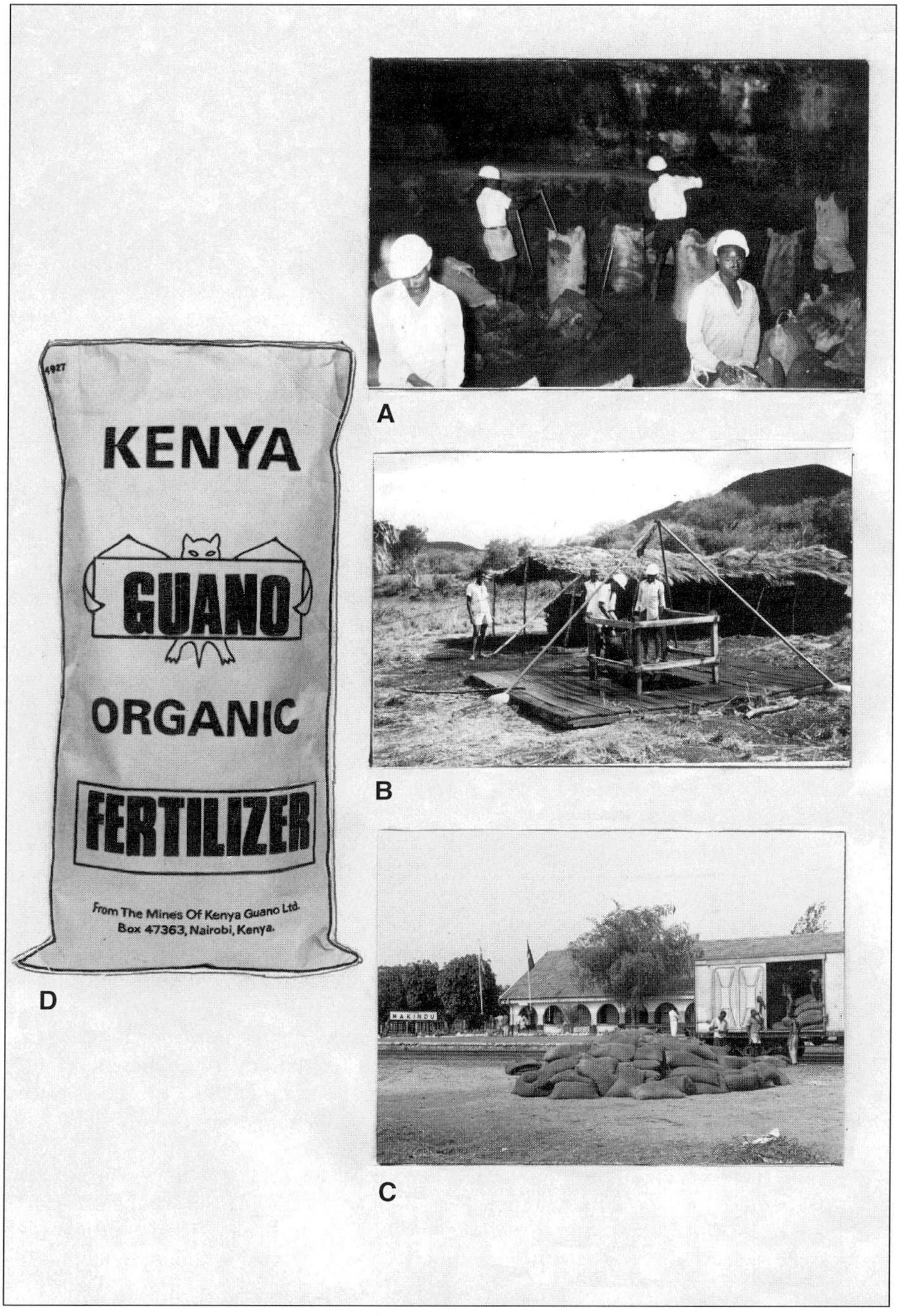


Fig. 6 - Guano mining & sales activities, Ithundu Mine, North Chyulu Hills.
A) Mining 1,5 m. deep guano in Kimakia Cave.
B) Hoisting guano sacks at Kimakia Cave.
C) Loading a bulk guano order at Makindu Station.
D) A 8 kg guano bag for retail to home gardeners.

to entrances and then carried or wire-winched from the caves to surface shelters (Fig. 6B). They were then trans-ported to storage, either near the Makindu or at the Kijabe railway stations, weighed, loaded into waggons and railed to the customer (Fig. 6C). In latter years, some orders were transported directly to estates. Individual sacks and small bags for Nairobi were delivered by company vehicle.

To permit access it was necessary to upgrade bush-tracks into the Kiboko lava flows, up the slopes of Suswa mountain, and pioneer new routes to certain cave entrances (Mathaioni Cave/Hole 28-Mt.Suswa). The caves required preparation to enable removal of the filled sacks by making entrance and tunnel paths, fixing stairs or ladders, installation of ariel rope-ways (Mathaioni Exit/14-18 Lower), and placing of surface platforms and windlasses over convenient roof holes (Kimakia/18 Upper).

All labour was locally contracted and gave work in areas where there was little alternative employment. Between 10 to 50 men might be employed in any one month depending upon orders. At Kiboko, the men camped at the caves, while at Suswa they lived in a compound at the mountain's base.

As a protection against guano dust, miners were supplied with face-masks and in the early years were skin-tested for Pulmonary histoplasmosis by members of the Medical Research Laboratory, Nairobi, and guano samples checked for fungal spores, all with negative results.

Mining of the deposits was undertaken in stages. Once the readily available guano had been removed from a particular tunnel, then another would be opened. As the the resources diminished, so some of the earlier sites would be re-worked and areas "farmed" of new accumulations.

Little treatment of the guanos was necessary beyond seiving out of stone close to the cave floors, and of bat carcasses, beetles and larvae from the top 10 cms. of some accumulations. Seiving and pellet break-down was undertaken when re-working the caves of "fresh" accumulations and prior to the filling of small packets destined for Nairobi retail markets. Due to its rather high moisture content, it was considered desirable to sun-dry the guanos from the Mathaioni Cave prior to re-bagging and sale.

THE GUANO PRODUCING BATS

The largest known colonies of the African Giant Free-Tailed Bat, *Otomops martiensenni*, occur only in the North Chyulu and Mt.Suswa lava tunnels and it is these bats that have been responsible for the greatest guano accumulations. The biggest single *Otomops* colony with many thousands of bats is that in the Kimakia Cave in the North Chyulu Hills. Those in the 18 Upper, 14-18 Lower and Paddington Station Passages on Mt.Suswa, are perhaps next in order of size. Studies of the larger colonies took place during 1970-1972 and it was demonstrated that peak pregnancies occured between October and January, with the largest number in November coin-ciding with peak rainfall and a higher abundance of food (Mutere, 1973).

Smaller species of insectivorous bats were also seasonally responsible for the guano accumulations in the other tunnels at both localities. At the Mathaioni Cave, *Miniopterus inflatus* was present as colonies in the Lower Guano Passage. Probably, it is the same species which occurs in large numbers in the Exit Passage, although a different bat, *Miniopterus schreibersi arenarius*, was collected at Skull Cave and was presumably responsible for the guano accumulations in that tube.

Many hundreds of *Miniopterus* (sp.) occupy the 14 Water Tunnel, on Mt. Suswa, and this bat probably accounts for much of the guano in that tube, although a species of

Rhinolophus has also been collected and may have been a contributor. This bat has also been noted in small numbers at both the Kimakia and Mathaioni Caves, while at the end of the New Maxwell House tunnel was another species, *Trianops persieus afer*, which occur in some numbers and may have also contributed to the guanos there.

THE GUANO INSECT FAUNAS

Except in certain tunnels where the *Otomops* bat predominated, insects on the guanos were suprisingly sparse. In Kimakia Cave, particularly under the major bat roosts and especially within the first 200m. of the south tube, many thousands of carnivorous beetles were present feeding off dead and moribund bats. Adult, and even new born, bats which had lost hold and fallen to the floor became mired in their own excreta, either to become buried and mummified, or were quickly consumed by the beetles and their larvae to leave gleaming skeletons!

A study of the Ithundu beetle population was undertaken prior to guano removal. From a series of transect samples it was estimated that the densest concentrations probably contained around 1000 beetles per 30 cm. square! Three species of tenebrionid beetle were identified, in order of abundance, as *Villersia trivialis, Alphitobius diaperinus* and *Pogonbasis (peristeptus) marginalis*. Less numerous were also one or possibly two species of a dermestid *(Attagenus sp.)* and a caribid beetle *(Somoplatus substriatus)*. All of these species were also recorded as occuring in the Mt.Suswa caves (McFarlane, 1971). While *Pogonbasis* was not as numerous at the Kimakia Cave, observations by this author suggest it was the predominant species at Mt.Suswa, at least in the Paddington Station tube where beetle concentrations were found to be greatest.

At the Kimakia Cave, mummified bats, the adult beetles and their larvae, were seived from the guano and returned to the cave floor. Not only was this done as a conservation measure, but it was also considered that the beetles were important to the breakdown of fresh guano pellets through their movement and ingestion. Although numbers have diminished since guano removal, many still do occur in the New Maxwell House segment.

Other species of insects present on the guanos in both cave localities included many fleas, bat parasites, large numbers of acalypterate flys which were attracted to lights, tineid moths, pale crickets with long antennae, small collembola, and pedipulpids (or whip scorpions).

GUANO ANALYSES

It has to be recognised that Bat Guano, as an entirely natural product and by its location in caves, is a very variable material with the levels of its constituents being influenced by many factors. Among these may be the nature or abundance of the food eaten by the bats, the type of rock in which the caves occur, and the weathering and environmental processes taking place underground at each individual cave. A single deposit of cave guano may vary greatly both laterally and at depth, with the degree by which the accumulation has been locally "leached" or otherwise affected by percolating waters probably playing a major role.

Initially, grab samples were analysed by several Nairobi laboratories to obtain an indication of constituents. For the most part, however, cores from auger drill-holes from the major deposits were "quartered" so as to obtain samples for analysis which would be representative of the accumulations as a whole and were submitted to the Government Chemist which department provided a "Certificate of Analysis". The guanos were sold largely upon their high organic content and reasonably balanced percentages of N.P.K. Averages of content were publiscised and bulk-buying customers provided with ranges of analyses on request.

While it is unwise to draw too many conclusions from the analyses, several interesting results have emerged through comparing the guanos of the two localities and from the different types of bats (Table 1, 2).

Table 1- Analyses of guano from the Kiboko Mines, North Chyulu Hills

BATS	Otomops					Not- Otomops					
CAVE	Kimakia Cave					Mathaioni Cave			Skull Cave		
PASSAGE	South Tunnel					Exit passage		Lower Tube	Main Tube		
ANALYSES %	SAMPLES			RANGE	AV.	SAMPLES				RANGE	AV.
	1966	73/39	73/48			74/5	74/8	74/6	76/1		
Organic	nd	51.8	64.0	51.8-64.0	59.7	57.5	62.5	41.0	20.4	20.4-62.5	45.3
Ash	nd	25.6	17.8	17.8-25.6	21.7	11.4	18.4	10.4	72.2	10.4-72.2	28.1
Moisture	nd	22.6	18.2	18.2-22.6	20.4	31.1	19.1	48.6	7.4	7.4-48.6	26.5
Nitrogen N	13.2	6.9	11.1	6.9-13.2	10.4	7.6	6.8	5.8	6.3	5.8-7.6	6.6
Phosphate P_2O_5	11.2	12.1	8.5	8.5-12.1	10.6	6.0	6.6	5.0	7.3	5.0-7.3	6.2
Potassium K_2O	3.5	1.3	3.1	1.3-3.5	2.6	2.8	0.7	2.7	2.3	0.7-2.8	2.1
Magnesium MgO	2.4	0.8	1.0	0.8-2.4	1.4	0.7	0.3	0.8	0.7	0.3-0.8	0.6
Calcium CaO	1.0	0.9	0.8	0.8-1.0	0.9	0.2	1.4	0.4	0.8	0.2-1.4	0.7
Sulphur Sa_3	2.9	0.8	1.0	0.8-2.9	1.5	2.7	nd	2.7	0.6	0.6-2.7	2.0
Sodium Na_2O	nd	0.3	0.5	0.3-0.5	0.4	0.5	0.2	0.5	0.6	0.2-0.6	0.4
pH	nd	6.5	7.7	6.5-7.7	7.1	6.7	4.9	6.1	6.0	4.9-6.7	5.9

Table 2- Analyses of guanos from the Mt. Suswa Mines, Rift Valley

BATS	Otomops										Not-Otomops			
CAVE	18 Upper Series				14-18 Lower Series						18-Upper Series	14A-8 Upper		
PASSAGE	Otomops Passage				Great Chamber						Silica Passage	Water Tunnel		
ANALYSIS %	SAMPLES								RANGE	AV.	SAMPLES		RANGE	AV.
	I	II	III	IV	1	3	4	10			74/1	72/6		
Organic	70.6	74.5	49.1	50.8	56.2	55.6	55.8	53.8	49.1-74.5	58.3	34.8	53.4	34.8-53.4	44.1
Ash	18.1	18.0	40.4	45.9	21.2	21.0	20.6	16.6	16.6-45.9	25.2	32.5	23.6	23.6-32.5	28.0
Moisture	11.2	7.4	10.4	3.3	22.5	23.3	23.5	29.5	3.3-29.5	16.3	32.7	23.0	23.0-32.7	27.8
Nitrogen N	9.6	9.8	6.6	9.4	8.0	8.5	8.6	8.0	8.0-9.8	8.5	3.8	7.7	3.8-7.7	5.7
Phosphate P2O5	9.1	8.7	16.5	19.6	8.9	9.1	8.9	7.9	7.9-19.6	11.0	9.3	10.9	9.3-10.9	10.1
Potassium K2O	2.2	2.0	2.4	0.5	4.9	4.7	4.5	2.7	0.5-4.9	3.0	1.7	3.5	1.7-3.5	2.6
Magnesium MgO	3.7	1.7	1.9	3.0	2.0	2.2	1.7	2.1	1.7-3.7	2.3	0.9	2.9	0.9-2.9	1.9
Calcium CaO	0.8	1.1	1.4	1.5	0.4	0.5	0.8	0.8	0.4-1.5	0.9	2.8	1.1	1.1-2.8	1.9
Sulphur Sa3	2.4	2.7	2.5	1.4	5.6	5.0	5.9	4.5	1.4-5.9	3.7	3.0	4.2	3.0-4.2	3.6
Sodium Na2O	0.4	4.3	0.3	0,2	1.3	1.4	1.5	1.4	0.2-4.3	1.3	1.0	1.0	1.0-1.0	1.0
pH	7.4	7.8	6.5	6.5	6.6	6.6	6.6	6.8	6.5-7.8	6.8	6.0	6.7	6.0-6.7	6.3

The guano of the *Otomops* bat at both localities is found overall to have similar percentages of high organic matter (58%), Nitrogen (8-10%), Phosphate (10-11%) and Potassium (2-3%). The Magnesium, Sulphur and Sodium content, however, appears to have been somewhat greater in the Mt.Suswa guanos, with the Sulphur element in particular being twice the amount found in the Kiboko Caves, at 3.7% as opposed to 1.5%. This is largely due to the high percentages in the samples from the 14-18 Lower accumulation. The results may perhaps be attributed to differences in the cave lavas and leaching of a presumed higher Sulphur and Sodium content from the Mt.Suswa phonolites than from the Kiboko basalts.

While the guanos of the smaller insectivorous bats are also similar between the two localities, these appear overall to contain less organic matter (44-45%) and Nitrogen (6-7%) than those of the *Otomops* bats. The differences might be due to these bats capturing smaller insect prey and contributing less amounts of food with lower nutrients to the caves, or because it so happens that they have favoured tunnels which are little ventilated and humid where higher moisture contents, as in Mathaioni Cave, could have resulted in the leaching-out of the water soluable portion of the Nitrogen element. A lower Phosphate content is indicated in the Mathaioni guanos but the difference is less marked at Mt.Suswa. As with the Otomops guanos, the analyses also show that the Magnesium, Sulphur and Sodium elements are higher in the Mt.Suswa accumulations. With a range of between 6-7, there was little difference in the ph. values between the guanos by both bat type or locality.

GUANO PRODUCTION, SALES RECIPIENTS & CROP RESULTS

Production

The first guano extractions and sales came from the Ithundu Mine with the greatest bulk being removed between April 1966 and April, 1970, following which a move was made to mine the Mt.Suswa caves.

A temporary suspension of activities at Ithundu, however, took place during 1967/8 due to a crisis in the coffee industry when large orders were cancelled. On resumption of mining, stacks of filled sacks which were left in the cave beneath the roof hole had rotted due to the ingress of rainwater and the bags and guano were steaming and hot to the touch! It is known that guano can "burn" and it would seem that the sacks were, like in a haystack, in the process of internal combustion?

By August, 1970, mining from the Mt.Suswa Mines was underway and lasted until 1974. These 5 years were the period of greatest extraction with 1971 and 1972 being the highest period of deliveries. The increased business may be attributed to the success of sales promotions and the product gaining a reputation as being highly beneficial to crops.

The greater part of the 18 Upper deposit was removed between August, 1970 and June, 1972. The whole area was worked over in the latter half of 1972 and again during 1974. The guano accumulations on Location 324/1-3 were mainly worked during 1972-1974, although small amounts were later extracted and sold in 1977, 1979 and 1984.

With the depletion of easily won material at Suswa, a return was made to the N.Chyulu where sectors of the Ithundu Mine were re-worked from 1973 onwards and extraction at the Mathaioni Cave was commenced late in 1974. The guano piles in this cave were largely exhausted by July, 1977, although further re-working of the areas took place in 1978. Extraction at Skull Cave ran during 1976-8, with the guano being sold together with that from the Mathaioni Cave. These two caves were to provide 60% of the sales tonnage over the 5 years up to 1978.

Mining of Bat Guano continued for a period of 19 years from 1966 to 1984, although really significant sales only lasted until 1976, by which time most of the easily won deposits had become exhausted, some tunnels had been re-worked, and the business had already become un-economic due to the higher extraction costs. Sales over the following six years were insignificant and barely covered the production costs.
A total of 3,618 metric tons were sold, realising nearly UK £ 91,000, with almost equal amounts coming from each cave region (Table 3).

Table 3 - Kiboko & Mt. Suswa Mine production, sales and values

	KIBOKO MINES				KIBOKO MINES				TOTAL ANNUAL PRODUCTION & SALES	
YEAR	ITHUNDU MINES	MATHAIONI MINES	TOTAL M. TONS	VALUE K£	SUSWA I 18 UP	SUSWA II 14-18	TOTAL	VALUE K£	METRIC TONS	VALUE UK£
1966	169.50	-	169.30	3081.00	-	-	-	-	169.50	3081.00
1967	231.00	-	231.00	4938.00	-	-	-	-	231.00	4938.00
1968	68.75	-	66.75	1460.00	-	-	-	-	66.75	1460.00
1969	275.75	-	275.75	5303.75	-	-	-	-	275.75	5303.75
1970	383.00	-	383.00	6953.50	76.00	-	76.00	1437.00	459.00	8391.00
1971	-	-	-	-	240.25	-	240.25	4943.00	240.25	4943.00
1972	5.00	-	5.00	346.00	591.00	152.50	743.50	15027.00	748.50	15373.00
1973	135.00	-	135.00	3107.60	-	437.50	437.50	9107.50	572.50	12215.00
1974	106.00	20.25	126.25	4472.00	126.75	100.75	227.50	6873.75	353.75	11345.75
1975	65.75	233.50	299.25	11902.50	-	-	-	-	299.25	11902.50
1976	53.75	73.75	127.50	5914.00	-	-	-	-	127.50	5914.00
1977	4.00	14.75	18.75	1333.50	-	19.75	19.75	1476.00	38.50	2809.50
1978	4.50	15.25	19.75	1623.50	-	-	-	-	19.75	1623.50
1979	-	0.50	0.50	51.25	-	5.50	5.50	557.50	6.00	608.00
1980	-	-	-	-	-	-	-	-	-	-
1981	3.00	-	3.00	306.25	-	-	-	-	3.00	306.25
1992	1.00	-	1.00	118.75	-	-	-	-	1.00	118.75
1983	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	6.00	6.00	624.00	6.00	624.00
TOTALS	1504.00	358.00	1862.00	50911.50	1034.00	722.00	1756.00	40046.75	3618.00	90958.25
% TOTAL PRODUCT.	41.5%	10%	51.5%	56%	28.5%	20%	18.5%	44 %		
% AREA PRODUCT.	81%	19%			59%	41%				

Some 1,862 metric tons was produced and sold from the Kiboko Mines, which repre-sents just over 50% of the production from all caves. 1,500 tons of this, or more than 40% of all production, came from the Kimakia Cave alone and this is probably a reflection of the greater size of the *Otomops* bat population in that single tunnel. Nearly 360 tons was extracted from the Mathaioni I & II concessions, representing around 10% of total production. From the Mt.Suswa Mines, over 1,750 metric tons were extracted, of which more than 1,000 tons or nearly 30% of the entire production, came from the 18 Upper tunnels. The 14 and 14-18 Series of tunnels made up the remaining

20%, with at least two-thirds of this being extracted from the 14-18 Lower passage. Again, the largest quantities came from the three *Otomops* bat tunnels which, all together, produced as much material as the Kimakia Cave.

Sales Recipients & Crop Results

The principal value of guano lay in the fact that it was an entirely natural material containing a high organic content and balanced N.P.K. elements. The breakdown of the organic material enabled plants to more readily take-up the other beneficial mineral constituents than would have been the case with applications of manufactured fertilizer.

One drawback was that heavier application rates were generally necessary when compared to chemical fertilizers in order to meet the N.P.K. requirements for a particular crop or farm. This was counteracted by providing the material at a competative price based upon the average N.P.K. percentages in the guanos.

Guano sales may be divided into that which went largely in bulk and direct to the client for the two monsoon rain seasons when fertilizer was generally applied, and amounts which went through Nairobi retailers for onward sale and was mostly in small bag quantities. For the bulk sales, markets were established with Coffee, Tea and Flower growers, which were prepared to pay a free-of-rail price of K.Shs.420/- per metric ton. Discounts were offered on large orders of 50-100 tons.

Over the years, guano was supplied to almost 70 coffee estates in the Nairobi, Kiambu, Kahawa, Ruiru, Thika and Makuyu areas, and as far north as Nyeri. No less than 3,200 m.tons, or nearly 90% of total guano production, went to coffee with the orders being supplied almost equally from the two mine areas (Table 4).

Tab. 4 - Approximate guano tonnage sold by location and recipients

	KIBOKO MINES		MT. SUSWA MINES		GRAND TOTAL METRIC TONS
	ITHUNDU	MATHAIONI	SUSWA I	SUSWA II	
DIRECT SUPPLIES					
Coffee Estates	1,332.50	308.50	901.00	605.75	3,207.75
Tea Estates	85.00	-	97.50	15.00	197.50
Flower Farms	36.50	15.00	18.00	16.00	85.50
Small holders, Golf Clubs, Home					
Gardeners, Trial & Charity Gifts					
12.00					
2.50					
17.50					
16.10					
48.50					
RETAILER SUPPLIES					
Large Sacks (40-50 kgs.)	9.50	2.75	-	8.75	21.00
Small Packets (3, 5, 8 Kgs.)	28.50	29.25	-	-	57.75
TOTAL SALES	1,504.00	358.00	1,034.00	722.00	3,618.00

Guano was generally applied to coffee during the rains at a rate of 1lb. (0.5 kg.) per tree, often without the addition of any other chemical fertilizer, and would usually be used to provide an organic boost to poorly yeilding blocks. Estate managers frequently commented on the general improvement of the trees, darker and shinier leaf colour, increased sucker growth and "spiking". More importently, it was not umcommon to hear that guano treated blocks were producing the best coffee on the estate and giving higher yields!

A trial undertaken on Manyika Estate in 1969 to compare guano applied at a rate of 1.5 lbs (0.7kg.) against N.P.K. chemical fertilizers with ratios of 17.17.17 & 25.25.0 at standared applications, resulted in a slight increase by 12 debbies (standard size tin cans) of coffee per acre on the guano treated blocks. Again, when comparing the results of cattle manure and bat guano, both applied at a rate of 1 lb. (0.5kg.) per tree and mixed with basic slag, Kathangi Estate found that the guano block produced a quicker heavy flowering, the trees were in excellant health with no signs of disease or stress, and carried an estimated 1.25 tons of coffee, or well in excess of twice the norm.

A disasterous attack by a fungus, known as C.B.D.(Coffee Berry Disease), in the late 1960's put many coffee estates on the verge of bankruptcy and caused a temporary closure of mining operations during the worst period. However, some estates noted that blocks on which guano had been applied remained healthier and were less affected. The assistance of bat guano in combatting the disease probably contributed to the higher volume of guano sales to that industry in the early 1970's.

A smaller market was found with Tea Estates in the highlands of the Limuru area, north-west of Nairobi, where a little over 190 m.tons were supplied. Smaller quantities of 1 ton. each, also went to the Tea Research Institute and several estates in the Kericho and Sotik area, as well as 1/2 ton to the Tea Research Institute in Tanzania, but these were largely for experimental purposes.

Response to the use of bat guano on tea was similar to that on coffee. Nyara estate, Limuru, reported that during the period September, 1968 - June, 1969, poor plots treated with guano at a rate of 0.5 ton per acre showed a distinct boost, improved leaf, and an increased yeild of 90 lbs.of made tea per acre over plots of similar age and condition treated with chemical C.A.N. at 135 lbs. of N.per acre. In 1970, it was reported that guano treated blocks were then the best on the estate and were yeilding an increase of over 300 lbs. of made tea per acre!

One custome, near Limuru, annually placed orders for 5-10 tons of guano for intensive flower production and took no less than 85 tons for this purpose. Around 0.5 kg. of guano per sq.m. was mixed with lime, manure and phosphates as required by soil analysis. Performance on carnations was reported to be good and very good on roses and gladioli.

Various African small-holders, golf and sports clubs, schools, plant nursuries, landscape gardeners and home gardeners placed orders ranging from a few sacks up to several tons of material for use in growing vegetables and fruit, for greens and lawns, general flower beds, potted plants and even for growing orchids! Small amounts went gratis to some growers for trials and, by way of promotion, to charities. Sacks were also supplied to a number of Nairobi Garden Centres, usually for onward sale, and accounted for a little over 20 m.tons of production.

Small packets of seived guano from the Kiboko Mines, aimed at the home gardener, were introduced in 1968. Up to 1973 over 2,000 polythene bags, of 3kg. and 5kg.weight were sold direct to retail Garden Centres and vegetable shops in Nairobi, with sales increasing from 1971 as the guano became more widely known. A specially printed and lined 8kg. paper bag, with a bat emblem (Fig. 6D), was marketed in 1974 and nearly 6000 were sold to retail outlets via a sole distributor up to 1977 when sales were discontinued. During the 9 years, over 8,000 packets were purchased and this alone accounted for nearly 58 m.tons of the production from the Kiboko Mines and made a significant contribution to the company revenue.

Controlled plots of various vegetables, specifically for small bag sales, were set-up by the company in the Nairobi area in 1968. Guano was applied to the plots at increasing rates from 0 to 5 oz. (gm.) and marked growth differences were noted. This led to suggesting a mean rate of around 115 gms.(4 oz.) per square meter, well-watered into the soil, as an optimum application. Too heavy an application could result in "scorching" of the plant roots, stems and leaves. Many home gardeners spoke highly of the results acheived on a wide range of plants and several producers of strawberries were impressed with their yields.

CAVE AREA CONSERVATION

Mining by Kenya Guano Ltd. provided a temporary means of protecting areas of outstanding natural beauty, their caves and bats, for a period of nearly 20 years. However, it was obvious that this would diminish along with the guano deposits and a permanent means of area and cave conservation has long been sought by this author under various guises.

The uniqueness of Mt.Suswa was recognised as early as the mid-1960's and, while reports to Kenya Government departments calling for the caldera and caves to be set aside as a National Reserve have been submitted (Brown & Glover, 1969; Simons, 1965B, 1973, 1980), these have so far gone unheeded. The principal problem lies in the fact that the caldera is divided between two Maasai group ranches lying in different districts and agreement on alternative land use is difficult to acheive.

Boundaries to create a national park along the eastern part of the main Chyulu hills were surveyed in the 1970's, but these ommitted the northern wilderness area and its bat caves. Gazettment occured in 1993 after further area studies and consultant recommendations (Simons, 1980). Inbetween time, the impressive southern segment of the Mathaioni Cave was developed for visitors in 1974. It remained open a semi-wild attraction until 1978, during which time it had received over 700 visitors. This not only added protection to that cave for a time, but also lent weight to calls for the conservation of the area as a whole.

Further attempts were made with the Kenya Wildlife Services to have the northern area protected and the Mathaioni Cave re-developed (Simons, 1992, 1993). Renewed interest was aroused and meetings took place with Government officials during 1992-1993 which resulted in an agreement that the Chyulu National Park should be extended. But, even as boundary work progressed, illegal squatters invaded and ploughed the area and spoiled its wilderness aspect. In 1996, gazettement was ultimately acheived and the squatters were evicted from the National Park extension. The area, with its caves, is now protected by a ranger sub-station but further development awaits a return to its natural state.

CONCLUSIONS

Commercial mining of Bat Guano as a source of fertilizer in Kenya became possible through the discovery of significant deposits in the lava tunnel caves of Mt.Suswa Volcano and in those of the Northern Chyulu Hills. Mining of these accumulations by Kenya Guano Ltd. was a pioneer venture which ran from 1966-1984 and, over this 19 year period, no less than 3,500 metric tons of guano was extracted and sold with almost equal amounts coming from the major deposits of the two distant areas.

Guano was introduced to important agricultural industries, and in the absence of any other purely locally available organic N.P.K. fertilizer, Kenya greatly benefited through the saving of much needed foreign exchange which otherwise would have been spent on chemical fertilizer imports. In addition, the local populaces of the outlying areas also directly benefited through employment, transport hire and general purchases during the period.

Coffee estates purchased the largest guano tonnage and significant amounts also went to Tea and intensive flower farms. Smaller, but no less important, tonnages went to small-holders of various crops, golf clubs and home gardeners, either as directly or as sales through retail garden centres in sacks and small packets of various weights. In all cases, the results of use of the natural organic guano were lauded and was found to be at least as beneficial as some chemical fertilizers and definitely improved crop health, quality and yields.

In the process of mining, much new information concerning the areas and the caves, their bats, guanos and insects was obtained. The company initiated various scientific projects and its activities not only afforded a temporary measure of protection to the principal cave and bat locations, but otherwise brought to Government attention the need for cave area conservation and the concept of cave tourism, some of which has been acheived in the Chyulu Hills, but alas not on Mt. Suswa.

ACKNOWLEDGEMENTS

In addition to the writer's personal records, much of the content of this paper has been drawn from the archives of Messrs. Kenya Guano Ltd., and grateful thanks are extended to the author's co-directors to freely use this information. Thanks are also due to Miss A.Simons for initial reading and commenting on the manuscript and for other assistance.

REFERENCES

BROWN, L. and P.E. GLOVER, c.1969. A proposal to establish a chain of National Parks or National Monuments along the length of the Kenya Rift Valley.

BULPIN, T.V. 1962. The Hunter is Death. Nelson. Chap.21 "The Guano Rush": 219-227

GLOVER, P.E., E.C. TRUMP and L.E.D. WATERIDGE, 1964. The Lava Caves of Mount Suswa, Kenya. Stud.Speleol. 1 (1), 1964 (1963): 51-66.

HALLIDAY, W.R. 1966. Depths of the Earth. Harper & Row (N.York/London). 398 pp.

McCALL, G.J.H. and C.M. BRISTOW. 1965. An Introductory Account of Suswa Volcano, Kenya. Bull.Volcan. 28:333-367.

McFARLANE, J.A. 1971. The Carnivorous Beetles of the Ithundu Caves, Kenya. Stud.Speleol. 2 (3-4), 1971 (1970-1): 149-158.

MUTERE, F.A. 1973. A comparative study of reproduction in two populat- ions of the insectivorous bats, Otomops martiensseni, at Latitudes 1 5'S and 2 30'S. J.Zool., Lond.(1973), 171: 79-92.

SIMONS, J.W. 1964. The Cave Exploration Group of East Africa. Stud. Speleol.1 (1), 1964 (1963): 73-74.

SIMONS, J.W. 1965 A. Two New caving areas in Kenya. Newsl.Cave Expl. Grp.E.Afr. 3 (Dec.1965): 25-36.

SIMONS, J.W. 1965 B. Discussion on a Proposal to open Mt.Suswa and its Caves as a Tourist attraction and Game Reserve.Min. 17th.Comm.Meet.Cave Expl.Grp.E.Afr., May, 1965: 1-5

SIMONS, J.W. 1972. The Mathaioni Series, North Chyulu Hills, Kiboko, Kenya. Bull.Cave Expl.Grp.E.Afr., 3: 40-50.

SIMONS, J.W. 1973. Mt.Suswa National Park or Reserve - A Proposal. Mar. 1973: 23 pp. (Private-to Kenya National Parks).

SIMONS, J.W. 1974. The Lava Caves of the Northern Chyulu Hills, Kenya. Stud. Speleol. 2 (6), 1974 (1973): 238-255.

SIMONS, J.W. 1980. Caves and Cave-Associated Wilderness Areas of Kenya. Background Working Report for Wildlife Planning Unit, Ministry of Environment & Natural Resources. Submitted by Kenya Caverns & Lodges Ltd.(Consultants) Apr.1980.

SIMONS, J.W. 1982. Kenya Cave Mummies. Bull.Cave Expl.Grp.E.Afr., 6 (June): 32-37.

SIMONS, J.W. 1992. Tourism Development of the N.Chyulu Hills in Chyulu National Park. Aug.1992, 6pp., 2 maps. (Submitted to Kenya Wildlife Services via Kenya Caverns & Lodges).

SIMONS, J.W. 1993. Mathaioni Cave, Chyulu Hills National Park. Aug. 1993, 15pp.(Submitted to Kenya Wildlife Services via Kenya Caverns & Lodges Ltd.)

SIMONS, J.W. 1998. Volcanic Caves of Kenya - A Guide for the 8th. International Symposium on Vulcanospeleology. Privately published, Feb.1998. 37pp. Maps & plans.

TEALE, E.O. and F. OATES. 1935. The Limestone Caves and Hot Springs of the Songwe River (Mbeya) Area with Notes on the Associated Guano Deposits. Jnl.E.Afr.Uganda Nat.Hist. Soc. 12:

WILLIAMS, L.A.J. 1963. Lava Tunnels on Suswa Mountain, Kenya. Nature, Lond., 199: 348-350.

Int. J. Speleol., 27 B (1/4), (1998): 53-56.

LAVE CAVES OF KILIMANJARO. MAWENZI LAVA TUBES

Clive Ward

ABSTRACT

This is the first short report on the exploration of lava tubes in the upper part of Kilimanjaro. The area seems to be extremely interesting from vulcanospeleological point of view

Keywords: vulcanospeleology, lava tubes, Kenya

Kilimanjaro is situated approximately 100 kilometres East of the Rift Valley. Geologists believe that the volcano origin was associated with forces that created the Rift System. The main reasons being that the massive is made of lava similar to eruptions in the rift and formed during the same period of time.

The Base of the present massive extends 80 X 40 kilometres in an East-Southeast direction. There were a number of vents involved in the construction of the initial volcano that is now Kilimanjaro, little is known of earlier stages as out pouring of lava mask these preceeding phases.

Activity became concentrated in three main centres. The first major activity was at Shira, followed by Mawenzi and the last centre was Kibo. At present Shira is considerably eroded and reaches a height of 4006 m, only the southern and western rim remains of a collapsed caldera, Mawenzi to the east by contrast is very spectacular with numerous-pinnacles and huge crags, stands at 5149 m. Kibo at 5895 m, formed between Mawenzi and Shira is considered to be the most recent, continued to grow after volcanic activity ceased on Mawenzi. Although dormant, fumaroles in the inner crater are evident. Recent volcanic eruption may have taken place within the last three hundred years.

Evidence of lava tubes from reports indicates an extensive system thousands of years ago in the region of the Horombo Hut Complex (3720 m). The writer has investigated the area and found remains of vertical walls, slightly curved in places of up to twelve metres high. A small stream runs after the rains down one such collapsed tube and the sewage drainage from the complex past another. Although it is possible that past flows from Kibo would have extended to Horombo area the directional flow and situation appear to indicate that they originate from Mawenzi.

A hearsay report of a tube or tubes extending down to Lake Chala on the Kenya-Tanzania border is unconfirmed. Numerous blisters or gas bubbles are found, particularly on the Northern slopes from Shira to Mawenzi. Many in the past have been used for bivouacking by mountaineers.

On 15th August, 1995, the writer approached Mawenzi from the North ascending the Northern Valley on a lava ridge west of Tarn Valley and discovered a tube entrance measuring approximately 1.5 m X 1.5 M. A survey revealed a 41 metre tube running down stream in Northwest direction. The top end closed by a latter lava flow. (Fig. 1). Situated S 03° 04 301 E 037° 27 020.

* Cave Exploration Group of East Africa - P.O. Box 47363 - Nairobi, Kenya.

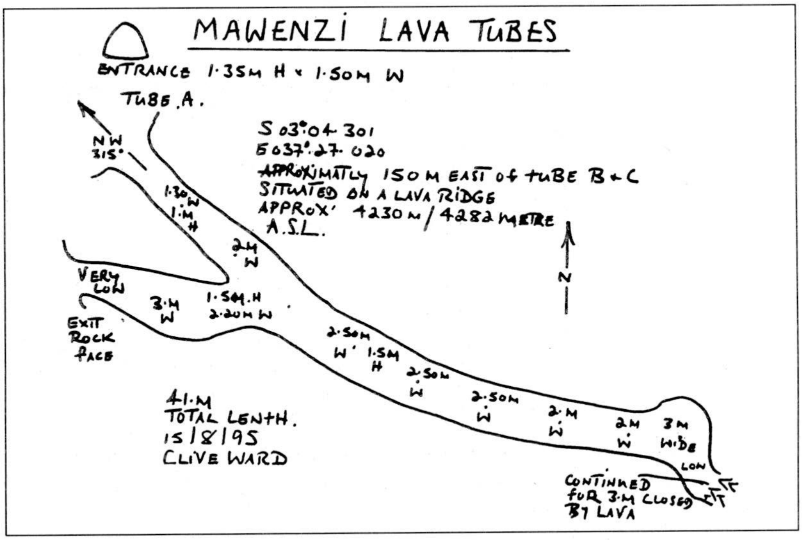


Fig. 1- Sketch of the lava tube A

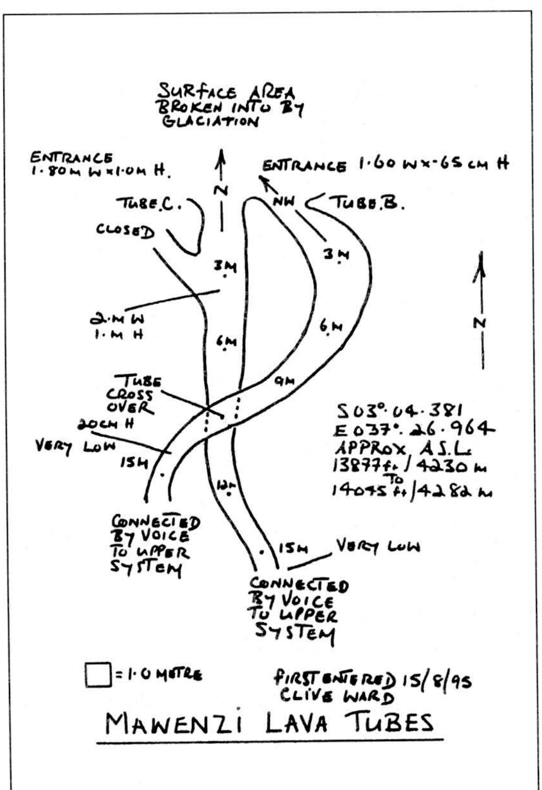


Fig. 2- Sketch of the lava tubes B and C.

From the entrance of Tube A, 150 metres west and 50 m higher across a shallow valley which forms the upper extremity of Northern Valley two more entrances were discovered. Discernible from the ridge above Tube A, two classic tubes can be ascended for 15 m until they become too restricted to continue. Tube B and Tube C appear to cross over each other. (fig. 2 & 3) situated S 03° 04 381 E 037° 26 964.

Twenty five metres higher and slightly to west another entrance can be found. Tube D (Fig. 4) is far more intricate and has been voice connected to Tube B and C. The combination of the tubes various passages amount to 79.50 m of passage. The area of tubes are at the altitude of between 4230 m and 4280 m A.S.L.

Other small tubes can be found to the west and south but extend no more than a few meters, often obstructed by subsequent flows. One such formation is seen near a campsite on a low bluff, one kilometre away in line with fore mentioned and 100 m higher to the South. At the base of North West Ridge of Mawenzi. Extensive glaciation during the Pleistocene epoch is still evident as polishing and striations can clearly be seen on surface rock. It appears that all entrances of these tubes were the result of glacier erosion.

In general the direction of tube flow is from South to North and would suggest at one time a tube swarm originated from the Mawenzi vent, most of which no longer exist due to substantial erosion at the time when the cone was striped away.

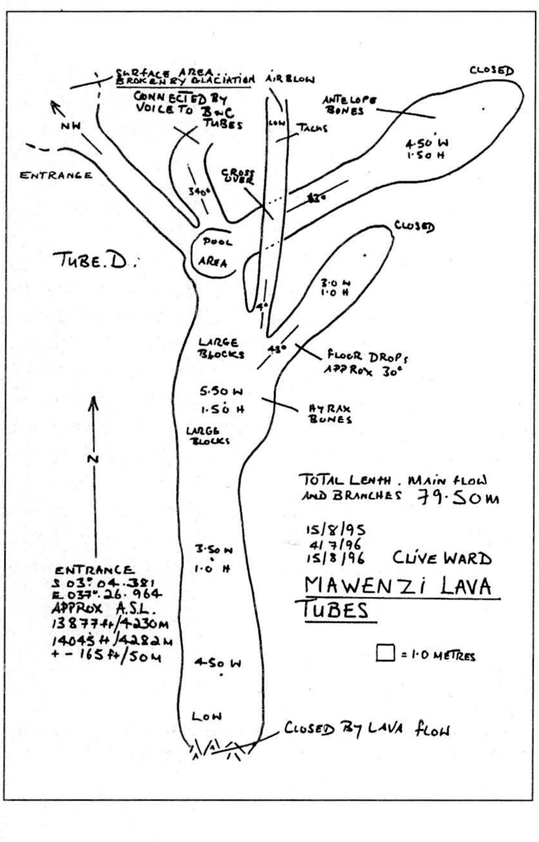


Fig. 3- Sketch of the lava tube D.

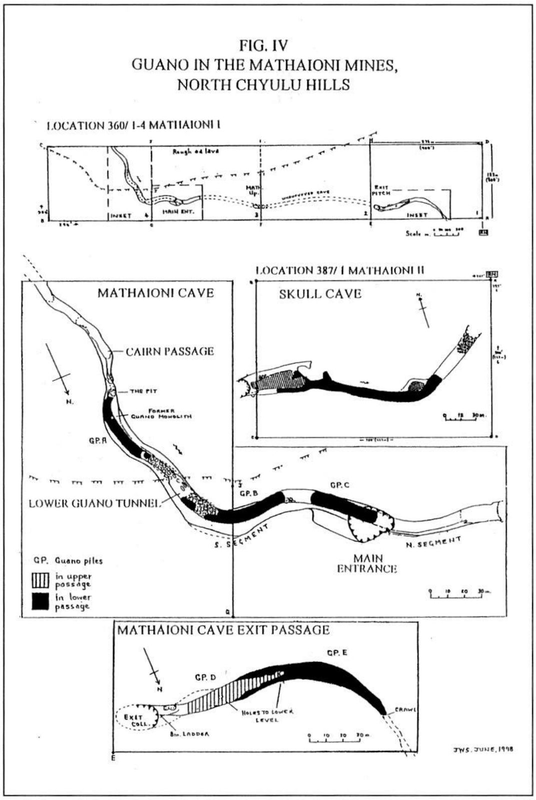


Fig. 4- Sketch of the lava tube E.

Further surface survey between 4000 m and 4500 m may uncover more formations but it is doubtful any significant will be found. A collapsed entrance of one small tube to the West of B, C, and D could prove interesting but major excavation would be required.

However, on 2nd August 1996 a large tube was discovered on the Northern Slope of Mawenzi at the altitude of 3780 m. (Map E) situated S 03° 02 802 E 037° 26 409.

Tube E runs continuous south to north approximately Northeast 40° for 160 m and in some sections is 12 m wide and 3 m high. From the Kilimanjaro map alignment one can speculate that this tube is related to the system above (A, B, C, and D) some 2.5 kilometres distant. The intermediate county is deeply scored by old glacial riverbeds and in places lower than incline of the tube, so the continuation up hill for any appreciable distance is unlikely. Nevertheless, this area holds the most promise for further discoveries.

REFERENCES:

SAMPASON, D.N. 1991 The Geology and Volcanology of Kilimanjaro Guide Book to Mount Kenya and Kilimanjaro, edited by Iain Allan. Published by The Mountain Club of Kenya, Nairobi, p.191.

Int. J. Speleol., 27 B (1/4), (1998): 57-67.

"HADES" - A REMARKABLE CAVE ON OLDOINYO LENGAI IN THE EAST AFRICAN RIFT VALLEY

Gordon J. Davies

ABSTRACT

Oldoinyo Lengai is the world's only active carbonatite volcano, situated in northern Tanzania within the Eastern Rift Valley, at 2.751 degrees S, 35.902 degrees E. It forms an isolated symmetrical cone at the southern end of Lake Natron, with a summit elevation of 2,890 m (9,480 ft). Periodic eruptions of ash and lava have been recorded since about 1880, and with increasing precision during this century since 1904. In 1990 a routine expedition to monitor activity levels at the summit led to the discovery of a remarkable cave located in the crater floor, filled with numerous long delicate pale yellow stalactites and stalagmites of unknown composition. Within 100 m there was considerable volcanic activity taking place, and black lava was spraying from a small cone at a height of some 10 m above the crater floor. Due to the regular emission of lava at the summit of Lengai, it is unlikely that the cave could have survived intact for more than a few months at most. High internal temperatures and lack of safe access precluded any attempt at entry and sampling of the very unusual and attractive formations within the cave, but a good photographic record was obtained.

Keywords: speleothems, volcanic caves, Tanzania

INTRODUCTION

This paper is based on a brief presentation made by the author to the 8th International Symposium on Vulcanospeleology held in Nairobi, Kenya, on 7/8th February 1998. This described an unusual and spectacular cave located on the crater floor of Oldoinyo Lengai (translating as "the Mountain of God" from the Maasai language), an active carbonatite volcano situated in Northern Tanzania in an isolated section of Eastern (or Gregory) Rift Valley. The cave was discovered and photographed during an expedition led by Professor Celia Nyamweru in August 1990, which was one of a series of visits to monitor and record volcanic activity within the summit crater.

LOCATION AND GEOLOGY

The Eastern branch of the Great Rift Valley (known in its central section as the Gregory Rift) is part of a complex graben structure of great geological interest which extends more than an eighth of the way round the globe, and is associated with considerable volcanic and geothermal activity. The system becomes particularly highly developed and visually impressive in Tanzania and Kenya, although the Rift can be traced from Malawi as far north as Syria. The East African section is characterised by numerous extinct volcanoes and by lakes, many of which are alkaline to a greater or lesser extent. Kenya in particular is also noted for extensive and complex lava tubes both within the Rift (e.g. Suswa with c 40 caves total length 11+ km) and close to its eastern

* Cave Exploration Group of East Africa.

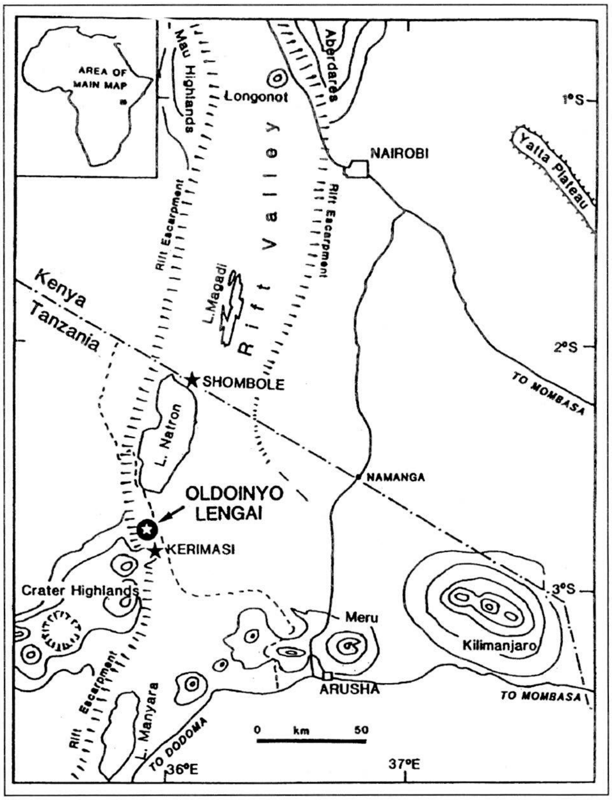


Fig. 1 - Location map for Oldoinyo Lengai.

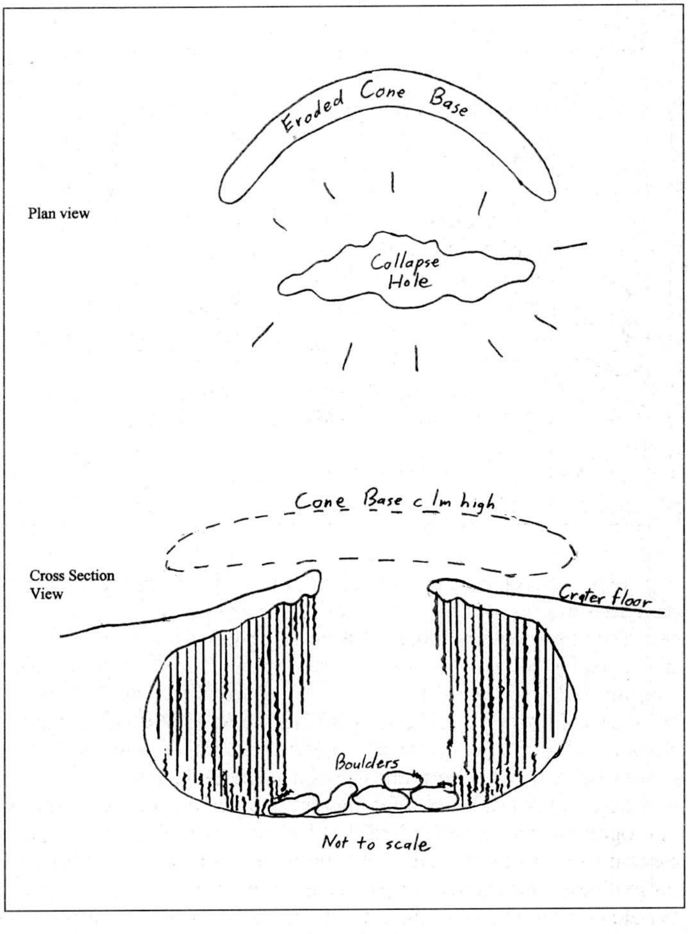
edge e.g. Leviathan Cave total length c 12.5 km in the Chyulu Hills (Sutcliffe 1973, Simons 1998).

The author spent a total of 8 years based at Lake Magadi (110 km SW of Nairobi) which contains c 100 million tonnes of trona, or sodium sesquicarbonate, a mixture of sodium carbonate and bicarbonate, with significant quantities of sodium chloride and fluoride also present. Lake Magadi lies 95 km NNE of Lengai, just across the Kenya border and is an important commercial source of pure sodium carbonate (c 250,000 tonnes per annum) used mainly for glass manufacture.

South of Magadi lies a far bigger alkaline deposit, Lake Natron, which, from satellite photographs, was probably once part of one vast alkaline deposit or lake stretching from Lengai to north of Magadi, with the extinct volcano Shombole lying in between on the current Kenya/Tanzania border. Lengai's periodic major eruptions have undoubtedly contributed to the existing alkaline deposits. However it is likely that the majority of the material has accumulated via numerous hot alkaline springs which emerge all round the shores of Lakes Natron and Magadi and evaporate in the hot, dry atmosphere. For most of the year the summit of Oldoinyo Lengai is clearly visible from Magadi and major eruptions can be identified. With the aid of the Mountain Club of Kenya an unofficial four wheel drive track was opened up from Magadi during the '60's along the shore of Lake Natron to Lengai, making one day ascents possible during a (long) weekend from Nairobi (Davies, 1968). In recent years Lengai has had to be approached via northern Tanzania.

In the vicinity of Lengai are several ancient, inactive, volcanoes including Shombole, Gelai, Kerimasi and the world famous Ngorongoro Crater with a caldera some 19 km in diameter (Fig 1). Most have been quite thoroughly explored and no caves have been reported. The last major faulting in this area was about 1.2 Ma ago. Lengai is the most recent of the group of nepheline-phonolite-carbonatite volcanoes which post-date this faulting, and is at most some 370,000 years old .Historical activity has consisted of small tephra eruptions and emission of numerous natrocarbonatite lava flows on the floor of the summit crater.

Fig. 2 - Sketch of "Hades" Cave on Oldoinyo Lengai.



RECENT ACTIVITY ON OLDOINYO LENGAI

Lengai is now the only active volcano in the Gregory Rift Valley, and has been well known to the Maasai tribe, who inhabit this region, for many centuries. Periodic major ash eruptions have destroyed extensive areas of grazing and even killed the tribe's livestock on occasion. There are well documented records of major periodic activity commencing in 1904, with major ash eruptions in 1917, 1926 (visible from Magadi) and 1940-41 (Richard, 1942). Lava extrusions occurred between 1958 and 1966, when a major ash eruption also took place. The author took part in a routine Mountain Club of Kenya expedition which reached the summit of Lengai on Sunday 7th August 1966, and descended about 100m to the crater floor. During this visit there was considerable activity, with black lava being ejected into the air at several locations. Boiling lava pits were also present but no caves were observed. On the following Tuesday, 9th August, an East African Airways pilot reported seeing an ash plume above Lengai reaching a height of about 4000m. Thus the expedition narrowly escaped, by only a few hours, witnessing a major volcanic eruption at disconcertingly close quarters, which could have spoiled their entire day.

After a quiescent period activity resumed in 1983, characterised by considerable effusion of lava within the crater. In December 1985 a party led by Bill Waldron (Waldron, 1998) observed a number of unusual features within the summit crater on Lengai, apparently created by a substantial fall in the level of the underlying molten lava. These included major faults in the crater levels, including short tunnels, a collapse hole and one small tube partially blocked by a secondary flow (Fig. 2, Fig. 3-5). In addition he discovered small groups of stalactites (c 50 cm long) fringing a small cave (Fig. 6-8) and recorded examples of elaborate secondary mineral deposits on the crater wall above the cave and on the crater floor (Fig. 9).

On many occasions, including the 1990 expedition featured in this paper, molten lava ponds and emissions from small parasitic cones have been observed, and the crater floor level has risen as lava has flowed out across it. Some flows on Lengai in the past have been measured as the most mobile of any terrestrial lavas (Dawson et al., 1990), whilst others have been exceptionally viscous (Dawson et al., 1994, Nyamweru, 1997). Spasmodic activity within Lengai's crater has continued up to early 1998, with periodic flows of new black aa pahoehoe lave flows, many being tube fed, from tubes between 10 and 150m long. Considerable variations in lava levels have been observed, with a chimney 30 m deep in one instance and a lava pond level which dropped leaving solid lava "stalactites" on the walls.

A most interesting and detailed account of the historic and recent activity of Lengai may be found in a paper publisched by Springer-Verlag (Dawson et al., 1995), which also contains a large number of valuable references.

DISCOVERY OF THE CAVE

In August 1990 the author joined a small expedition to ascend Lengai and camp inside the crater on the summit. This was organised by Celia Nyemweru, who has made a comprehensive geological study of the mountain over a number of years, including numerous visits to the summit to record activity levels and changes in topography. Lengai forms a perfect isolated cone, at the angle of repose of ash and possible earlier lava flows from the summit, rising from the shores of Lake Natron which lies at an altitude of c 610 m (2,000 ft.). Depending on recent activity, its flanks may be covered in pale grey or whitish alkaline dust deposits, or by the remarkably hardy vegetation which rapidly re-establishes itself within a few years of a major eruption. The cone is also eroded by vertical rain gullies which have cut deep into the lower sections of consolidated ash, forming narrow canyons crossed by natural bridges in some places. An ascent of the volcano is not lightly undertaken, as the steep and unprotected slope is unremitting for some 2,000 m. When the vegetation has been destroyed by recent activ-

Fig. 3 - Crater floor with tunnel (December 1985) - Photo by Bill Waldron.

Fig. 4 - Pit in crater floor (December 1985) - Photo by Bill Waldron.

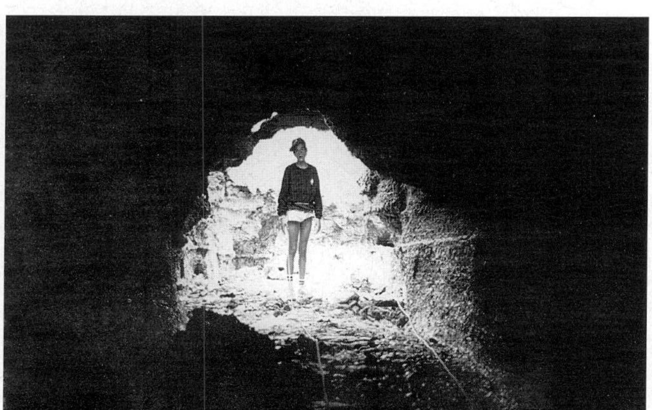


Fig. 5 - Close up view of lava tunnel (December 1985) - Photo by Bill Waldron.

Fig. 6 - Small cave with secondary flow (c. 1.5 m wide) (December 1985) - Photo by Bill Waldron.

Fig. 7 - Close up of tubular secondary mineral deposits on cave wall (December 1985) - Photo by Bill Waldron.

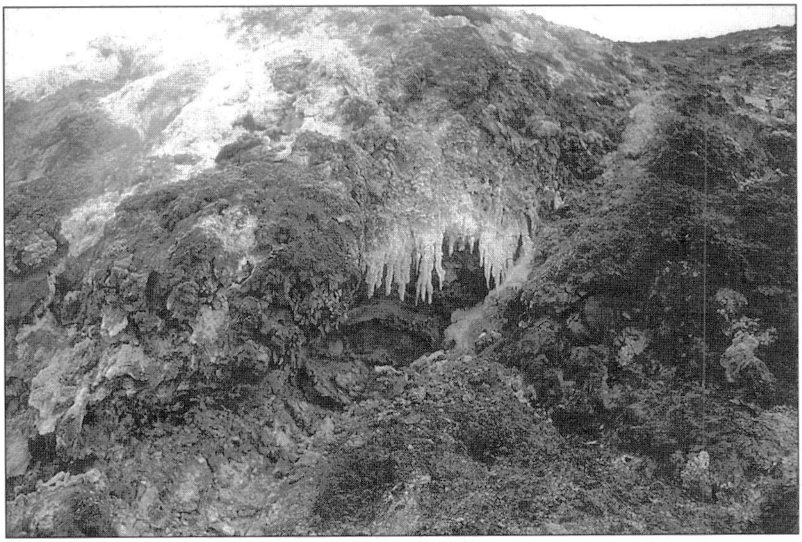


Fig. 8 - Cave in crater wall with stalactites (December 1985) - Photo by Bill Waldron.

ity, the degree of exposure is considerable and the route very treacherous and slippery. In fact crampons have often been found of great assistance, as the points dig into the smooth solidified ash and lava surfaces and disconcertingly uncontrolled descents can be avoided. There is no surface water on the summit, so porters are normally required to assist in carrying full camping gear, food etc. if the planned visit exceeds one day.

On arrival at the summit on 7th August 1990, the appearance of the crater was much as expected - a well defined roughly oval depression some 400 x 500 m in diameter and about 50 to 60 m deep, with steam venting from some sections (Fig. 10). The crater floor was almost horizontal, and covered by overlying and probably quite recent lava flows with at least four spatter cones, one of which was active and emitting sprays of black lava at intervals (Fig. 11). About 100 m south of this active cone was what appeared to be the remains of a similar cone, with an adjacent slight mound featuring a prominent irregularly shaped collapse hole at the top, measuring about 10 m across the widest part (Fig. 12 & 13). The edges of hole revealed that the surface layer was only about 0.5 to 1 m thick, and totally unsupported all round the collapse, making its load bearing characteristics distinctly unpredictable. Through the hole could be glimpsed numerous delicate, pale yellow stalactites, descending some 5 m to the uneven floor of the chamber, which was covered by sections of the collapsed roof. The stalactites were estimated to vary in diameter from less than 1 cm to 3 to 4 cm, and were highly irregular in cross-sectional area.. This can be more clearly seen in the close up of the cave floor (Fig. 14) which shows some very erratic formations, particularly near the floor with considerable departures from the vertical. In addition some fractured sections can be seen lying horizontally on the ground below. The cave was subsequently given the name of "Hades" by the author. It was difficult to estimate the horizontal extent of the chamber, which was probably 20 to 30 m.

The expedition did not possess any climbing ropes or related equipment, so that descent into the chamber - and more importantly rescue from it - was out of the question. It was thus with considerable trepidation that the author crawled precariously to the edge of the collapse, spreading his weight as widely as possible to avoid an inadvertent descent.. This concern was reinforced by the discovery that extremely hot (estimated to be >60°C) and moist air (but with no noticeable fumes) was emerging from the pit below. The prospect of being gently poached to death should the roof collapse any further did not appeal, and the situation did not encourage prolonged observation. After taking a series of colour photographs a rapid retreat took place to somewhat firmer ground.

As a large intact cone (Fig. 11) was emitting fresh lava at a height of some 10 m, only about 100 m away across the crater, there were evidently considerable variations in the lava levels beneath the crater surface, a fact noted by other observers at various times. However the "Hades" stalactites were completely different in size and character to molten lava versions, which are typically a few cm in length and often curved. Some small isolated stalactites had been observed on Lengai in 1985 (Fig. 8) in 1985, but nothing of similar size and complexity to rival the Hades phenomenon.

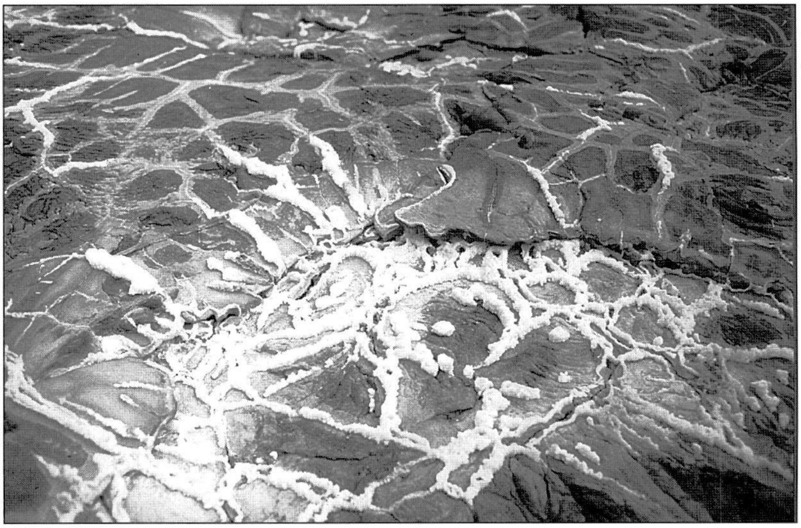


Fig. 9 - Secondary mineral deposits on crater floor (December 1985) - Photo by Bill Waldron.

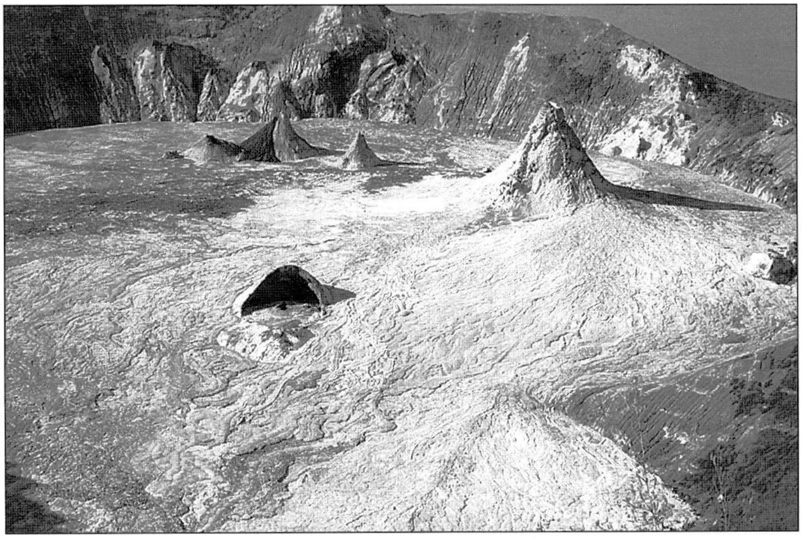


Fig. 10 - General view of crater showing cones and site of Hades cave (left centre) (August 1990).

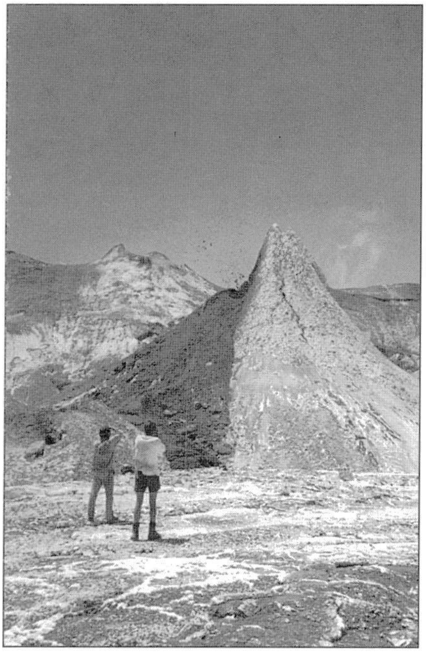


Fig. 11 - Active cone on crater floor (August 1991) - Photo by Gordon Davies.

Fig. 12 - View of Hades cave entrance (August 1991) - Photo by Gordon Davies.

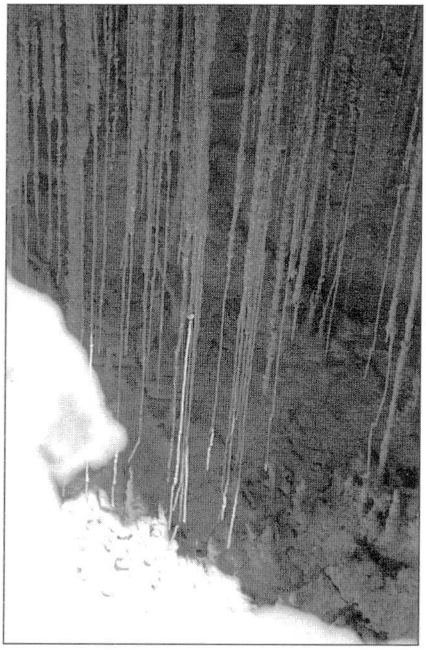


Fig. 13 - Close up view of Hades cave floor (August 1991) - Photo by Gordon Davies.

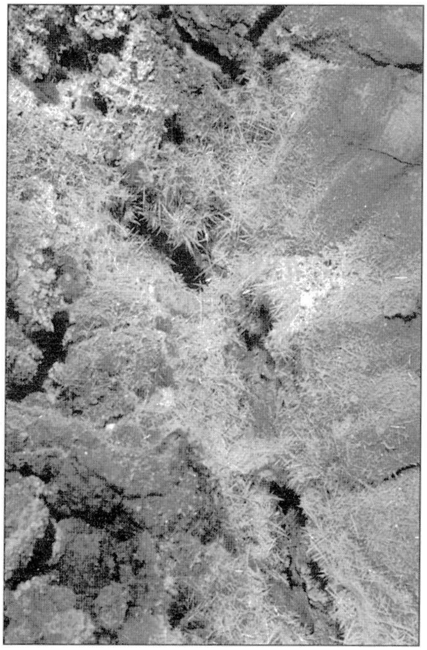


Fig. 14 - Close up of sulphur deposits in crater (August 1991) - Photo by Gordon Davies.

CONCLUSIONS

Lengai is situated in a very arid area of the Rift Valley, with an average rainfall in the surrounding countryside of about 25 to 30 cm, much of it precipitated in violent but short lived storms. However Lengai's altitude undoubtedly generates additional precipitation, and it is frequently is covered by a cloud cap even when the surrounding sky is clear.

Whilst no regular recordings have been made, it is reasonable to assume that rainfall on Lengai crater may be quite considerable, especially in the two annual rainy seasons, and certainly there are always numerous stream jets emerging from fissures in and around the crater rim. A storm depositing 7.5 cm (3 in) of rain on the summit would result in at least 10,000 m^3 of water entering the crater and percolating through cracks and dissolving some of the largely soluble materials of which the lava surface is composed. The author is unable to comment in detail on the possibility of additional water sources, although the highly reactive rocks of the crater floor are also subject to attack from gases and water given off by the magma.

The fact that the crater surface is composed largely of sodium carbonate, and the irregular appearance of the stalactites in Hades and elsewhere, would tend to support the theory that they have a similar chemical composition, and that rain water has played a major role in their formation. The yellow colour is almost certainly sulphur, which does occur elsewhere in the crater (Fig. 14), and might possibly have been deposited on the stalactites by a process of sublimation from subterranean sources. It is likely that the structures were extremely delicate, although no attempt was made to throw in any missiles to test this theory.

The cave itself is likely to have been formed by a lowering in level of molten lava which had originally contributed to the formation of the nearby collapsed cone. This is a very different mechanism to the normal formation of lava caves, although similar cavities with symmetrical, overhanging walls penetrated by a collapse at the top are not unknown, and indeed occur on Suswa, an extinct volcano some 180 km to the north of Lengai. Here on the southern flanks are a line of 7 raised domes with well-like shafts between 15 and 30 m deep. Some bell out into chambers with one having a 10m passage section leading out at the base of the dome (Simons, 1998)

Due to the relatively intense level of volcanic activity on the summit of Lengai e.g. it was estimated that some 30,000 m^3 of fresh lava flowed out onto the crater floor within 14 days in August 1996, it is unlikely that Hades would have survived intact for more than a few months at most.

As so often happens in subterranean structures, the profligate forces of nature create complex and often extremely beautiful secondary mineral deposits, most of which, fortunately, are relatively stable and available for long term study. In the case of Hades, situated at the summit of unique and highly active volcano, the delicate and ephemeral beauty of the formations in this remarkable cave now exist only in the memories of a fortunate few, and in the photographs which recorded this rare phenomenon for posterity.

ACKNOWLEDGEMENTS

The author wishes to thank delegates attending the 8th International Symposium on Vulcanospeleology held in Nairobi on 7/8th February 1998 for the interest they took in the initial presentation concerning Hades and their helpful comments. Thanks are also due to the Hon Chairman of the Cave Exploration Group of East Africa, Jim Simons, for his advice and assistance, and to Bill Waldron (General Manager of Simbarite Ltd, Mombasa) who kindly loaned some personal slides and provided a stalactite sample from his 1985 visit to the mountain.

Considerable gratitude is owed to Professor Celia Nyamweru, Department of Anthropology, St Lawrence University, Canton, NY who provided much helpful background information and also commented on a draft of this paper.

REFERENCES

DAVIES G. J. 1968 Lengai West. Bulletin, Mountain Club of Kenya 67 : pp 4 - 11

DAWSON J.B., H. PINKERTON, G.E. NORTOND. AND M. PYLE 1990 Physicochemical properties of alkali carbonatite lavas: Data from 1988 eruption of Oldoinyo Lengai, Tanzania. Geology 18: pp 260-263.

DAWSON J.B., H. PINKERTON, D. M. PYLE AND C. NYAMWERU. 1994. Eruption of Oldoinyo Lengai, Tanzania: Exceptionally viscous and large carbonatite lava flows and evidence for coexisting silicate and carbonate magmas. Geology, v.22, pp 799 - 802, September

DAWSON J.B., J. KELLER AND C. NYAMWERU 1995 Historic and Recent Eruptive Activity of Oldoinyo Lengai. Carbonatite Volcanism - Oldoinyo Lengai and the Petrogenesis of Natrocarbonatites. Editors; K Bell and J Keller. Pub Springer-Verlag.

NYAMWERU C. 1997. Changes in the crater of Oldoinyo Lengai: June 1993 - February 1997. Journal of African Earth Sciences, Vol 25, No 1, pp 43-53

RICHARD J.J. 1942 Volcanological Observations in East Africa I - Oldoinyo Lengai. The 1940 to 1941 eruption. Journal E African & Ugandan Natural History Society 16 (2-3) : 89-108 (19 figs)

SIMONS J. 1998. Volcanic Caves of Kenya - A guide for the 8th International Symposium on Vulcanospeleology. Privately published by J. Simons in Nairobi.

SUTCLIFFE A.J. 1973. Caves of the East African Rift Valley. Trans. Cave Research Group of Great Britain, Vol. 15. No. 1 pp 41-65 February

WALDRON W. Personal communication. (P O Box 90662, Mombasa, Kenya)

Int. J. Speleol., 27 B (1/4), (1998): 69-74.

TECTONIC CAVES OF SOLAI IN THE KENYAN RIFT VALLEY

Robert A. Davis *

ABSTRACT

Tectonic caves at Solai, Kenya, were explored in 1970. These lie in a complex geological area of the Great Rift Valley in columnar-faulted Ignimbrite. Fissures are presumed to have been widened by later tectonic activity - e.g. the major eathquake of January, 1928. The caves and exploration are briefly described. Questions of formation, drainage and possibilities of steam reservoirs are discussed.

Keywords: vulcanospeleology, tectonic caves, Rift Valley, Kenya

INTRODUCTION

In 1969 - 70, the CEGEA[1] explored tectonic fissures around Nakuru in Kenya's Rift Valley. Nakuru is a strategically placed market town 160 km north of Nairobi. Immediately to the north of this township with its famous flamingo lake, lies the large caldera of Menengai. The caves described lie 7 km further north at 0-° 4'S, 36° 6.5'E.

At that time the cave area was owned by two European farmers, "Lofty" Reynolds and Dick Milton. Their farms lay in a 4km wide graben at the foot of an escarpment that rises steeply from 6000' to Lolderodo summit at 9400'. A railway siding ran from Nakuru. The agriculture was coffee and mixed farming, with cattle ranching on the valley floor. In those days, wild animals were not rare. Several different tribes of local people could be found, both as farmers and farm workers. The rainfall varies from 160cm down to 90cm p.a. at the valley floor. There was a small lake, Solai, and the Ol Punyatta swamp. Three small rivers drained east - west. Both the Tinderess and Watkins rivers soaked away on the farms. Only the Olobainita made it to the Ol Punyatta swamp, cutting tunnels on its way through the soft Tuff further downstream. A few kilometres to the north, on Horst Von Kaufmann's farm, all the bore-holes bore continual warm water. Several seasonal hot springs lay along the base of the Solai escarpment.

The geology is extremely complicated. Since the Miocene, each volcanic outpouring has been succeeded by movement, normal faulting compatible with distension of the crust. Menengai has Recent, blocky, black Trachite flows which have not yet succumbed to vegetation. No outcrops of the underlying crystalline rock have been found. The amazing topography of this area includes a textbook example of fault scarps, a magnificent flight of thirteen 'steps' up the Bahati escarpment. The major Lolderodo fault lies along the length of this escarpment. Thirty km to the north, and 3000' lower, lies Lake Bogoria (called Hannington at that time) which has active fumaroles and boiling hot springs. The farms mentioned are situated on Tuffs with a volcanic soil overlay. The two major Tuffs are a soft, reddish brown, unstratified Lapilla ("Solai") Tuff from the Upper Pleistocene, and an "Ignimbrite" - a welded Tuff dating from the Pliocene.

* Member of CEGEA. Now at Telemark College, Norway.

[1] Cave Exploration Group of East Africa.

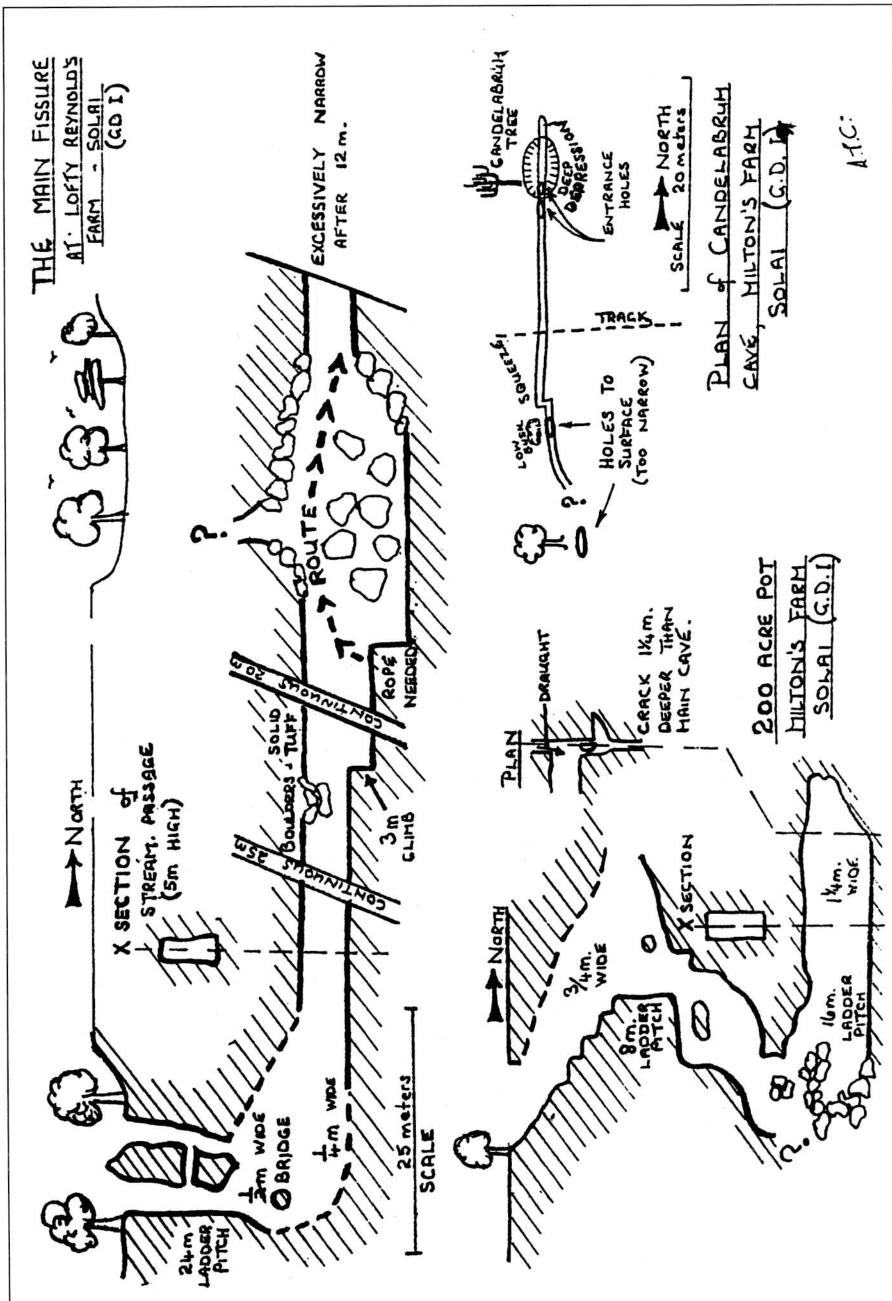


Fig. 1a - The main fissure at Lofty Reynold's farm, Solai (GD I).
Fig. 1b - 200 acre pot, Milton's farm, Solai (GD I).
Fig. 1c - Plan of Candelarum Cave, Milton's farm, Solai (GD I).

According to our field notes written at the time, the Lapilla Tuff contained "blebs of obsidian and a honeycomb stone" - presumably a pumice - and the Ignimbrite had a "laminar texture".

The Solai Ignimbrite was almost certainly laid down in an overland flow. Presumably, its columnar faulting occurred during cooling and was enlarged by later tectonic activity. For example, in 1926 & 1928 there were sizeable earthquakes. The one in January '28 had its epicentre near Bogoria and was measured at 7.0 on the Richter scale. A reliable resident[2] at the time told that a 6m high 300m long scarp of Lapilla tuff appeared after the 'quake, and that the three rivers went underground, and that both the Ol Punyatta swamp and Solai lake shrank considerably. Also, it is recorded[3] that a 2m wide crack opened up at the bottom of the escarpment, just S of Lake Bogoria[4].

With the thirteen fault scarps to the east and the Menengai crater to the south, it is not surprising that tectonic caves occur here. Although (unlike the nearby Lake Naivasha) Lake Nakuru is not an old caldera, Menengai could well be the centre of a radial stress pattern which complicates the geological picture even more.

THE CAVES

The caves explored are marked on the geological map as "fissures". In that area some 37 depressions were found, all lying N-S in two parallel lines about 70m apart, over a length of a kilometre. These depressions varied from 1 to 4 m deep. About thirteen of these opened into fissures. Several were fenced off, presumably to prevent accidents. Only one of those fenced was still open. This might indicate their changing state.

Nakuru district abounds with stories about the ground opening up. One such tells of a Boer who coupled six oxen together to pull his tractor out. In Solai, both farmers told of cows falling down. And even that this poor beast could be heard for some time after - apparently walking to other fissures (something which seems most unlikely in practice). It was also reported that two workers digging a well had disappeared. This shaft was later used as a very 'long-drop' toilet but proved unsuitable because of the strong updraughts.

All the explored fissures had narrow entrances in Solai Tuff. None of these entrances were particularly large. They were as much 'shafts' as 'fissures'. Lower down, however, they were definitely fissures. Most were in the Solai Tuff for at least 6m depth, and descended into the Ignimbrite where the hard, parallel walls of the welded Tuff showed some signs of water transport. They were up to 25m deep, 1.3m wide, and 125m long (Fig. 1). The height of the lower passages sometimes increased in steps, by as much as 3m. This says something about the way the Ignimbrite cracks up. Also, as might be expected, there were sometimes transverse cracks running E-W at the end of a fissure. The widest found was 20cm and carried a draught.

No artefacts were noted, although mummified remains of cow, deer, dog & hare were found (Fig. 2). The ill-fated well-shaft was not descended further than one ladder-length because of the smell - but it was plumbed deeper than 30m. In one case there was noted a difference in vertical displacement between matching features on opposite fissure walls. All of the explored fissures ran N-S and were vertical. However, one very narrow extension was tilted from the vertical and appeared to swing out of the N-S line.

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[2] Colonel Sam Reeder.
[3] Tilloston, 1937.
[4] In our explorations in 1970, this crack appeared to have become almost filled with soil.

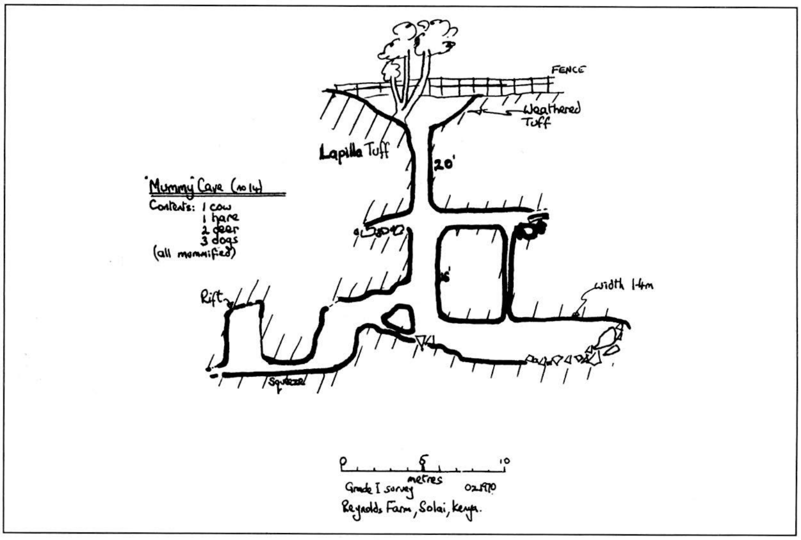

Fig. 2 - "Mummy" Cave (Contents: 1 cow, 1 hare, 2 deer, 3 dogs - all mummified).

These caves required a degree of climbing skill, and some needed ladders. From a caving point of view they were "sporting". Explorers in African caves should be aware of the dangers of caving and of low lying carbon dioxide.

DISCUSSION

1) Presumably these fissures originate in the natural columnar faulting of the Ignimbrite, much disrupted by later faulting due to tectonic fragmentation of the crust - for example, during the earthquakes of '26 and '28; (later earth tremors have also been recorded.[5]) However, the height variations in some of the explored fissures suggest a more complex faulting than a simple columnar structure.
2) Without more evidence than we have from 1970, it might be that these fissures occur primarily in the Ignimbrite, entrance being made through the more plastic Solai Tuff by surface water and other mechanisms. Because "fissures" are marked on the 1959 geological map, and a dozen 'blind' depressions were fenced, it opens up discussion about whether these were more open at that time. And indeed, about whether these entrances could have been filled in by some mechanism - natural or otherwise - and whether they might reopen.
3) At the time of the original exploration a further shaft was explored and descended to 55m on Nye Chart's farm in Njoro, west of Nakuru. This cave had appeared suddenly when a stream suddenly went underground. The soft Tuff rapidly disappeared into a hole which enlarged to 25m in surface diameter, 55m depth in less than a year. The farmer strung a cable across this and descent was made to a jammed tree 30m down - reputedly by a nine-year old!
   Further significant enlargement did not occur afterwards. This raises the question of

[5] By Mrs Jill Simpson, Naivasha, on Dec. 24, 1977. Personal communication.

where could 10,000 m^3 of soil go so easily? McCall (1957) observes that the drainage goes down through porous rock and fissures to the water table. Presumably, there is plenty of open space down there.

4) The most interesting question of "where does the water go?" could lead to much speculation. The signs of water transport - i.e. apparent vadose enlargement of some lower fissures - seemed to indicate that the water flowed away at speed. This would be as expected, of course.

5) At Ol Punyatta Station (at boreholes 131 & C1066) the writer was informed of "considerable quantities of (low pressure) steam". Hot springs occur along the foot of the Solai escarpment near the Watkins Stream and several farms had warm water (at about 39°C). These might be sourced by returned ground water, but the persistence in supply at Von Kaufmann's suggests sourcing from depth, as a shallow supply would be seasonal.

   The steam jets and geysers at Lake Bogoria are sourced by hot juvenile CO_2, according to the Geological report[6]. The same report suggests that there is no extensive, economically exploitable steam reservoirs in the area. The writer wonders if this is correct. At any rate, a good deal of water disappears somewhere. On the question of drilling for steam, however, the problem of unstable rock rises. It is necessary for both drill and borehole to be precisely near-vertical. Any shifting of the horizontal alignment is unacceptable. With the slight movements probable in the ground discussed, this would make drilling difficult, if not impossible. Not to mention the huge deformations which occurred in '28. However, the possibility should not be forgotten, and future technical developments might open up an energy source here in Solai.

   At Olkaria some 70 km further south there is exploitation of a very substantial steam reservoir which is not being depleted as was originally estimated. The water has been traced not to come from the nearby Lake Naivasha, as originally assumed. The drilling goes down to 2200m where the temperature is over 300°C. The reservoir starts at 600m depth. That describes a volume measured in cubic kilometres. As early as 1953, J. Scott suggested "immense quantities of steam trapped under an impervious cover". This idea seems very likely to the writer. It may not be necessary for this "cover" to be so very impervious, either. For example, it is possible for temperature inversions to occur in stable atmospheres. And fresh water can lie under salt water[7]. Similarly superheated water and steam could lie trapped beneath a cooler water body lying in the pervious/fissured rock above.

6) The question of how the Ignimbrite is laid down has certainly been thoroughly discussed, researched and described. The writer has little specific knowledge of this, but is speculating:-

   In Solai we are talking about an overland flow. One presumes that the eruption was not so violent as to throw the particles into the air but appeared as a viscous outpouring. One assumes that this could have been from a central volcanic source, or from rifts. Gas charged lavas, sub-divided into particles enveloped in a tightly-compressed expanding gas, made up the flow. The gas was probably sourced mainly by continuous emission from the particles themselves - due to the sudden pressure reduction. This means that the eruption spews out 'exhaling' particles, a mix-

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[6] McCall 1967.

[7] Large quantities have been found under the Caribean, presumably from the Amazon. There has been some speculation as to whether the energy thus trapped could be harnessed; and also as to whether the unexpected release of such energy - for example, by a ship on the surface - could cause an explosive release of the fresh water which would destroy surface objects. - Personal communication from Norwegian pipelineconsultant Sivert Vaagen, Skien, Norway.

ture of solids and fluids. The expanding gases act as a propellant which add to the effect of gravity alone. The escaping gases cause a great reduction in viscosity so that the flow might travel overland at great speed. The topography of the terrain delimits the flow's expansion until finally the particles are laid down, welded together into the Ignimbrite.

From this theoretical presumption one might expect to find a porous Tuff. As this is not the case one wonders why not. One suggestion might be that the particles varied from size-zero upwards, and thus packed into a solid rock when they were laid down, with the gas escaping upwards.

It would be interesting to experiment with models of this mechanism. For example, with particles of dry ice with heated iron-filings and ball-bearings.

REFERENCES

DAVIS, R.A. 1971 "Kenyan Rift Caves". The Second Bulletin of the Cave Exploration Group of east Africa

MCCALL G.J.H. 1967 "Geology of the Nakuru-Thompson's Falls-Lake Hannington Area". Geological Survey of Kenya.

MCCALL G.J.H. 1959 Geological map of the Nakuru Area. Geological Dept of Kenya.

MCCALL G.J.H. 1957 Geology and groundwater conditions in the Nakuru area. Technical report no 3. Ministry of Works (Hydraulic Branch) Kenya.

SCOTT J. 1953 The Great Rift Valley and it's economical Possibilities - private printing, Nairobi.

SUTCLIFFE A. 1973 Caves of the E. African Rift Valley. Transactions of The Cave Research Group of Gt Britain, Vol 15 no 1. pp 41-65. Feb '73

TILLOSTON E. 1937 The African Rift Valley Earthquake of Jan 6th, 1928. Royal Astronomical Society: Monthly notes, Geophysical supplement 4 pp 72-93.

TILLOSTON E. 1938 Further notes on the African Rift Valley Earthquake of Jan 6th, 1928. Royal Astronomical Society: Monthly notes, Geophysical supplement p 315.

Part II

Contributes from outside South East Africa

Int. J. Speleol., 27 B (1/4), (1998): 77-86.

LAVA CAVES OF GRANDE COMORE, INDIAN OCEAN: AN INITIAL RECONNAISSANCE, SEPTEMBER 1997

Gregory J. Middleton *

ABSTRACT

What are believed to have been the first speleological investigations in the Comoros Islands were carried out on Grande Comore island between 7 and 13 September 1997. A number of caves were located with the help of local informants and the more significant ones surveyed. Exploration of some caves was not able to be completed. The potential for further significant discoveries is believed to be high.

Keywords: vulcanospeleology, lava tubes, Comore Islands

BACKGROUND

When Bill Halliday appointed me to the Commission on Volcanic Caves in October 1996 he asked me to assume responsibility for the Indian Ocean islands (because of my efforts in documenting the lava caves of Mauritius and my interest in Madagascar). He pointed out that the Comoros were virtually unknown territory, speleologically, the only information he had being a verbal report from the French vulcanologist, Haroun Tazieff, who had been in Grande Comore some years before as a consultant during construction of the airport and noted lava caves intersected by the works.

I was able to visit the Comoros briefly, in September 1997, following the 12th IUS Congress and, thanks to a Mauritian acquaintance then resident on the island and a tourist guide she contacted, was able to inspect a few of the island's lava caves.

The Comoros, more properly known as the Federal and Islamic Republic of the Comoros (or République Fédéral et Islamique des Comores - R.F.I. Comores) consisted of three islands (Grande Comore or Ngazidja - 1025 sq.km.[1], Anjouan or Ndzuani - 424 sq.km., and Mohéli or Mwali - 211 sq.km.) located in the Indian Ocean about 600 km west of the northern tip of Madagascar (Fig. 1). A fourth island, Mayotte or Maore - 374 sq.km. - is geographically part of the group but, following a referendum in 1974, remains a French *Collectivité Territoriale*. Since its unilateral declaration of independence in 1975 RFI Comores has claimed Mayotte as part of its territory - but it now faces a much bigger problem keeping even the three islands together. Anjouan (and possibly Mohéli) declared its independence from the federation shortly before my visit, resulting in considerable political instability. Despite demonstrations, curfews and rumours of impending coups, I was able to carry out my investigations with little difficulty.

The Comoros are entirely of volcanic origin, having begun to emerge from the sea about 15 million years ago (Swaney & Willox 1994). Mayotte is the oldest, followed by

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[1] For comparison, Mauritius is 1825 sq. km., Flinders I. in Bass Strait is 1374 sq. km, Hawaiian island of Kauai is 1437 sq. km.

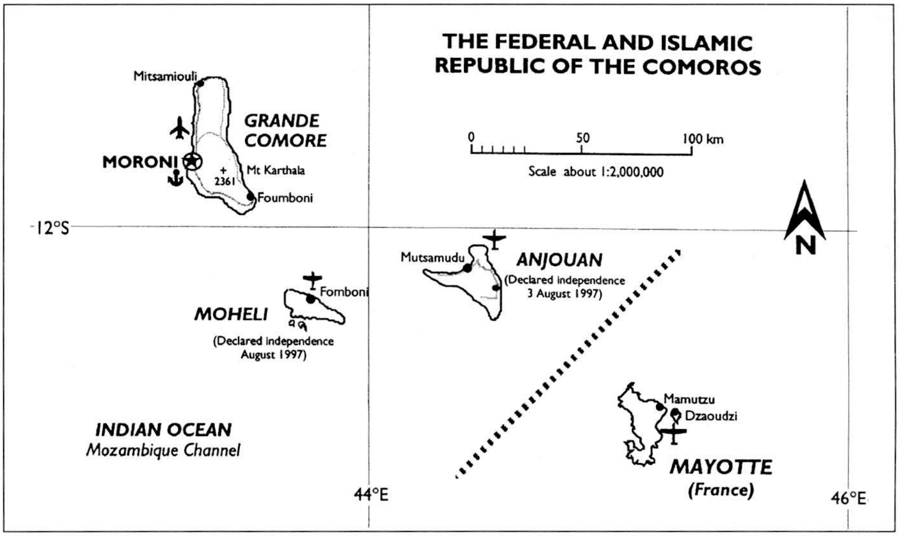

Fig. 1 - The Comoros Archipeligo.

Anjouan, Mohéli and, finally, Grande Comore, the largest island and the only one to still have an active volcano, 2361 m Mt Karthala[2].

A search of the international speleological literature confirmed Bill's view that there was no published documentation on the caves of the Comoros. However, it must be acknowledged that the Lonely Planet guidebook, *Madagascar & Comoros* (Swaney & Willox 1994) does mention "the small cave, Grotte du Capitaine Dubois", but it gives only its location.

LAVA CAVES INVESTIGATED

I engaged a tourist guide, Ahmed Said, to show me the caves he knew of and to locate others reported by the local office of tourism.

The local people, numbering about 220,000 and of whom 99% are Moslems, display an almost total lack of interest in (or outright fear of) caves. I was told they are regarded as the likely dwelling place of malevolent spirits known as *djinns* or *ndgins* (genies). Whatever the reason, very few caves appear to have been entered and they are not generally used for rubbish dumping as is the case in Mauritius. Even my guide, although he knew of a number of entrances, had entered none of them and had no idea how long any of the caves were.

1: Hilimandsodé or Grotte du Capitaine Dubois is shown on the IGN 1:50,000 map of Grande Comore and is mentioned by Swaney & Willox (1994). It lies at a height of about 860 m asl, about 6.5 km inland, north-east of the capital. Stone steps lead up to the western side of the very obvious entrance which faces approximately south. The opening is 12 m wide and up to about 10 m high, but unfortunately only about 6 m deep (Fig. 2). The floor is smooth, composed of crushed lava, obviously modified by human

[2] See Volcano World web site: http://volcano.und.nodak.edu/vw.html.

activity over a long period. My guide claimed that a hole about 4 m above the floor on the eastern side of the cavern lead to a descent of some 400 metres! It was not possible to investigate this directly but the hole was subsequently found to connect with a small higher chamber.

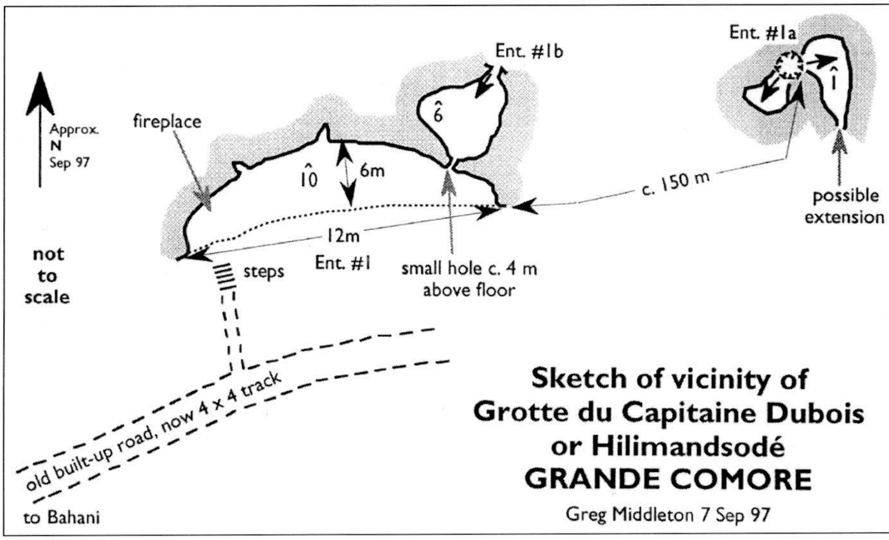

Fig. 2 - Sketch of vicinity of Grotte du Capitaine Dubois.

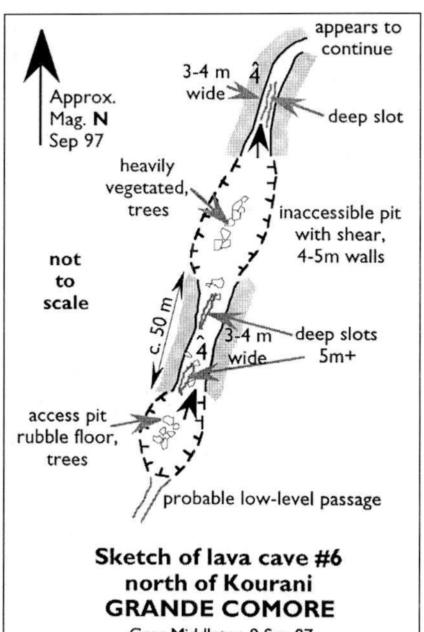

Fig. 3 - Sketch of cave 5 north of Kourani.

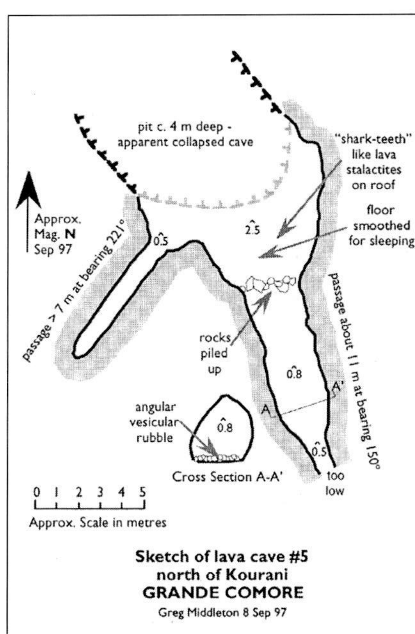

Fig. 4 - Sketch of cave 6 north of Kourani.

1a: A small heavily vegetated hole about 150 m from 1, on the side of the same hill. It is about 4 m in diameter and drops about 3 m to a rockpile. Straight ahead the hole goes down about 10 m but is sealed by the rockpile. A small space below the point of entry leads to a cavity with a solid roof, with small lava stalactites on the ceiling, and rubble floor. To the right it is possible to crawl for about 6 m until the space becomes too tight. It is possible that the hole continues but is very restricted and unstable. There is no noticeable draught.

1b: This small hole, located on the opposite side of the hill from 1, is about 1.5 m in diameter and leads down into a chamber about 6 m by 4 m, and around 3 m high. To the right is an aven perhaps 6 m high but not, apparently, reaching the surface. The only other feature is a small hole to the lower left, through which daylight is visible. Investigation revealed this to be the other side of the hole 4 m above the floor of 1.

2: This is a vertical entrance near the junction of Route Nationale 5 and Route Régionale 118, near the village of Simboussa. Immediately north of RN5 is a pit about 3 m in diameter and perhaps 6 m deep. Naturally, such a convenient hole has collected some rubbish. Without climbing gear descent appears impossible, unless one is prepared to rely on some convenient tree roots.

3: About half an hour's walk from the village of Kourani, on the lower slopes of Mt Karthala, there is a small hole on the right side of the path, about a metre in diameter. It appears to go down at least 4 m, but gets progressively tighter. Ahmed had not entered it (as with all the caves he knew of). I did not attempt to descend it.

4: A further half hour's walk brings one to a smaller hole on the left side of the path. It is quite narrow and part filled with sticks and banana leaves. One can see down 3 to 4 m but entry would not be possible for a normal adult.

5: In another 10 minutes one comes to another hole to the right of the path. There is a descent of about 3 m into what is obviously a collapsed lava tube, running approx. north-south and about 5 m wide. At the southern end is a section of intact tube about 2.5 m in diameter, though it narrows rapidly. One can scramble in a total of 11 m before the roof comes down to about 0.5 m high (Fig. 3). The floor is composed of very jagged pieces of vesicular rubble and short lava stalactites hang from the ceiling. A couple of metres inside the entrance rocks have been piled up, forming a wall and leaving a level area where people have obviously made camp. A smaller tube enters on the right side but it is only about 0.6 m in diameter and perhaps 7 m long.

6: Well south of the previous holes, in forest on the edge of a clearing, is a quite large and complex hole. It is 5-6 m wide and trees have grown in and fallen into it (Fig. 4). A loose rubble slide leads down about 5 m to where one can see into a narrow slot which appears to extend at least another 4-5 m below. The slot is 3-4 m across at the top, but becomes more narrow below. It is possible to get down another two metres or so to a level where boulders are lodged in the slot, making access possible towards the north. In a southerly direction the slot appears to continue at a lower level but with no base in sight. The section of cave to the north is about 50 m long before the roof opens again into a large collapsed section, 5-6 m wide with many growing trees and everything heavily covered in moss. After perhaps 100m the roof closes over again and the passage continued on about 3 m wide and 4 m high. The floor was unstable here, too, and the slot continues down to undetermined depths. Sections of the wall peel off if held onto and the whole place is not particularly stable. One can descend about 4 m further but the slot is blocked at various levels with highly angular rocks which are not very strong.

7 & 8: Further south, on both sides of road RR125, not far above Nioumamilima, Ahmed pointed out holes which have vertical sides and descend 5 to 6 m, not unlike 2.

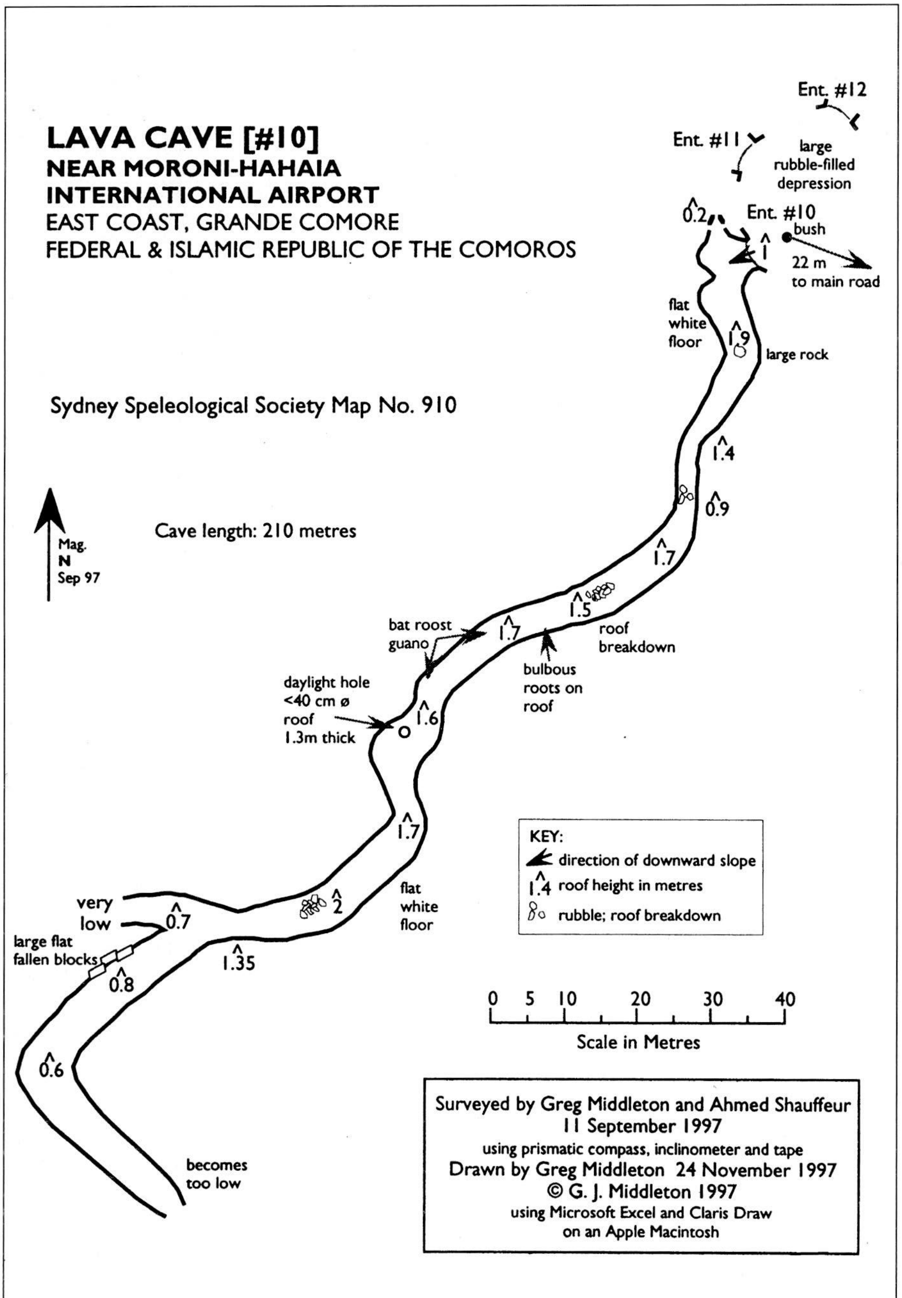

Fig. 5 - Lava Cave 10 near Moroni-Hahaia Airport, Grande Comore

Neither appears free-climbable but they are evidently connected, meaning the road crosses a narrow bridge of lava between them. Ahmed suggested that these two holes, together with 6, a few hundred metres north, and 2, 3.5 km to the south, form part of a system. Certainly these holes are aligned and succeed each other downslope from the main volcano but it seems unlikely that an accessible tube connects them. Only investigation by a properly equipped team could resolve this.

9: lies about 100 m directly below the sawmill at the abandoned village of Nioumbadjou. It is a small cavern with a 7 m wide entrance, 2 m high and 4 m maximum depth. The floor is dirt, covered with a maze of roots.

10: This entrance, near two others, lies within 22 m of the main east coast road (RN1) adjacent to the runway of the main international airport. This is the lowest of the three holes and looks least promising, yet it leads to over 200 m of accessible passage, most of it less than 1.8 m high. The floor is generally solid, smooth and clean, with little breakdown; eventually it just becomes too low. A survey was carried out, with the help of Ahmed (Fig. 5), though he complained most of the time about the bad odours, lack of oxygen, heat, hitting his head, bending his back and being attacked by "les ouiseaux" (actually they were small insectivorous bats - which of course didn't 'attack' - but he had apparently only ever seen the large *Pteropus* fruit bats, didn't know about the smaller ones and took a lot of convincing they weren't birds). There were perhaps 50 bats in the cave and only a few small patches of guano. Where tree roots come through the ceiling (which at the entrance is only 0.9 m thick, increasing to 1.3 m at a daylight hole) they form round balls on the ceiling and rarely reach the floor.

11: This cave was also surveyed (Fig. 6). After only about 50 m, a 4 m undercut drop impedes further access without a rope. The lavafall has produced a typical plunge pool with a widened passage at its base, narrowing again beyond. A rope was obtained to enable safe descent of this drop. Although overhung, there are footholds which facilitate the climb. At the "plunge pool" the passage is about 9 m high. It then narrows to about 6 m and the roof descends to about 6 m high. The floor is in places clean and level but elsewhere is strewn with slabs of rock fallen from the roof. A survey was carried out for about another 300 m before a failing lamp forced its termination. At this point the passage, which is 10 m wide and 2.5 m high, splits in two, both about 8 m wide. A large crab was noted here, moving around in a narrow slot. The passage heads towards the sea (and the airport runway) but at this point is at least 600 m from the shore. It could be that small spaces in the underlying rock allowed the crab to penetrate to this point, though the benefits are not immediately obvious. It is likely that if the passage reaches the vicinity of the airport runway it would have been detected when the airport was built and would have been collapsed and filled.

12: This hole, near 10 and 11, is blocked by a rockfall after only about 20 m (Fig. 7), clearly the result of earthworks related to the main road (RN1) which it would have passed underneath. A search upslope might reveal another access point.

13: The tourism office reported a cave near the coastal village of Fassi. A youth from the village, Yousoof Alismael, showed us the cave and said it is known as "Nyamaoui" and that the Comorian word for cave is "panga". The entrance is at least 500 m inland, in extremely dry, poor, country. The entrance pit, hidden in vegetation, is about 20 m in diameter and 10 m deep. The vertical sides of the pit make unaided access impossible but one of two large trees growing in it has a trunk growing quite close to the lip which makes descent (and ascent) possible. At the bottom there are two large passages; one leads west, towards the coast, and the other, east, or inland. That to the east was clearly larger (7.5 m wide by 5 m high) and so was checked first. At the top of the scree at the tunnel entrance, a dry stone wall about 1.5 m high has been built almost

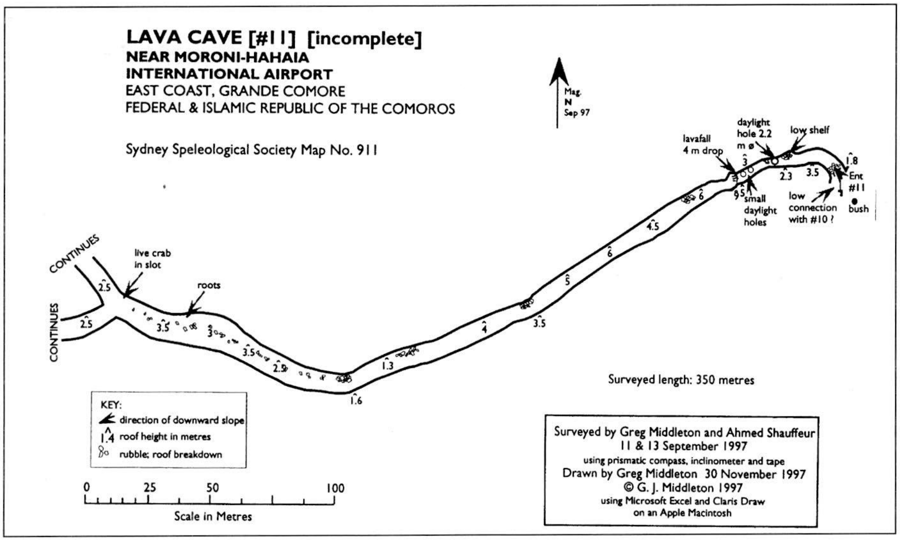

Fig. 6 - Lava Cave 11 near Moroni-Hahaia Airport - exploration incomplete.

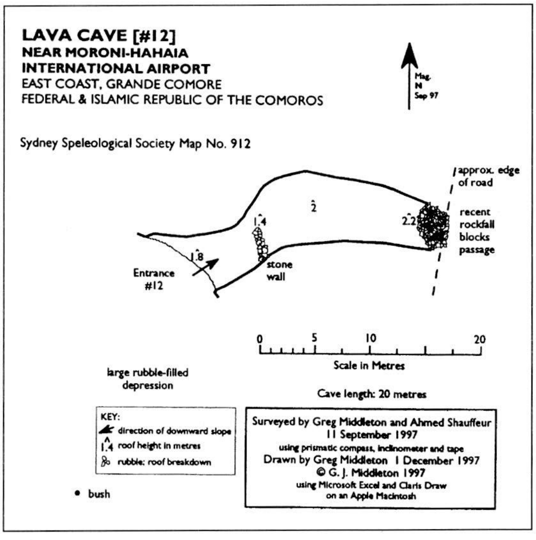

Fig. 7 - Lava Cave 12 near Moroni-Hahaia Airport.

right across the entrance, for a purpose unknown. At the northern end of the wall was a very old large ceramic vessel which may have been used to carry water. The eastern passage reduces in height as one goes further in and the floor is covered with irregular roof breakdown. A smaller passage branches off to the south, leading to a bat chamber after about 20 m. A few metres further on the main passage narrows and the ceiling lowers to about 2.5 m but it then rapidly rises and the passage widens out again. About

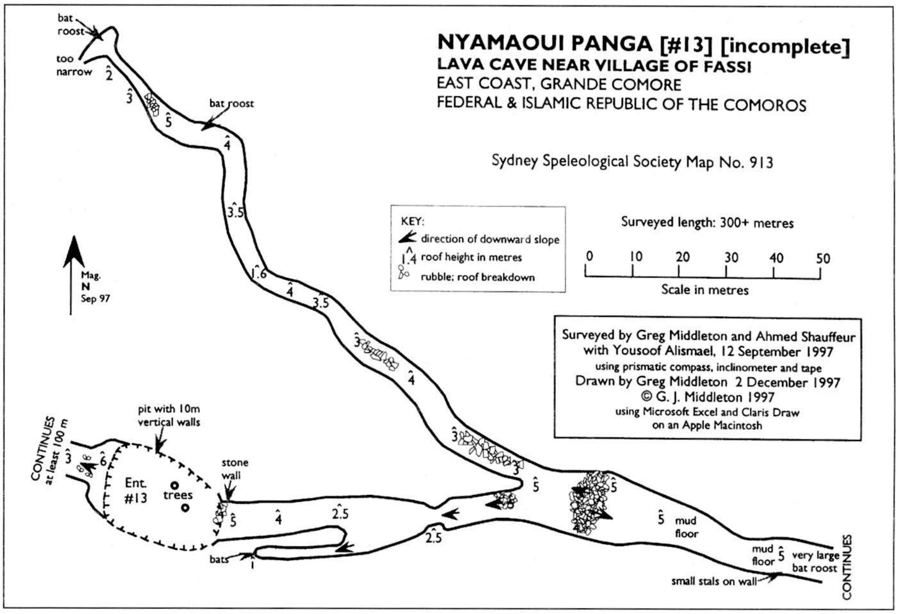

Fig. 8 - Nymaoui Panga (13), a lava cave near Village of Fassi, Grande Comore - exploration incomplete.

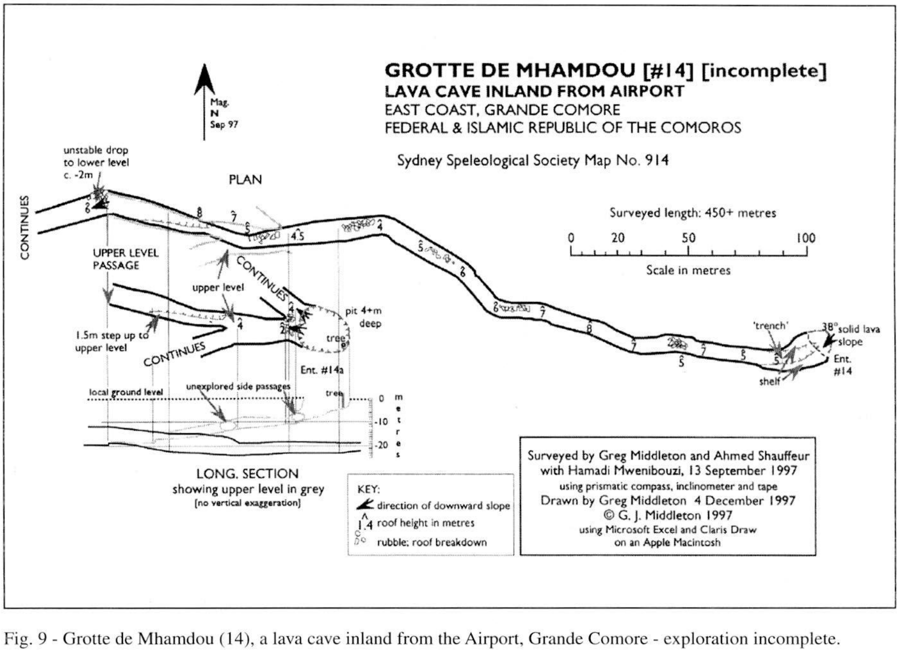

Fig. 9 - Grotte de Mhamdou (14), a lava cave inland from the Airport, Grande Comore - exploration incomplete.

15 m further in a large passage comes in from the north-west. This appears to end, after about 150 m, in a bat roost but a small passage may continue. Continuing east in the main passage (8 m wide x 5 m high), one climbs over a rockpile to a mud floor. At this point one encounters a huge bat roost; the floor is thickly covered in guano and large numbers of very light-coloured cave crickets are evident.. We terminated our exploration at this point as we did not wish to further disturb the bats. The passage shows no sign of decreasing in size. The passages were surveyed as we returned to the entrance (Fig. 8). From the entry pit a rock scree leads down into the western passage which is then more or less level; it was checked for about 100 m but not surveyed. It is about 4 m wide and 5 m high and shows no sign of tapering. This cave is clearly a highly significant one, with an extremely large bat population.

14: also in the airport area, was shown to us by a local farmer, Hamadi Mwenibouzi, who told us it was known as Grotte de Mhamdou. The entry hole is perhaps 15 m in diameter. This hole is unusual, and distinctive, in that entry can easily be made down a solid lava flow, rather than the usual pile of roof breakdown or vertical face. The cave is 5 to 6 m wide and from 4 to 8 m high, with breakdown material covering the floor after the entrance chamber, which has a distinct cleft cut (?) in the centre of the floor. About 350 m of the cave was surveyed (Fig. 9), to a point where daylight is visible from a higher level. The passage continues beyond this point but requires a descent of a steep, unstable section. It is possible to climb up to a shelf at the higher level which is about 4 m high. Proceeding towards the pit which is the source of the daylight, one passes passages on both right and left, each about 4 m high and 5 to 7 m wide. Both appear to continue but were not investigated. The survey shows we had explored over 450 m of passage - and left three passages unexplored.

15: lies on the eastern side of the main road; before construction of the road it may have been connected to 12. The entrance is about 6 m wide and 2 m high. In the entrance chamber were two old truck tyres. A passage about 6 m wide x 4 m high runs inland for about 80 m. The floor is fairly clean until the substantial roof fall which appears to block the passage - though it is possible that there may be a way around it to the right.

At the village of Bangoua Kouni I sought information on a cave reported by the tourism office. We were directed to a spot on the north side of the main road (RN3), a couple of hundred metres SW of the village. Here a local youth pointed to a jumble of broken rocks and said that the cave entrance had been filled a few years earlier when the road was widened. It was evident that we had no hope of re-opening this cave without official sanction and machinery or labourers.

OTHER REPORTED CAVES

1. In the south-east, a cave is reported in the vicinity of Gama Mbwebe (Tourist Office).
2. Cave containing water, "on the other side of the island", in which a man is said to have died (reported by guide).
3. The 1:50,000 topo map shows a 'Grotte de Milembeni' inland from the village of Mbatse, near the east coast.
4. The 1:50,000 topo map shows 'Gouffre' near the edge of the crater on the summit of Mt Karthala at a height of 2,260 m a.s.l.

RECENT MAJOR LAVA FLOW

I also visited a recent lava flow, reported to have occurred in 1977, in the vicinity of the village of Singani[3]. This town has been rebuilt since the flow, which, according to Swaney & Willox (1994, p. 348), left only the school standing. The higher part of the flow (above road NR2 at about 400 m asl) is now almost completely covered by lichen, with many ferns. Below the road, however, the rock appears to be much darker (almost black) and there is hardly any vegetation. The rock is highly vesicular and friable aa lava. It decomposes into a sort of sand very readily and is being worked to extract that material for building. In some places cave-roof-like structures are exposed, composed of stronger grey basalt but they are invariably filled with the vesicular, friable material. This latter material does not appear strong enough to form a stable tube roof. Inspection of a fair part of this new flow revealed no evidence of holes, collapses or tubes. The rock forms beautiful natural sculptures in places, though this is readily destroyed when the land is levelled.

OFFICIAL SUPPORT

Before leaving, I attended a meeting with an advisor to the President who expressed great interest in my investigations and their possible value to the country. He also indicated an awareness of the country's environmental problems and a wish to see the remaining natural environment protected by a national park - after the current political problems are resolved. He expressed his full support for the continuation of the investigation of the island's caves.

CONCLUSION

I conclude that there are a large number of significant caves on Grande Comore, especially in the north where the gradients are more gentle. The potential for the finding of further caves is extremely high. There has been no interest in the caves locally and the fear of spirits which may inhabit them has probably protected the caves and their contents from damage by casual visitors. The search for water, which has been a scarce resource (there appear to be no permanent watercourses on the island), may have at times enticed people underground and this is reported (by my guide) to have led to the death of a man looking for water when his flaming torch went out.

A small, well-equipped team, would be necessary to complete the exploration of some of the caves I located and, in cooperation with knowledgable locals, would have a good chance of finding more significant lava tube caves on Grande Comore.

My sincere thanks to Rosemay Oxenham who made my stay on Grande Comore much more enjoyable, and successful, than would have been possible without her, and to Dr Bill Halliday for suggesting the enterprise.

REFERENCES

SWANEY, D. and R. WILLOX. 1994. Madagascar & Comoros - a travel survival kit. 2nd Edn. Lonely Planet Publications: Hawthorn, Australia p. 350.

[3] According to Volcano World web site, the most recent eruption was a phreatic explosion in 1991.

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LAVA CAVES OF THE REPUBLIC OF MAURITIUS, INDIAN OCEAN

Gregory J. Middleton *

ABSTRACT

In their *Underground Atlas*, MIDDLETON & WALTHAM (1986) dismissed Mauritius as: "very old volcanic islands with no speleological interest". Recent investigations indicate this judgement is inaccurate; there are over 50 significant caves, including lava tube caves up to 687 m long (one 665 m long was surveyed as early as 1769) and 35 m wide. Plaine des Roches contains the most extensive system of lava tube caves with underground drainage rising at the seashore.

Notable fauna includes an insectivorous bat and a cave swiftlet *(Collocalia francica)*, the nests of which are unfortunately prized for "soup". The caves are generally not valued by the people and are frequently used for rubbish disposal or filled in for agricultural development.

Keywords: vulcanospeleology, lava tubes, Mauritius

RÉSUMÉ

Bien que les îles Maurice ne soient pas connues pour leur intéret spéléologique, de récentes recherches indiquent qu'il y a plus de cinquante cavernes importantes, comprenant des tunnels de lave allant jusqu'à de 687 m de long et 35 m de large, l'un d'entre eux, de 665 m de long a été découvert dès 1769.

La Plaine des Roches contient le système le plus étendu de tunnels de lave avec un écoulement souterrain qui s'élève au niveau du rivage. La faune importante de ces caves comprend de chauves-souris insectivores et de petites hirondelles *(Collocalia francica)*, les nids desquelles sont malheureusement recherchés pour soupes de gourmets. Les caves ne sont généralement pas appréciées par les habitants qui trop fréquemment s'ent servent comme dépôts d'ordures ou d'entrepôts agricoles.

LOCATION AND GEOLOGY

The Republic of Mauritius is comprised of two main islands in the southern Indian Ocean, the main one of 1,860 sq km, about 850 km east of Madagascar, and Rodrigues, 110 sq km, 560 km further east.

The main island is almost entirely volcanic, having originated about 13 million years ago in seabed eruptions which took until about 8 million years ago to reach the ocean's surface. The island's spectacular mountain chains and peaks are remnants of a large shield volcano, the centre of which subsided 5.5 million years ago to form the Mauritian caldera. The rest of the island was fashioned by suites of lavas (Hawaiian flows) emitted from 23 smaller, more recent volcanic structures. Lava flows have occurred as recently as 26,000 years ago in the Plaine des Roches area in the north-east (ANTOINE 1983). There are some limited exposures of calcareous aeolianite on the coasts of both islands and it comprises some small offshore islets. Karst caves are best developed on Rodrigues.

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THE LAVA TUBE CAVES

Lava tube caves occur throughout the main island of Mauritius. Commonly they are the result of rapidly flowing basic (low silica) lavas cooling on the surface and forming a crust over the molten rock below. If the flow is cut off at its source and the lava continues to flow it can leave behind a void, the inner surfaces of which may contain a record of events during the cave's formation. Access to the tubes is generally only made possible by the eventual collapse of part of the roof.

These caves tended to form where conditions were optimal: small, non-explosive eruptions of basic lavas onto gently-sloping surfaces. By noting the orientation and extent of lava tubes it is possible to infer the sources of the relevant flows. Most lava tube caves are found in recent flows as these have had the least time to collapse and as later flows tend to obliterate features beneath them.

The principal localities in Mauritius where lava caves occur (Fig. 1, Table 1) are Plaine des Roches and Nouvelle Decouverte (originating from the Bar le Duc-l'Escalier volcanic system), Vacoas-Palma (Curepipe Point-Trou aux Cerfs-Verdun volcanic structures) and Mont Blanc-Surinam (Bassin Blanc volcanic system) (SADDUL 1995). In the south there is a scatter of small caves in the area extending from Savannah to Plaine Magnien and there is a single, isolated cave in the north at Réunion Maurel.

For convenience the main island has been divided into six regions and within these caves have been grouped into somewhat arbitrary 'cave areas', shown (in bold) on Fig. 1.

Table 1 - Documented lava caves by Region and Area

Region	Area	No. of caves	Length (m)
North-West	Mapou	1	225
North-East	Plaine des Roches	16	2,500
Central West	Plaine St Pierre	6	920
	Plaine Wilhems	9	1,752
Central East	Nouvelle Decouverte	11	1,535
	Trou D'Eau Douce	2	35
South-West	Chamarel Falls	6	110
	Mont Blanc	6	755
South-East	Plaine Magnien	1	85
	Savannah	3	205
	TOTAL	61	8,120

The greatest concentration of caves occurs at Plaine des Roches. This is a flat to undulating area, comprised of probably the most recent lava flows on the island, derived from the Bar le Duc-L'Escalier volcanic system and partly from the Mont Pilon volcano (SADDUL 1995, p. 136). The author has documented some 29 cave entrances in this area and 16 discrete caves. The largest of these was surveyed by BILLON *et al.* (1991) at 520 m. It is a consistently large tube, 10 to 15 m wide and averaging about 10 m high. It contains one of the largest bat colonies in Mauritius, estimated at different times at from 10,000 individuals to 10 times that number. It also contains a small but important swiftlet colony of around 50 birds. Nine other lava tubes in the area exceed 100 m in length. A number of the Plaine des Roches caves contain water and, although no tracing has been done, it is believed that the water bodies are interconnected and that

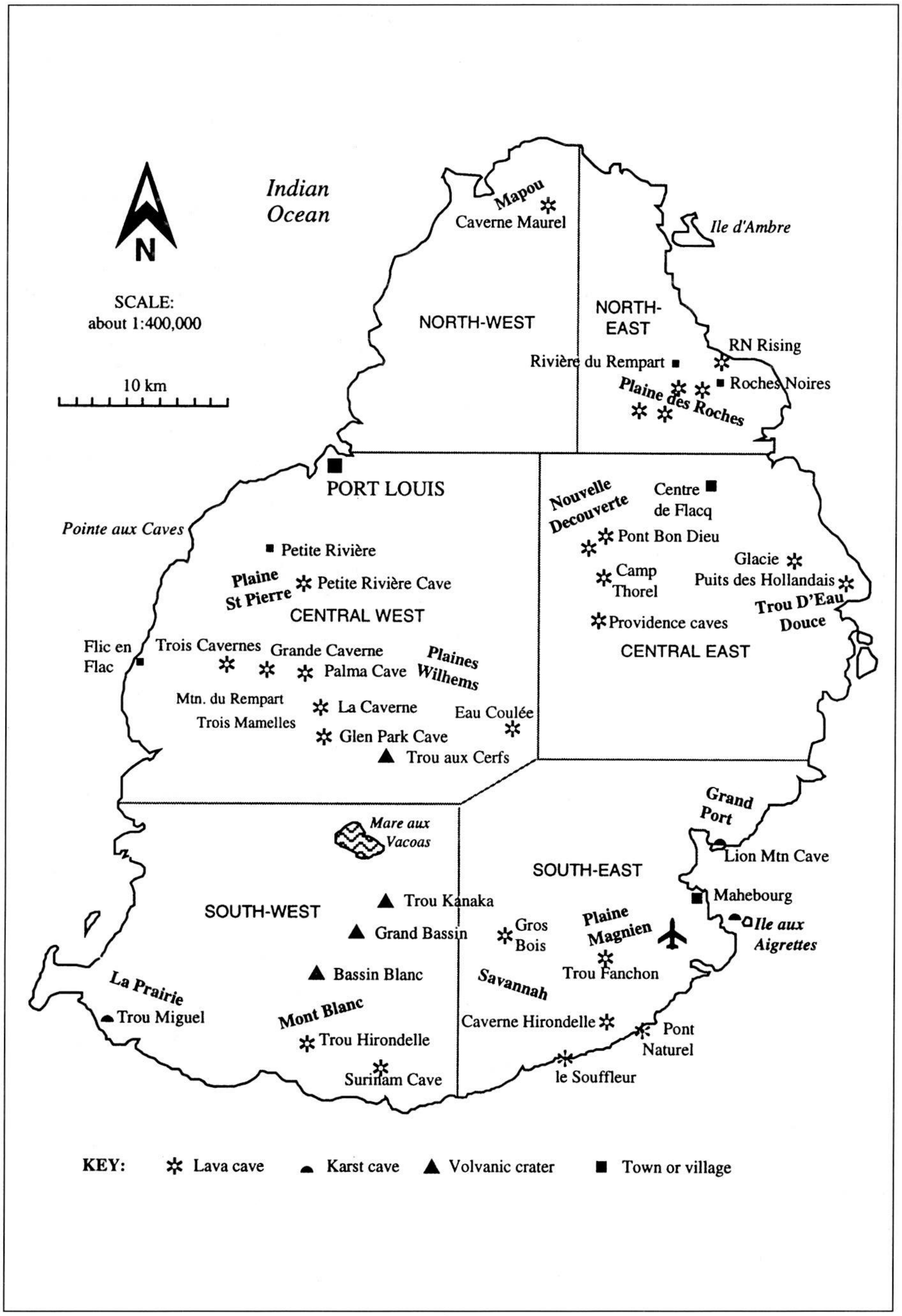

Fig. 1 - Location of the principle caves of the main island of Mauritius showing unofficial cave areas and region.

the whole system rises at an inlet on the coast. The rising was noted by CLARK (1859) and again by HAIG (1895) who suggested that the inlet was itself a collapsed cave.

Further south on the east coast, near Trou D'Eau Douce, lies the interesting Puits des Hollandais ('Dutch Well'), a water filled circular hole over 10 m in diameter and around 28 m deep. The hole opens out with increasing depth attaining a diameter of over 40 m at the bottom (MIDDLETON, 1996a).

Inland from Plaine des Roches, but probably derived from lava from the same source, lie the 35 m wide Pont Bon Dieu and the nearby colourful Pont Bon Dieu Jardin Cave which approaches 400 m in length. Both are biologically significant and the main arch has been provided with improved tourist access. In the same vicinity lies Camp Thorel Cave, the longest lava cave (687 m) and the most complex, with up to five parallel passages (BILLON *et al.* 1991).

The isolated Petite Rivière Cave on Plaine St Pierre is 665 m long (BILLON *et al.* 1991; MIDDLETON 1994a) and was the first to be documented, having been mentioned in a letter written by Bernardin de Saint-Pierre in 1769 and published in 1773 (MIDDLETON, 1995, 1996c). Saint-Pierre included a table setting out the lengths, width and heights of each section of the cave prepared by one Marquis d'Albergati in 1769. These details would have been sufficient to draw up a plan of the cave but unfortunately there is no evidence that this was done.

Petite Rivière Cave is also the Mauritian cave most frequently referred to in the literature, notably by GRANT (1801), BAILLY (1802, quoted by MILBERT 1812), PIKE (1873) and HAIG (1895). It also has the distinction of being the first Mauritian cave to feature in a published illustration (Fig. 2). Although the correspondence with reality is slight, there can be little doubt that de Sainson's drawing of 1828, published in D'URVILLE (1830) is meant to be the Petite Rivière Cave.

South of Petite Rivière on Plaine St Pierre lie the Trois Cavernes, caves of considerable historical interest because FLINDERS (1814) recorded that the largest was used as a refuge by escaped slaves in the 1770s, over fifty having been caught there on one occasion by police. He recorded that "little oblong enclosures, formed with small stones by the sides of the cavern, once the sleeping places of the wretches, also [still] existed, nearly in the state they had been left" (FLINDERS 1814). MIDDLETON (1995, 1996c) believes some of these stone arrangements persist to this day. Nearby, at Xavier on the Black River road, in January 1997, a bulldozer driver broke into a lava 'blister' or hol-

Fig. 2 - "Une Grotte du quartier de la grande rivière (Ile Maurice)" by de Sainson - first published illustration of a Mauritian Cave.

low tumulus, about 5 m high and 12 m in diameter with a crust about 1.5 m thick. This became an instant, if short-term, tourist attraction.

There are a few caves in the Plaines Wilhems area near the centre of the island, notably Glen Park Cave (440 m) and Palma Cave (210 m) and recently discovered La Marie Cave (195 m). The first frequently contains a significant stream, the second is of considerable biological importance and the third appears to flood completely at times of heavy rain. A cave at La Caverne has clearly been known for a long time as it gave its name to the locality; it was modified with concrete in the past for the storing of cheese and butter.

Of the caves in the south, probably associated with the Bassin Blanc volcano, Trou Hirondelle, 442 m long and containing a significant swiftlet colony, is worthy of mention (MIDDLETON 1994b), as is Surinam Cave which contains the largest known swiftlet colony (650 individuals in August 1996 - Hauchler, pers. comm.) and a unique sudden drop of about 10 m.

CAVE FAUNA

The most obvious element of the cave fauna is the cave swiftlet, *Collocalia francica*. This bird, which navigates underground using audible echolocation 'clicks', nests in suitable caves all over the island and was once very numerous (CHEKE 1987). It is now threatened by sealing of caves and by thefts of its nests, apparently for making 'birds nest soup'. Populations in particular caves have dropped from 'thousands' to rarely more than a hundred. They also occur in Réunion, which is the western limit of the genus, but not on Rodrigues.

Another cave-dwelling vertebrate is the free-tailed bat, *Tadarida acetabulosus*. Very large colonies occur in two caves in the Plaine des Roches cave area but elsewhere colonies seldom number 2,000. A second species, the tomb bat, *Taphozous mauritianus*, is not known to inhabit Mauritian caves. Neither species occurs in Rodrigues but both are found in Madagascar and Africa.

Egg scars on the roofs of caves at Roches Noires and Plaine St Pierre indicate that these provided suitable sites for Gunthers gecko, *Phelsuma guentheri*, to attach its eggs. These are presumed to be very old as the species has been extinct on the mainland for about 200 years.

The shells of many species of land snails are regularly found at cave entrances and under daylight holes. Subfossil shells of *Tropidophora carinata* (extinct since the 1880s) are common in at least two caves at Plaine des Roches and Pont Bon Dieu. The fact that some still had their opercula in place indicates they died in situ and were not washed into the cave (O. Griffiths, pers. comm.).

Little has been published on the invertebrate fauna of Mauritian caves, but thanks to STRINATI (in press), Mauritius will soon be included in *Encyclopaedia Biospeologica II*. Strinati has collected at least two new species, an endemic thysanuran (MENDES 1996) and an amphipod (Stock 1997).

THREATS TO THE CAVES

Most Mauritian caves have been damaged or are under some form of threat. An unknown number have had their entrances filled in the development of sugarcane plantations. This practice still continues, as does the widespread dumping of industrial and household waste into caves. At Palma a cave has been sealed by the construction of an underground temple.

Although water from caves is sometimes used for irrigation and domestic purposes, there are places where domestic waste, including sewage, discharges directly into the ground. There appears to be no realisation that the aquifer is at a shallow depth and that very limited purification takes place where there is conduit flow.

It is not unusual for local youths to burn tyres in the lava tube caves of Mauritius, with disastrous results. The worst case is at Caverne Maurel where most of the cave's surface is covered with a deposit of carbon. In at least one cave "black magic" is still being practiced; in the process material is burned on a stone "altar".

The numbers of cave swiftlets have declined steadily over the years and their nests are still taken indiscriminately despite the fact that this is illegal. Recent reports (Hauchler, pers. comm.) indicate this practice may be declining.

The only lava caves with any measure of protection are:

Pont Bon Dieu where the Ministry of Environment has built a fence to prevent rubbish dumping and local youth groups have tidied the access pit;

Palma Cave where the Ministry has, with the concurrence of the owner, built a fence around the entrance to try to prevent removal of swiftlet nests (unfortunately the fence has been cut and the padlock of the gate broken open); and

Petite Rivière Cave where the Medine Sugar estate has built a substantial grille across the entrance to try to protect the swiftlets (unfortunately the gate, which was regularly broken open, was demolished in August 1996 with explosive).

Appreciation of the country's cave resources is coming only slowly and belatedly to Mauritius. It now seems likely that a project to fully document, assess and conserve at least a representative sample of Mauritian caves will be undertaken.

ACKNOWLEDGMENTS

Dr Trevor Shaw provided many of the historical references; Clement Moutou, Jörg Hauchler, Mario Allet and Paul Moolee made invaluable contributions to the field work; Owen Griffiths and Pierre Strinati contributed the de Sainson illustration and biological details; Carl Jones advised in relation to vertebrates; thanks to Prem Saddul for geological and geomorphological details and for constructive criticism; thanks to Jörg Hauchler for constructive criticism and updating; Yousoof Mungroo, Director of the National Parks & Conservation Service, made much of the work possible.

REFERENCES

ANTOINE, R. 1983 La derniere coulée de laves à l'île Maurice. Revue Agricole et Sucriere, 62(2):91-92

BILLON, F., P. CHOJNACKI, C. BILLON, AND G. ROUSSEAU. 1991. Explorations souterraines à l'île Maurice Spéléo-Club Nivernibou: Decize, France 46 pp.

CHEKE, A.S. 1987 The ecology of the smaller land-birds of Mauritius [in] Diamond, A.W. (Ed.) Studies of Mascarene island birds Cambridge Univ. Press: UK pp. 151-207

CLARK, G. 1859 A ramble round Mauritius with some excursions to the interior of that island ... [in] Palmer & Bradshaw The Mauritius register: historical, official and commercial pp. i-cxxxii Port Louis: L. Channell. Reprinted in La Revue Agricole, 24(1):34-51; (2):96-114 (1945)

D'URVILLE, J.S.C. DUMONT, LE COMTE 1830 Voyage de la corvette l'Astrolabe. Exécuté par ordre du Roi, pendant les années 1826-29 sous le commandement de M. J. Dumont D'Urville. J. Tastu: Paris. "Atlas", vol. 2, pl. 243.

FLINDERS, M. 1814 A voyage to Terra Australis undertaken for the purpose of completing the discovery of that vast country G. & A. Nicol: London 2 vols.

GRANT, C. 1801. The history of Mauritius or the Isle of France and the neighbouring islands ... composed principally from the papers and memoirs of Baron Grant, ... by his son W. Bulmer & Co.: London

HAIG, H. DE HAGA 1895 Physical features and geology of Mauritius. Quart. J. Geol. Soc. London, 51(Aug. 1895):463-471.

MENDES, L.F. 1996 Further data on the Nicolettidae (Zygentoma), with a description of a new species from Mauritius. Revue Suisse de Zoologie, 103(3):749-756.

MIDDLETON, G. 1994a Rambles under Mauritius #1 - Petite Rivière. J. Syd. Speleol. Soc., 38(8):131-133.

MIDDLETON, G. 1994b Rambles under Mauritius #2 - Chemin Grenier. J. Syd. Speleol. Soc., 38(9):149-150.

MIDDLETON, G. 1995 Early accounts of caves in Mauritius. (Presented at Second Australian Seminar on Spelean History, Sydney, July 1994) Helictite, 33(1):5-18.

MIDDLETON, G. 1996a Rambles under Mauritius #6 - Puits des Hollandais. J. Syd. Speleol. Soc., 40(1):3-5.

MIDDLETON, G. 1996b Rambles under Mauritius #7 - Plaine Corail, Rodrigues. J. Syd. Speleol. Soc., 40(6):83-94.

MIDDLETON, G. 1996c Early accounts of caves in Mauritius. Proc. Roy. Soc. Arts & Sci., Mauritius, VI:49-87

MIDDLETON, J. and T. WALTHAM. 1986 The Underground Atlas Robert Hale: London. p. 134

MILBERT, J. 1812 Voyage pittoresque à l'isle-de-France, au Cap de Bonne Espérance et à l'Isle de Ténériffe Nepveu: Paris Vol. 1 pp. 358-360 and Vol. 2 pp. 102-104.

PIKE, N. 1873 Sub-tropical rambles in the land of Aphenapteryx: personal experiences, adventures & wanderings in and around the island of Mauritius Sampson Low, Marston, Low & Searle: London

[SAINT-PIERRE, B. DE] 1773 Voyage à l'Isle de France, à l'Isle de Bourbon, au Cap de Bonne Espérance par un officier du Roi Amsterdam, Vol. 1, pp. 249-254

SADDUL, P. 1995 Mauritius: A Geomorphological Analysis. Mahatma Gandhi Institute: Moka 340 pp.

STOCK, J. H. 1997 A new species of Brevitalitrus (Crustaces, Amphipoda, Talitridae) from Mauritius - first record of the genus from the Indian Ocean. Revue Suisse de Zoologie, 104(1):3-11

STRINATI, P. in press Ile Maurice [in] Encyclopaedia Biospeologica II.

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HOLLOW VOLCANIC TUMULUS CAVES OF KILAUEA CALDERA, HAWAII COUNTY, HAWAII

William R. Halliday *

ABSTRACT

In addition to lava tube caves with commonly noted features, sizable subcrustal spaces of several types exist on the floor of Kilauea Caldera. Most of these are formed by drainage of partially stabilized volcanic structures enlarged or formed by injection of very fluid lava beneath a plastic crust. Most conspicuous are hollow tumuli, possibly first described by Walker in 1991. Walker mapped and described the outer chamber of Tumulus E-1 Cave. Further exploration has revealed that it has a hyperthermic inner room beneath an adjoining tumulus with no connection evident on the surface. Two lengthy, sinuous hollow tumuli also are present in this part of the caldera. These findings support Walker's conclusions that hollow tumuli provide valuable insights into tumulus-forming mechanisms, and provide information about the processes of emplacement of paboehoe sheet flows.

Keywords: geomorphology, lava caves, speleogenesis, Hawaii

INTRODUCTION

In addition to lava tube caves with commonly observed features, sizable caves of several other types exist on the floor of Kilauea Caldera. Most of these were formed by drainage of partially stabilized subcrustal structures enlarged or formed by injection of very fluid lava beneath a plastic crust. Most conspicuous of these are hollow tumuli, of which at least two distinct types are present. In this paper I follow the usage of Walker (1991), thus differentiating tumuli from lava rises. Caves of the latter show significant differences from those discussed here, and will be the subject of a later paper.

Fig. 1. Walker's map Tumulus E-1 and tumulus study area. a) Plan view of the cavern in drained-out tumulus E-1; the contours of cavern roof heights are based on 320 measurements. b) Profile across tumulus E-1 on the same scale; c) Sketch map of part of Kilauea caldera floor showing the locations of E-1 and other measured tumuli and lava rises in relation to the well-known Uwekahuna "laccolith" on Uwekahuna Bluff.

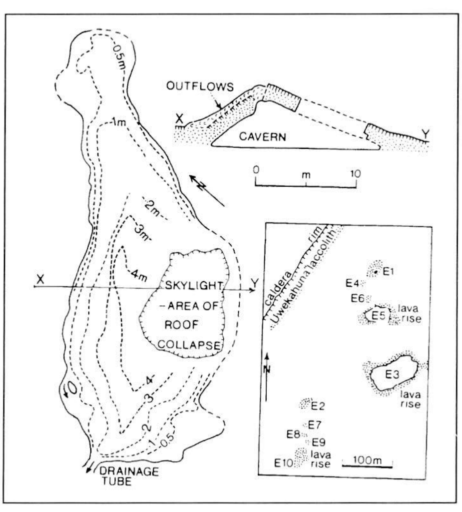

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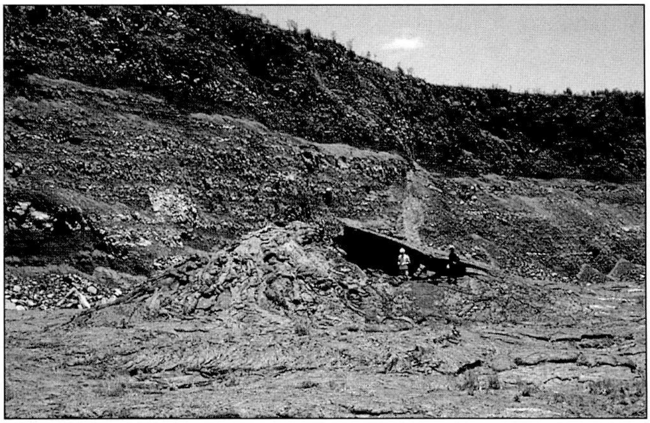
Fig. 2. Tumulus E-1 from caldera floor. Photo by the author.



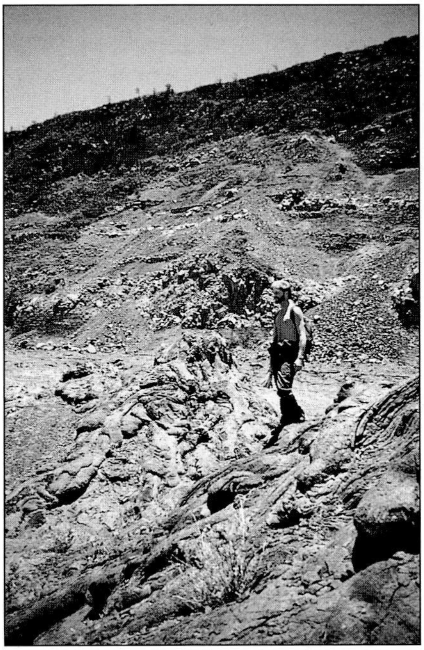


Fig. 3. Tumulus E-4 from Tumulus E-1. Photo by the author.

TYPES OF HOLLOW TUMULI IN KILAUEA CALDERA

In 1991, Walker published details of a hollow tumulus which he designated as Tumulus E-1 (Walker, 1991)(Fig. 1). It now may be considered the prototype of hollow tumuli. He described it as 24 m wide by 5.3 m high, with a cavern 43 m long, up to 28 m wide, and as much as 4.5 m high. He found that it had been pushed up to 5 m above its surroundings (Fig. 2) and that the cave extends a short distance beneath adjacent surfaces. This tumulus has a typical summit cleft, with lava outflow tongues and squeezeups. Its

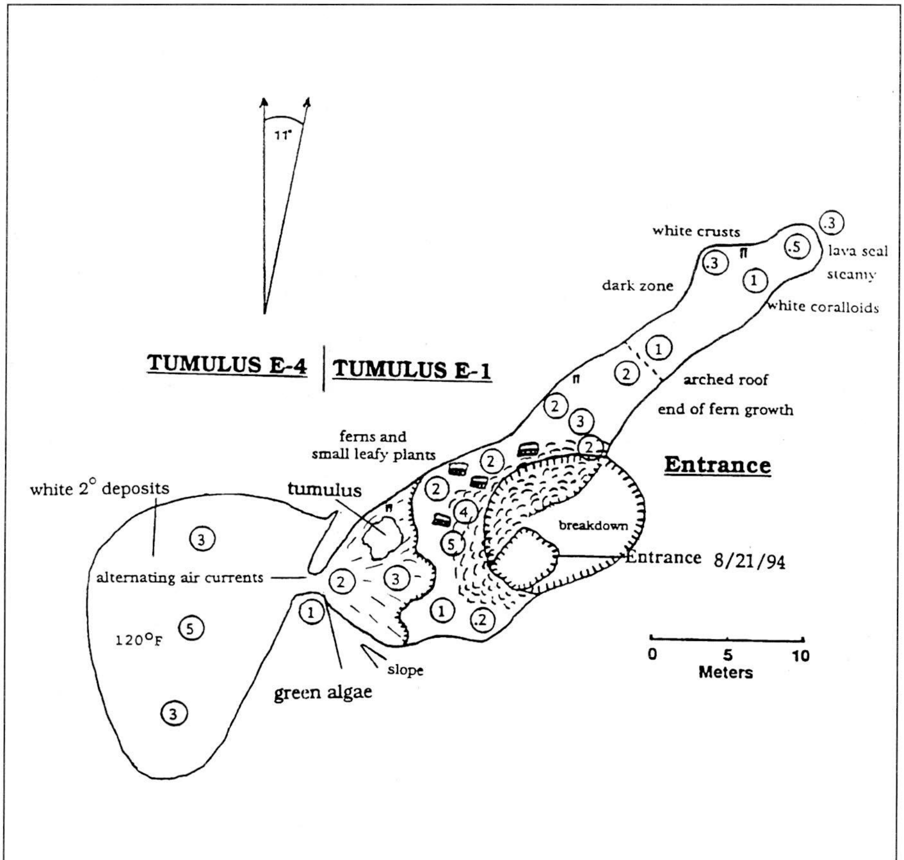


Fig. 4. Map of Tumulus E-1 Cave, Kilauea Crater, Hawaii Volcanoes National Park. Sisteco Compass/cloth tape survey, 21 August 1994 with field revision 1996, Hawaii Speleological Survey.

walls consist of tilted crusted plates lo-cally overrun by pahoehoe lava which welled up and out of the cleft. Innumerable tumuli of this type exist in the caldera, but to date, this is one of only two found to be hollow in the extensive 1919 Postal Rift lava flow. A smaller example with a simpler structure ("Standing Room Cave") is located about 0.8 km farther northeast in this flow. Another small example is known in a 1885 flow, and still another exists outside the caldera, 2 km to the northeast (Halliday, 1991, 1994).

Walker enumerated several other tumuli and some lava rises near Tumulus E-1. One of these (Tumulus E-4) is about 20 m southwest of Tumulus E-1. It is smaller and much more conical than Tumulus E-1 and its summit crack is not conspicuous (Fig. 3). Its general appearance is that of a wide-based driblet spire. Tumuli of this type are less common in Kilauea Caldera than the E-1 type and Walker apparently was unaware that any are hollow. Despite their proximity, there is no surface evidence of any connection or relationship between Tumuli E-1 and E-4. Only through subsurface exploration in a hyperthermal environment was it determined that Tumulus E-4 also is hollow, and that its chamber is connected to that of Tumulus E-1, forming a single cave (Fig. 4).

Fig. 5. View from caldera rim showing Almost Too Hot Cave tumulus and its lava rise. Sleeping Ohia and Sleeping's Sister caves' tumuli also are visible. Photo by the author.

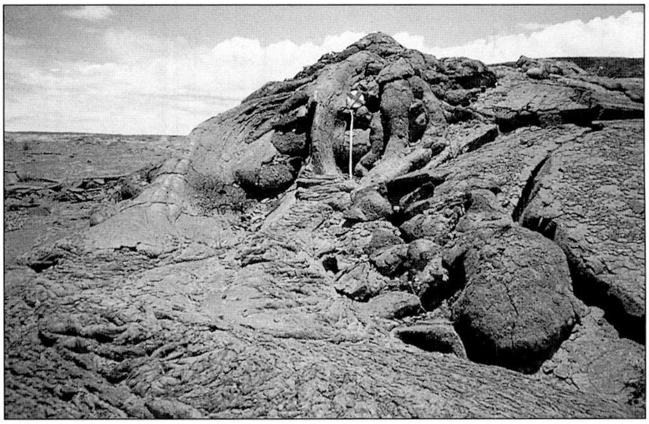


Fig. 6. Downslope end of Almost Too Hot Cave tumulus, showing extruded lava. Photo by the author.

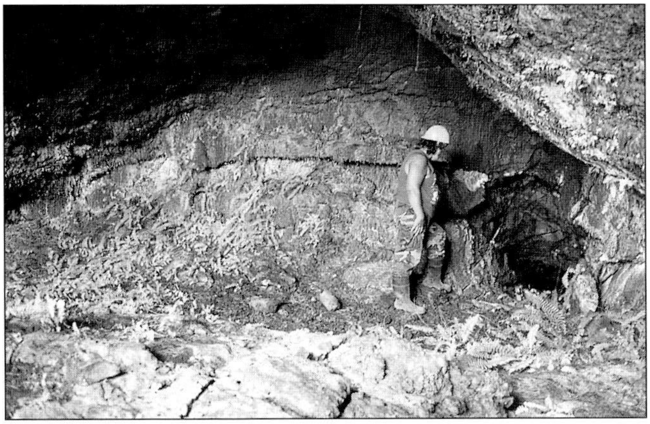


Fig. 7. Orifice between E-1 and E-4 chambers, showing scoured walls at lower end of E-1 chamber. Photo by the author.

Two examples of a radically different type of hollow tumulus now are known about 0.5 km east of Tumulus E-1. These are lengthy sinuous tubular structures partially raised above the caldera floor. Axial clefts confirm them as tumuli. The tubular caves within them lack the rheogenic features of classical lava tube conduits (e.g., flow lines, downcut trenches, etc.) From the rim of the caldera, the tumulus containing Almost Too Hot Cave is easily seen to have been a pressurized drain tube for an unnamed quadrilateral lava rise with a small central depression (Fig. 5). The upper end of this cave is within one boundary ridge of the lava rise, and the tumulus itself is a lateral extension from the boundary ridge. It rises two to three meters above the surrounding lava. Its lower end is quite abrupt, with festoons of pahoehoe outflows (Fig. 6).

The other sinuous tumulus (which contains Sleeping's Sister Cave) has the appearance of having "appeared out of nowhere". Its lower end is much like that of the Almost Too Hot Cave tumulus, but its upper end consists only of small lava folds not much larger than ordinary pahoehoe ropes. Downslope, its height and width increase rapidly as it seemingly curls partway around the Sleeping Ohia complex described below. Its long downslope section closely resembles that of the Almost Too Hot Cave tumulus, and it, too, has an axial cleft. While it also clearly was the result of injection of very fluid lava beneath a plastic crust, the source of the injected lava is not apparent and presumably was well below the surface of the flow. Presumably solid tumuli of this type have been reported in Kalapana flows on the seaward flank of this volcano (Kauahikaua et al, 1990) and seemingly innumerable ridges of similar appearance are present on the caldera floor. At this time, no others are known to be hollow. Too Hot Cave may be within another example, but has not been explored due to a minimum entrance temperature of 62.5°C.

FEATURES OF THE CAVES

The most important feature of the Tumulus E-1 chamber is the orifice Walker (1991) termed a "drain tube" (Fig. 1). It is 2 to 3 m long and ca. $1^1/_2$ m in diameter, opening widely at both ends. It slopes downward from the Tumulus E-1 chamber and opens into the similar chamber beneath and within Tumulus E-4. Air temperature within the latter is relatively high under optimum conditions: up to 56°C. Dense steam hinders observations and photographic documentation but the presence of fumarolic cracks and white mineral encrustations are seen easily. Its walls were not closely inspected but appeared to be relatively featureless. At times of less than optimum conditions, a dense plume of steam emerges from this inner chamber and rises 10 or more meters above the entrance of Tumulus E-1. The surfaces of the connecting orifice are dark and polished in appearance (Fig. 7). It appears to be a meltdown opening through the walls of adjacent sheet flow lobe chambers inflated above the surface of the surrounding lava. Commonly the air temperature is about 38°C at its ceiling, with wisps of steam drifting in and out. In the E-1 chamber, most of the walls have a thin accretionary lining. Along the hanging wall opposite the entrance are numerous vermiform lava stalactites. Its lower end has been scoured of the accretionary lining, revealing dense bedded lava in the wall (Fig. 7). In this area, the cave floor slopes to the orifice, with sagged fragments of lava crust "welded" to it. A well-defined ledge about $^1/_2$ m high is present where a considerable body of still-fluid lava pulled away from more solidified lava which forms a level floor elsewhere in this chamber. Fumarolic cracks with white mineral deposits are less prominent than in the E-4 chamber, but occur especially in its low northern extension.

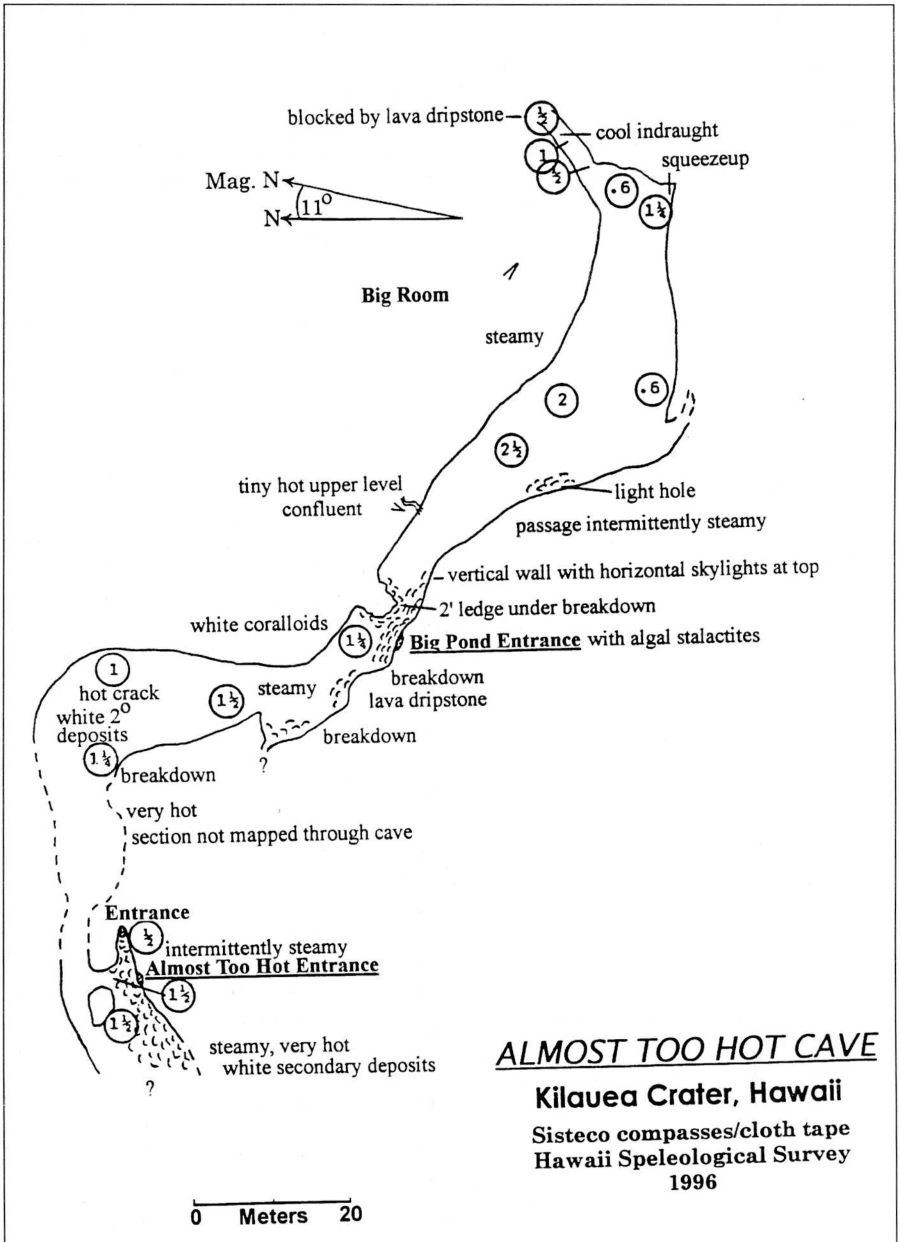


Fig. 8. Map of Almost Too Hot Cave, Kilauea Crater, Hawaii - Sisteco Compass/cloth tape, Hawaii.

Within the Almost Too Hot Cave tumulus (Fig. 8), the air temperature upslope from the main entrance usually is greater than 56°C. During one visit, the maximum in this main entrance chamber was only 47.8°C and a crawlway extending 23.7 m to a smaller entrance was observed. It is not shown on the map because a localized area of air temperature of 51°C halted exploration. Mapped length of the remainder of the cave is about 150 m. In the Big Room near its east (lower) end, its width is 20 meters. The remainder is narrower and lower. The Big Room is walking passage; upslope from it the ceiling height is 1 to 1½ meters. In the Big Room the passage cross section is a flattened cylinder; upslope it is narrower. An unusual little infeeder opens on a ledge on the north wall of the Big Room; its air temperature is greater than 56°C. The interior of this cave lacks flow lines and other common rheogenic features of lava tube caves. Patches of small vermiform lava stalactites and other lava dripstone are present. Much of the ceiling is vesicular. Especially when hot and steamy, transient white fumarolic mineral deposits are extensive in the upslope end of the cave, and elsewhere adjacent to hot cracks.

The rounded, lava-festooned downslope end of the tumulus (Fig. 6) corresponds with the downslope end of the Big Room. As shown on Fig. 10 a low terminal crawlway blocked by lava dripstone continues an unknown distance in the general direction of Sleeping's Sister Cave. On the surface at the approximate location of this terminal crawlway, a narrow width of pahoehoe has a pattern of small, closely spaced ripples extending in the same general direction.

Just upslope from the Big Room, the cave's south wall is vertical rather than curved as elsewhere in the cave. Nearby is a small cross-corridor ledge almost hidden by local breakdown. These features suggest block movement during cooling.

While the Big Room often can be visited in comfort, on other occasions dense plumes of hot steam arise from one or both principal entrances of the cave and it is much too hot to enter. The direction of wind in the caldera clearly controls ambient air temperature and steam output.

In Sleeping's Sister Cave, the maximum air temperature usually is 38°C or less, and the entire cave usually can he examined. On occasion, a reciprocal relationship has been observed between steam concentrations in these caves.

In general, Sleeping's Sister Cave is a smaller version of Almost Too Hot Cave. Its length is about 53 meters and its maximum width, 12 m (Fig. 9). Only in parts of its Big Room, downslope from its single entrance, is it possible to stand erect comfortably (Fig. 10). Unlike Almost Too Hot Cave, the axial cleft of its tumulus penetrates the ceiling of its principal section. This is the result of breakdown after cooling and the ceilings of both caves lack manifestations of the lava outflows from their axial clefts. Less lava dripstone is present than in Almost Too Hot Cave, and its walls otherwise are similarly featureless. Fumarolic cracks with white aerosolic minerals are present locally. The cave's tapering upper end permits crawling almost to the point of disappearance of the tumulus on the surface. When the cave was mapped, a cool inward breeze was present in this area.

RELATED CAVES

Hawaii Speleological Survey teams have found other caves within and beneath other mounds and ridges of the 1919 Postal Rift lava flow. To date, however, the surface features of these structures are much less clearcut than the examples cited above, and their caves are much less closely associated with surface features. Sleeping Ohia Cave

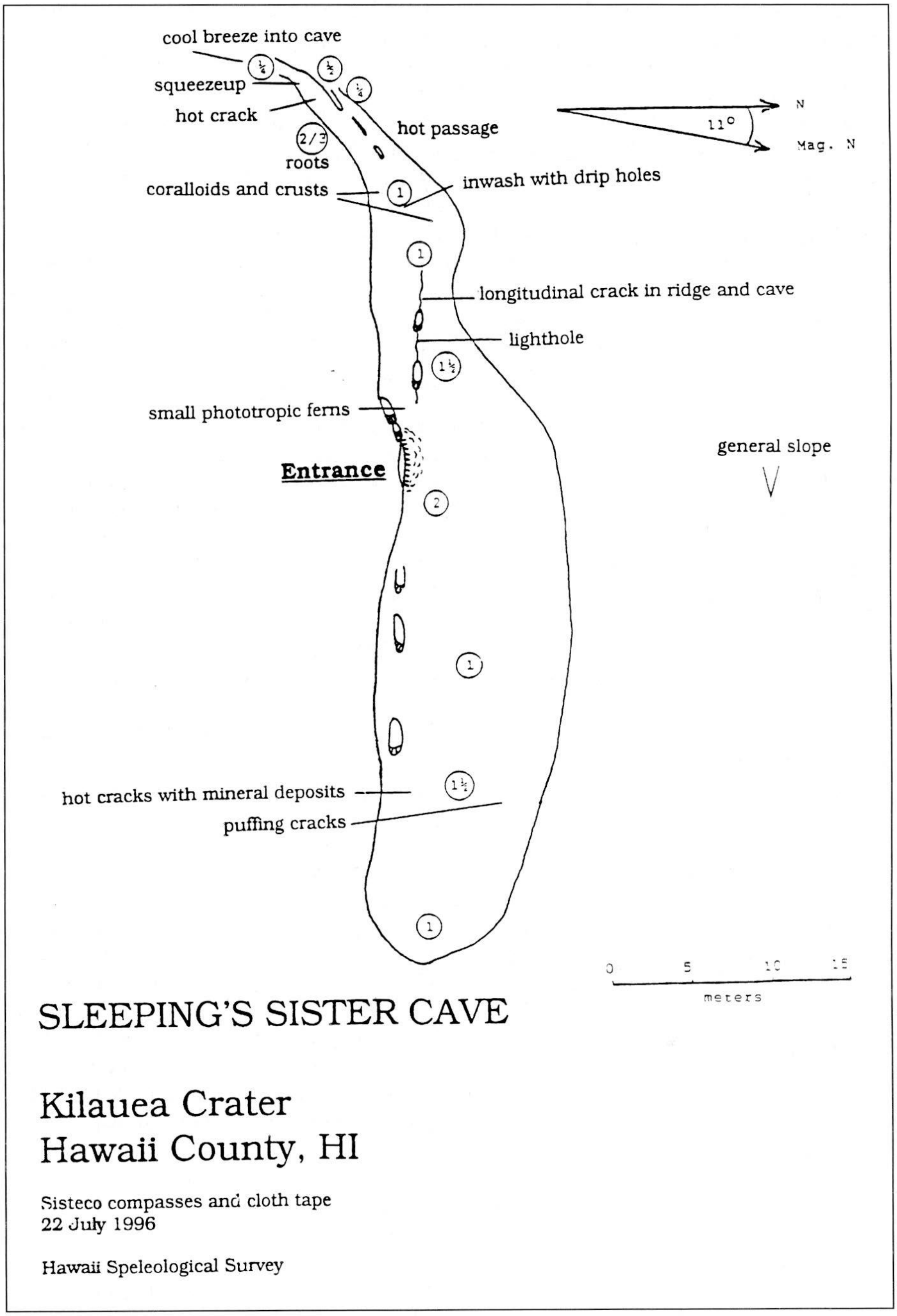


Fig. 9. Map of Sleeping's Sister Cave, Kilauea Crater, Hawaii - Sisteco Compasses and cloth tape, 22 July 1996, Hawaii.

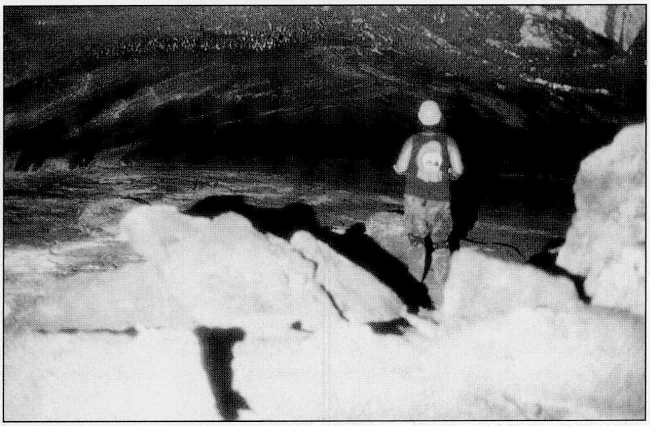


Fig. 10. Big Room of Sleeping's Sister Cave. Photo by the author.

is an example (Fig. 11). It is adjacent to Sleeping's Sister and Almost Too Hot Caves. Its entrance and part of its main room are within a small tumulus with one side collapsed, dividing its main room (Fig. 11). Much of the cave, however, is beyond the limits of the tumulus, and beneath ill-defined piles of breakout flows piled up irregularly. Within the tumulus section, part of the floor slumped into a drain tube extending downslope from the tumulus, without surface manifestation. Although the entrance of this cave is only 20 m from that of Sleeping's Sister Cave, and parts of the caves are much closer together, they are independent entities.

Some other caves in small lava mounds of this flow are merely drained lava breakouts with a simple remnant cavity. The origin of others is not well understood and requires additional study.

CONCLUSIONS

The additional findings reported here support Walker's assertion that hollow tumuli provide valuable insights into tumulus-forming mechanisms (Walker, 1991). They also support conclusions of Hon et al (1994) about the process of emplacement of paboehoe sheet flows, especially relating to drainage of some interconnected flow lobes. The long, sinuous type of hollow tumulus is believed to be a previously undescribed form. No conclusions are yet possible about any relationships which may exist between its caves and lava tube conduits.

ACKNOWLEDGMENTS

These studies were performed under National Park Service permit, and special thanks are due to Jim Martin and Bobby Camara for facilitating them. Jim Martin brought Tumulus E-1 Cave to the attention of the Hawaii Speleological Survey. Field interpretations by D.A. Swanson and Ken Hon contributed greatly to understanding of some of these features. The field assistance of many members and cooperators of the Hawaii Speleological Survey is hereby acknowledged, especially the contributions of Olé Fulks who discovered Sleeping's Sister Cave and participated in the hyperthermal traverse between the principal entrances of Almost Too Hot Cave. My thanks to all.

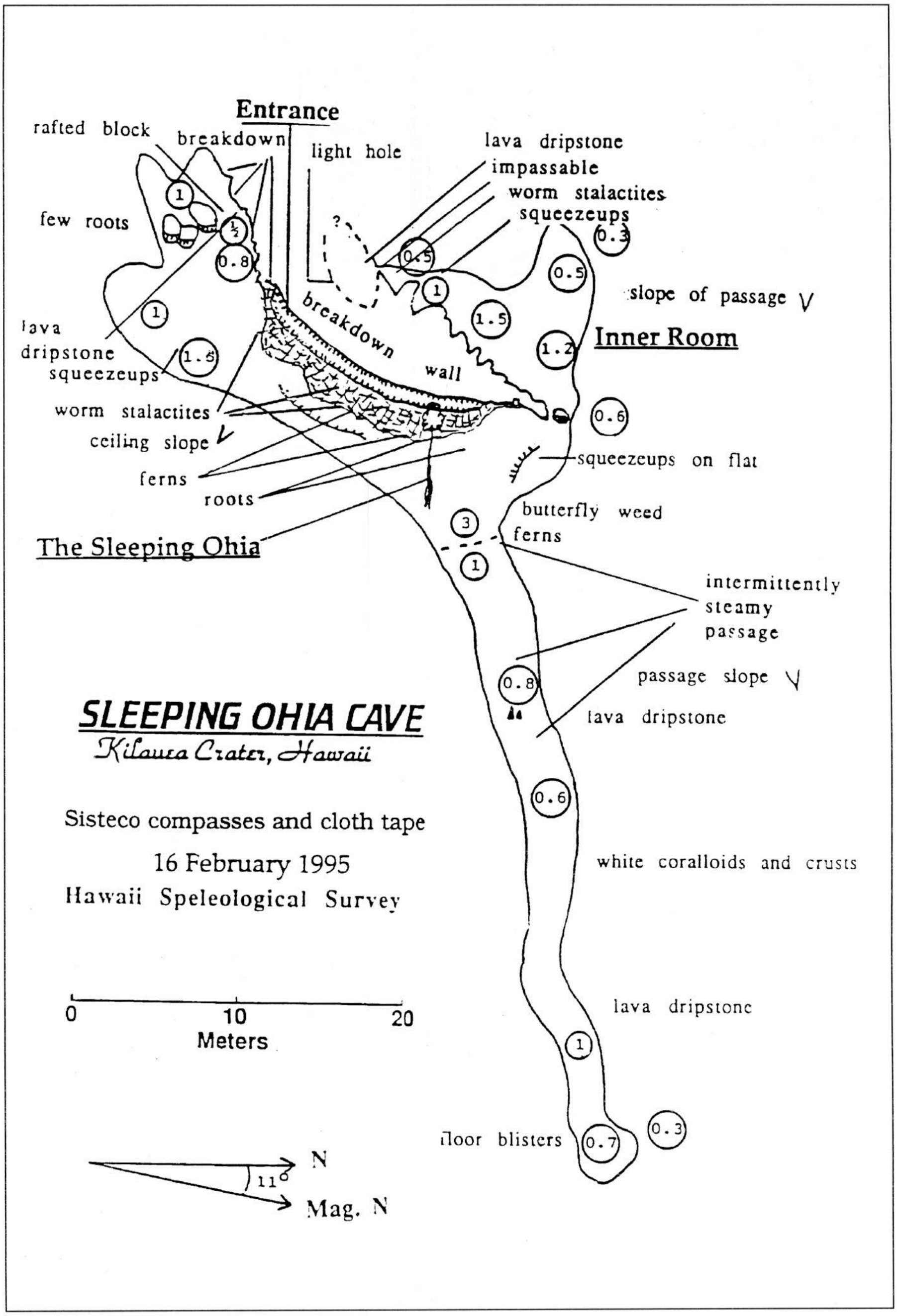


Fig. 11. Map of Sleeping Ohia Cave, Kilauea Crater, Hawaii - Sisteco Compasses and cloth tape, 16 February 1995, Hawaii.

REFERENCES

HALLIDAY, W.R. 1991. Introduction to Hawaiian Caves: field guide for the 6th International Symposium on Vulcanospeleology, Hilo, Hawaii, August 1991. 46 p.

HALLIDAY, W.R. 1994. Caves of Kilauea Caldera: cave re-source inventory and management recommendations. Report # 94-05, Hawaii Speleological Survey of the National Speleological Society, November 1994. 26 p. + maps.

HALLIDAY, W.R. 1997. Volunteers needed for Hawaii project. N.S.S. NEWS, vol., 53, no. 6, June, p. 168.

HON, K. ET AL. 1994. Emplacement and inflation of pahoehoe sheet flows: observations and measurements of active lava flow on Kilauea Volcano, Hawaii. Geol. Soc. Amer. Bulletin, vol. 106, p. 351, March.

KAUAHIKAUA, J. ET AL. 1990. Observations of lava tube formation in Kalapana, Hawaii. EOS, vol. 71, p. 1711.

WALKER, G.P.L. 1991. Structure, and origin by injection of lava under surface crust, of tumuli, "lava rises", "lava rise pits" and "lava inflation clefts" in Hawaii. Bull. Volcanol., vol. 52, p. 546.

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SHEET FLOW CAVES OF KILAUEA CALDERA, HAWAII COUNTY, HAWAII

William R. Halliday *

ABSTRACT

Terminal lobes of sheet flows of pahoehoe lava sometimes form three-dimensional nests, initially separated by partitions consisting of accreted "skins" of each lobe. Melting breaks down these partitions, forming a uniform flow unit. In Kilauea Caldera we have found and mapped sizable drained cavities in low-slope sheet flows. Their general pattern includes three-dimensional nests, with partially melted septa evident in some examples. Christmas Cave is the most extensive found to date, with 632 meters surveyed on two levels. It is located at the lower end of an inflated sheet flow tongue which underwent local deflation as a result of drainage through the cave after its parameters were partially fixed. Small conduit remnants persist in its boundary ridges. The major part of the cave consists of wide, low nested chambers. Meltdown of such partitions is one of the few emplacement mechanisms of thermal erosion which may not involve any mechanical element. Additional caves in this caldera are being identified and studied.

Keywords: geomorphology, volcanic caves, speleogenesis, Hawaii

INTRODUCTION

The 1990's have been a decade of greatly increased understanding of emplacement of non-channelized pahoehoe basalt flows and the caves within them. Especially important are new concepts of emplacement of sheet flows resulting from studies at the flow front of Kilauea Volcano's current Puu Oo flows (Hon et al, 1994).

In such sheet flows, tube-fed lava advances in sequences rather than uniformly, "with lava constantly being flushed through the flow" (Hon et al, 1991) by hydrostatic pressure. The overall lengthening of such flow fields is a slower process than some have assumed previously. At the flow front, however, lava toes and other small breakouts are emitted quickly and their surfaces chill rapidly, forming "skins" which initially are quite thin but have significant tensile strength. Upstream hydraulic pressure causes especially liquid lava to be injected into flow lobes supplying these breakouts, as elsewhere in the flow field where peripheral resistance is comparatively low. At the flow front, this injection creates one of a stack of semicircular sheets, eventually one to a few meters thick, more or less across the entire flow. Within this stack of lava sheets, rounded injection masses sometimes form well-insulated three dimensional nests of fluid lava (Hon, Ken, personal communication, 1997). Each unit in these nests originally is separated from the others by thin partitions representing the apposed outer surface "skin" of each rounded mass. The tensile strength of these septa ultimately is destroyed by prolonged exposure to the intense heat in the interior of each unit, resulting in coalescence into a continuous liquid lava core beneath a single upper-crustal layer "with complete fluid connection between adjacent lobes" (Hon et al, 1994).

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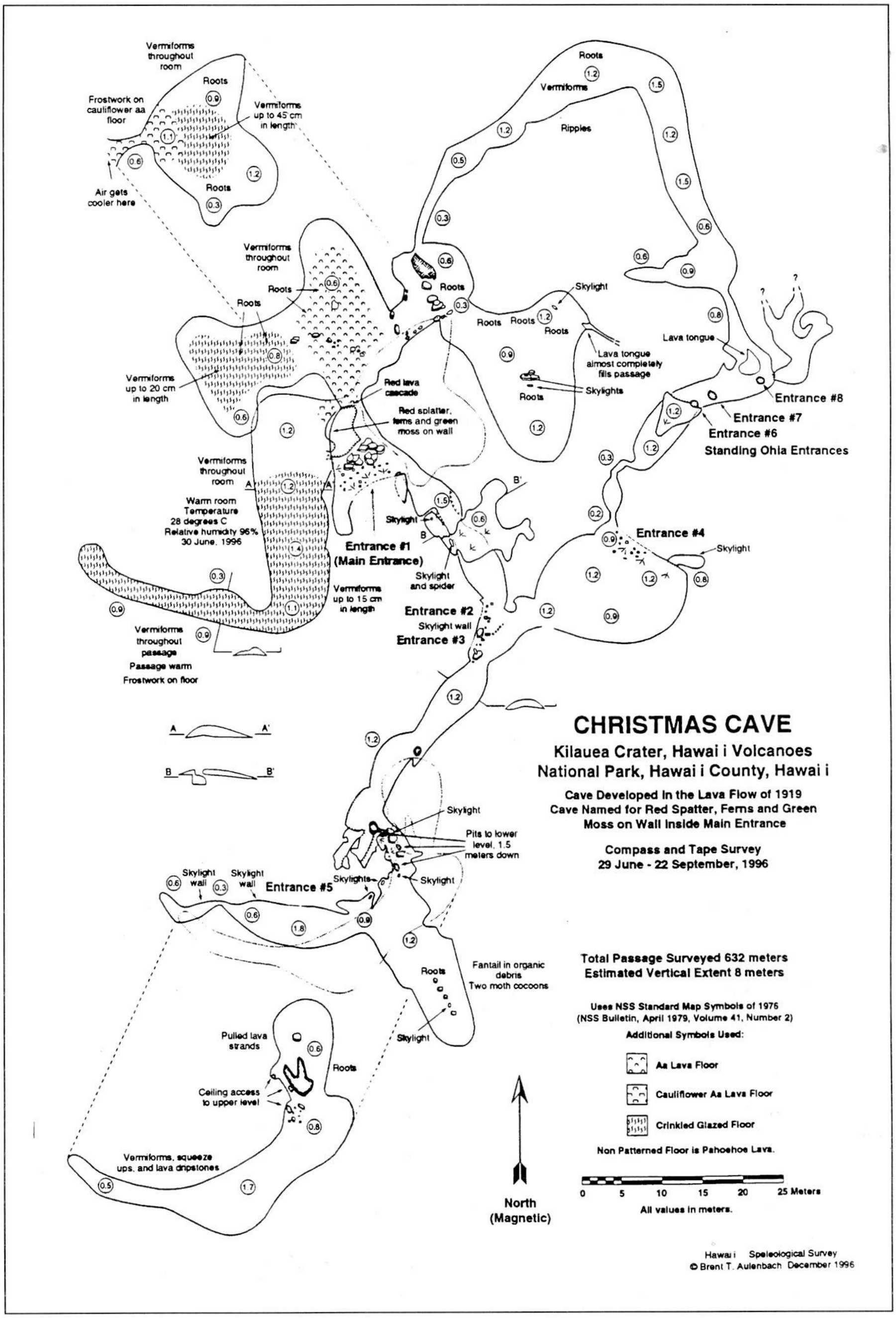

Fig. 1. Map of Christmas Cave, Kilauea Crater, Hawaii Volcanoes National Park, Hawaii County, Hawaii - Cave developed in the Lava Flow of 1919, Cave Named for Red Spatter, Ferns and Green Moss on Wall Inside Main Entrance - Compass and Tape Survey, 29 June - 22 September, 1996.

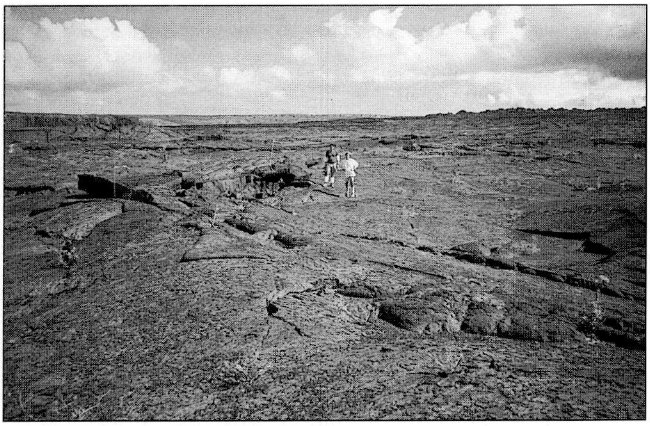

Fig. 2. The sinuous central depression of the deflated Christmas Cave lava tongue, with flagged poles (emplaced from the cave through "light-holes") marking the course of its east boundary ridge.

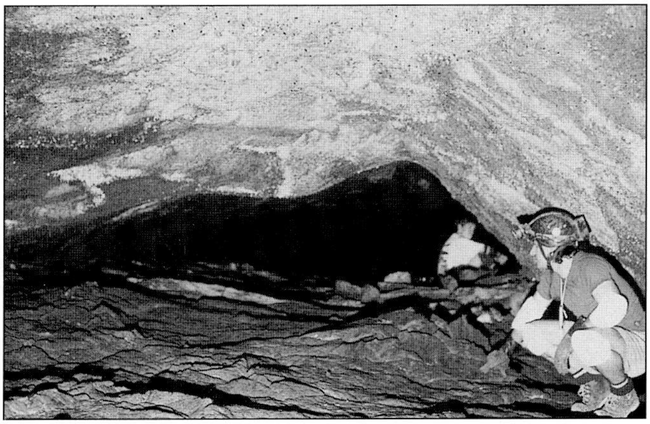

Fig. 3. East boundary ridge passage of Christmas Cave.

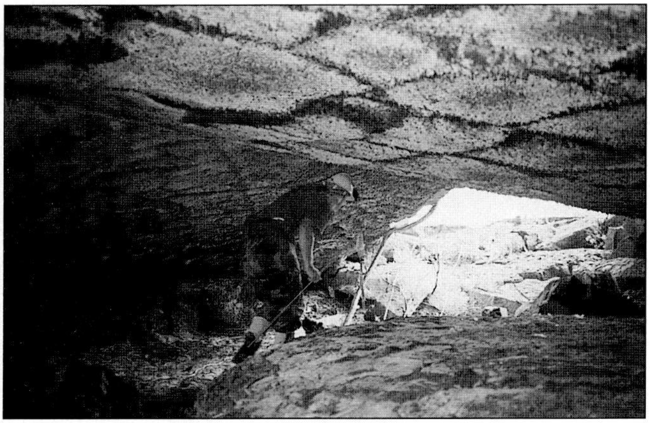

Fig. 4. Flat ceiling at entrance #8 of Christmas Cave.

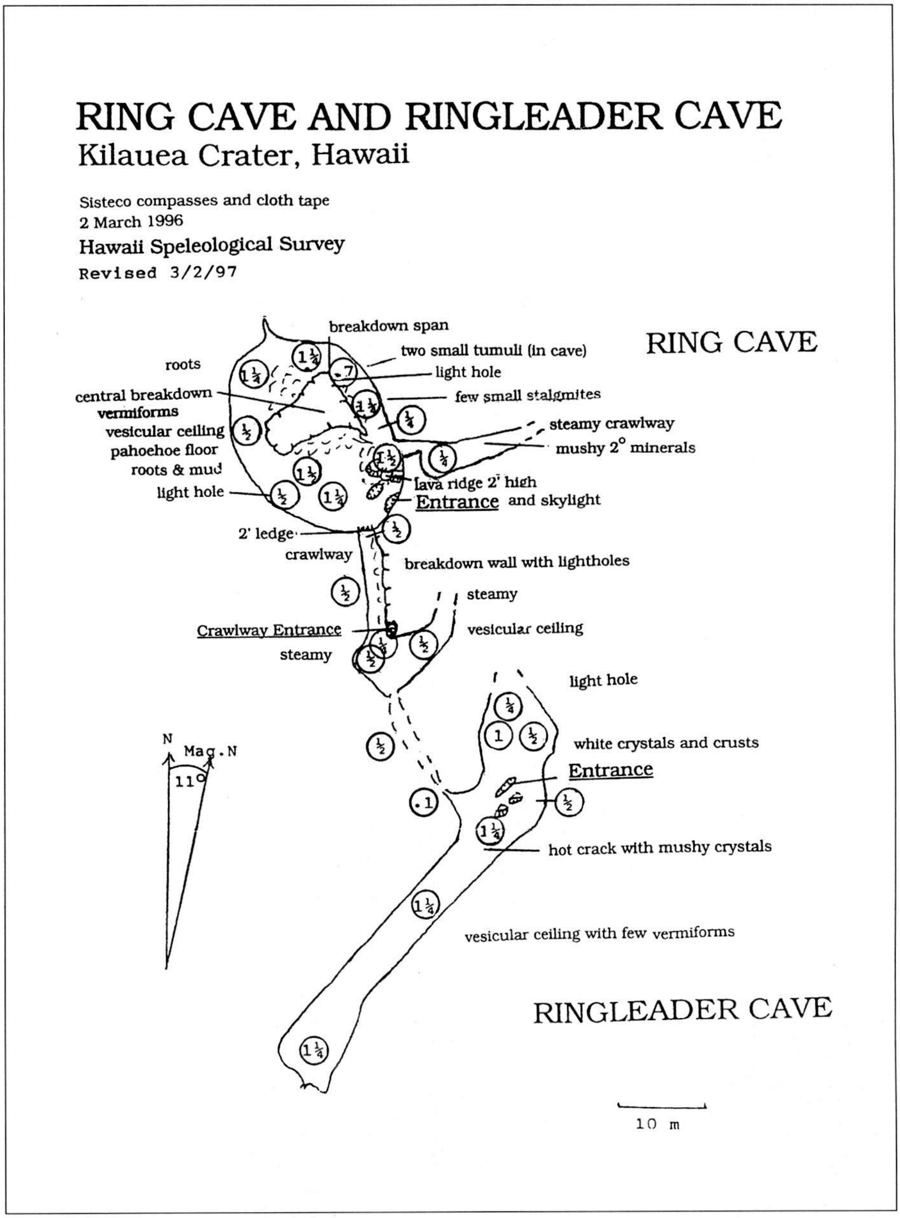

Fig. 5. Map of Ring Cave-Ringleader Cave complex, Kilauea Crater, Hawaii - Sisteco compasses and cloth tape, 2 March 1996, Hawaii.

CAVES FORMED BY DRAINAGE OF INJECTION MASSES

In Kilauea Caldera we have found evidence of drainage of some of these injection masses prior to coalescence, producing interconnected cavernous chambers and passages with partial septa. To date, Christmas Cave is both the largest and most illustrative of these. We have surveyed 632 meters on two levels in this cave (Fig. 1). It is at the lower end of an inflated sheet flow lobe which underwent local deflation as a result of partial drainage after its surface features were partly fixed (Fig. 2). Well-defined boundary ridges remain on both sides of what now is a sinuous central depression terminating at the main entrance of the cave (here the crust was too solidified to sag). Small elongate remnants of the central conduit persist in both boundary ridges; much more extensively within the east ridge (Fig. 3). The remainder of the cave consists of wide, low nested chambers, two drain tubes (Fig. 4), and two additional boundary ridge passages in a lower flow unit presumably emplaced earlier (Fig. 1). Lower level passages exist in two separate sections of the cave. The nested chambers are 1 to 2 m high and up to 20 meters in diameter, on both levels. Remnants of the melted partitions are clearly visible in the cave and on the map.

Some of the drained flow lobe caves of Kilauea Caldera have a more complex origin. The Ring-Ringleader complex (Fig. 5) has three interconnected but dissimilar components. The Ring Cave section is a small drained lava rise or tumulus with central breakdown and an effluent crawlway. The Ringleader Cave section is a simple primitive-appearing tube within a flat-topped lava rise which ends by a gentle slope at the lower end of the cave (Fig. 6). It drained into (and possibly formed) a small adjacent lava tongue at a level 1-2 meters lower than the floor of Ringleader Cave, by way of a small hole which widened progressively downslope. This lava tongue deflated, draining into Ring Cave, $^1/_2$-1 meter still lower. This deflation left intact its upslope boundary ridge which contains a crawlway passage connecting Ring Cave and Ringleader Cave. It appears that these two caves originally were independent bodies of injected lava. The small hole draining Ringleader Cave may have been a hydrostatic breakout, but the widely patent opening between the main room of Ring Cave and the connecting crawlway appears to have been caused by a septum disruption.

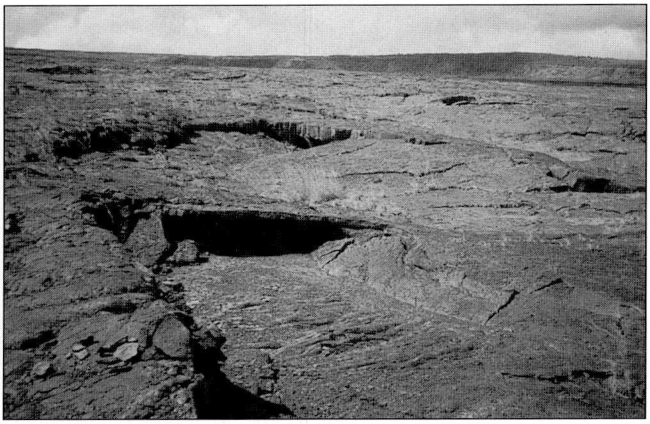

Fig. 6. Looking south from main entrance of Ring Cave to its crawlway entrance (center), drained lava tongue (lower left) and entrance of Ringleader Cave (background).

Meltdown of septa in these sheet flows is one of the very few emplacement mechanisms due to active melting: true thermal erosion which may have had no mechanical component. As more small caves are identified and studied in Kilauea Caldera, it is likely that much more will be learned about these and related processes.

ACKNOWLEDGMENTS

Olé Fulks merits special commendation as the discoverer of Christmas Cave. Ken Hon and Don Swanson independently confirmed the chambers of Christmas Cave as drained flow lobe cavities. Numerous members and cooperators of the Hawaii Grotto and the Hawaii Speleological Survey of the National Speleological Society provided essential field assistance. These studies were performed under permit by the National Park Service, facilitated by Superintendent Jim Martin and Cave Resource Specialist Bobby Camara of Hawaii Volcanoes National Park. My thanks to all.

REFERENCES

HON, KEN ET AL. 1994. Emplacement and inflation of pahoehoe sheet flows: observations and measurements of active lava flows on Kilauea Volcano, Hawaii. Geol. Soc. Amer. Bulletin, vol. 106, p. 351.

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"PIT CRATERS", LAVA TUBES, AND OPEN VERTICAL VOLCANIC CONDUITS IN HAWAII: A PROBLEM IN TERMINOLOGY.

William R. Halliday *

ABSTRACT

Almost from the 1849 publication of the term pit crater, volcanologists have disagreed about the parameters differentiating these features from other vertical volcanic structures. Kaluaiki is a jameo giving entry to Thurston Lava Tube in Hawaii Volcanoes National Park. Long-standing misidentification of it as a pit crater is an example of misunderstandings arising from the lack of a clear definition of pit crater. In general, pit craters are unrelated to lava tube caves genetically, but two special cases are discussed. One probably is genetically related to a rift tube deep below the surface; the other is a complex of a small pit crater with a partial rim of accreted plates plus an ordinary-seeming lava tube cave. The term pit crater should be redefined in such a way that it excludes collapses or subsidences related to ordinary superficial lava tubes and open vertical volcanic conduits. Otherwise, a non-definition like that currently listed for agglomerate may be appropriate.

Keywords: vulcanospeleology, volcanic caves, terminology, Hawaii

INTRODUCTION

The show cave section of Thurston Lava Tube in Hawaii Volcanoes National Park is the world's most visited lava tube cave. Almost from the time of its discovery, volcanological and popular accounts have described it as entered through an opening in the side wall of a pit crater named Kaluaiki - "the little crater" - or considered one of two supposedly round "Twin Craters" (Fig. 1). Actually Kaluaiki is a sinuous two-level collapse jameo with accreted lava walls (Halliday, 1993); an upslope trench section of Thurston Lava Tube per se. An additional cavernous part of the lava tube (in Mauka Thurston Cave) lies beneath the shallow upslope section of this trench, at the end opposite the entrance of the show cave.

Kaluaiki meets the definition of jameo in the 1997 4th Edition of Glossary of Geology (Jackson, ed., 1997) and is genetically similar to such type examples as Jameo de la Gente on Lanzarote Island, Spain (Fig. 2). Some influential publications and individuals, however, continue to call Kaluaiki a pit crater, and in that new 4th Edition of Glossary of Geology the term pit crater is defined vaguely:

Pit crater: A sink [volc.] or a small caldera
Sink [volc.]: A circular or ellipsoidal depression on the flank of or near a volcano, formed by collapse. It has no lava flows or rim surrounding it.

But whether it is round or sinuous, to term a jameo a pit crater inevitably is confusing to persons interested in volcanic speleogenesis or in mechanics of lava flows in general.

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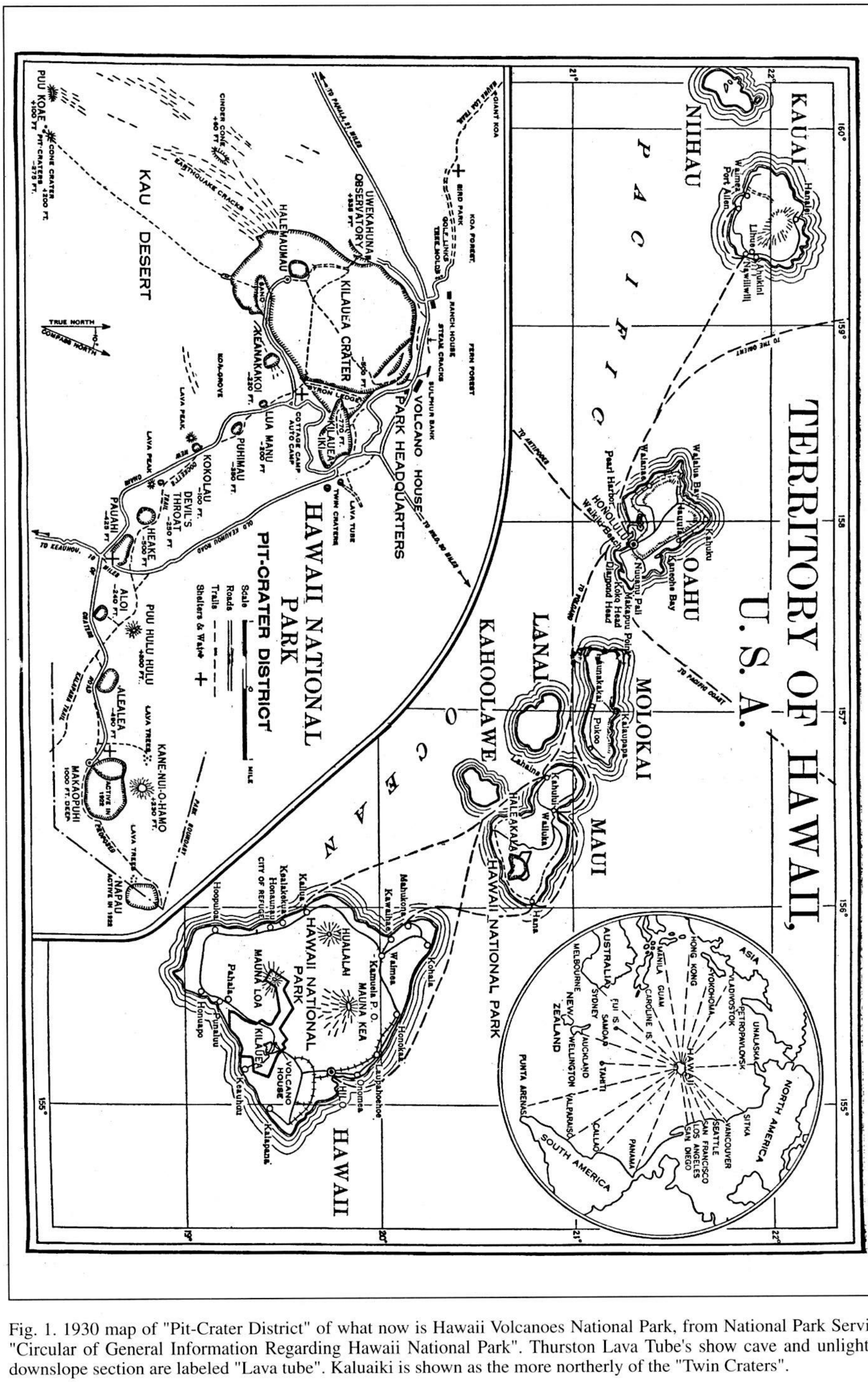


Fig. 1. 1930 map of "Pit-Crater District" of what now is Hawaii Volcanoes National Park, from National Park Service "Circular of General Information Regarding Hawaii National Park". Thurston Lava Tube's show cave and unlighted downslope section are labeled "Lava tube". Kaluaiki is shown as the more northerly of the "Twin Craters".

Confusion also has arisen from application of the term pit crater to other vertical volcanic structures in Hawaii. Use of that term for other collapse trenches, skylights, or sinks formed by collapse or slumping of the roof of ordinary lava tube caves probably has been the most confusing. Fortunately, the misuse of this term for ordinary spelean phenomena of this type seems to be declining. Yet it persists at least in informal usage for some deep examples close to vents (Fig. 3).

CHARACTERISTICS DEFINING PIT CRATERS: PRESENT DISAGREEMENTS

Among volcanologists there is little agreement on characteristics defining pit craters. The "Pit-Crater District" of Hawaii Island (Fig. 1, 4) commonly is considered the Hawaiian type locality for volcanic pits which qualify. Many (but not all) of the volcanic pits of this area open directly downward from the surface, with no ring nor cone of ejecta nor overflow (Fig. 4). Some volcanologists exclude all pits with rims or overflows, as well as similar-appearing pits at the apex of volcanic cones (Fig. 5). Others differentiate between rimmed pits inside and outside of calderas. Within the caldera of Kilauea Caldera, Halemaumau Crater (Fig. 6) is a typical example on which there is no consensus.

Generally similar features exist on Mauna Loa Volcano (Fig. 7, 8) and Hualalai Volcano (Fig. 9-12). The morphology of these pits differs largely in their ratio of width to depth, and the degree of overhang, not in wall structure. There are, however, some special cases to be considered. Na One Pit (Fig. 11, 12) has a very small rim of ejecta, and has an inner shaft reaching a total depth of -283 meters. Kaupulehu Crater (Fig. 10) is a bowl-shaped crater but has an inner vertical shaft of undetermined depth. These two inner shafts are lined with accreted lava, unlike the rough, broken walls of typical pit craters, and this may serve to differentiate them as a special type of open vertical volcanic conduit as defined by Skinner (1993).

PIT CRATERS AND LAVA TUBES

Located at the head of the Keana Oa Waa complex of Hawaii Volcanoes National Park, a small volcanic pit with a downslope rim of accreted lava plates angles sharply downward into the upper end of a normal-appearing, shallowlying lava tube cave (Fig. 13). To date, this is a unique occurrence. Otherwise, pit craters and similar-appearing volcanic pits appear to have no genetic relationship with ordinary lava tube caves. The openings of deeplying lava tube caves can be seen on the walls of a few other volcanic pits. Jaggar photographed a short-lived rift tube which briefly carried overflow from Halemaumau's lava lake (Jaggar, 1947). Three apparently small lava tubes were seen on pit walls near the bottom of Devil's Throat (Doerr, n.d.) and a filled tube exists near the bottom of one of the Kau Desert pit craters (Whitfield, 1980). On Hualalai Volcano, the apparent opening of a sizable lava tube cave is visible at approximately the 40 meter level of a volcanic pit estimated to be 200 meters deep (Moore and Clague, 1991), and a smaller example exists in Na One Pit at about the 60 meter level. These examples appear to be either preexisting buried tubes incidentally exposed during development of the pit or as deeplying rift tubes formed along linear structures genetically related to the pits. Clearly, however, their presence was not the cause of the formation and development of the pits. Only one probable exception has been found to date. At the bottom of the so-called Wood Valley Pit Crater near the Kau Desert (Fig.

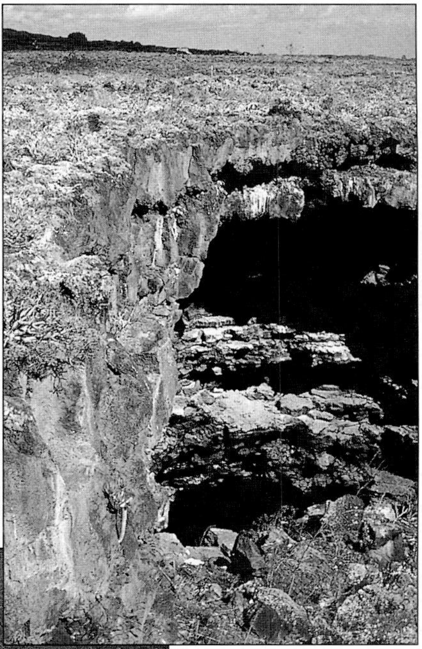


Fig. 2. Upslope end of Jameo de la Gente, Lanzarote, Canary Islands, a jameo type locality. Photo by the author.

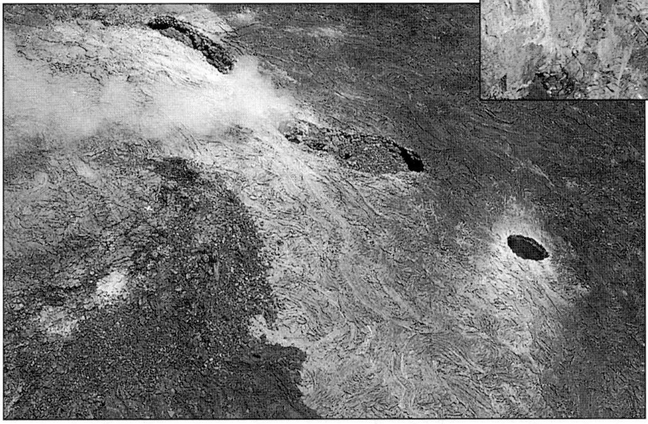


Fig. 3. Aerial view of trench segments and skylight of a large lava tube cave immediately downslope from Kupaianaha Crater. Photo by the author.

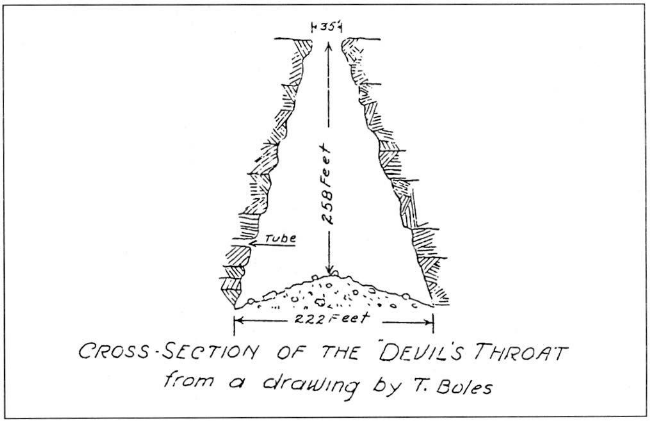


Fig. 4. Vertical section of Devil's Throat from Scribner and Doerr, n.d. The width of the surface opening now has increased to about 60 meters.

Fig. 5. Aerial view of pit at summit of Mauna Ulu, Hawaii, a composite cone. Photo by the author.

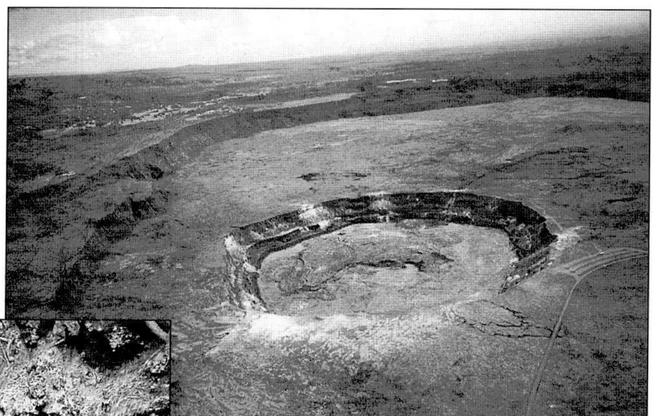


Fig. 6. Aerial view of Kilauea Caldera showing Halemaumau Crater, considered by some volcanologists to be a pit crater. Photo by the author.

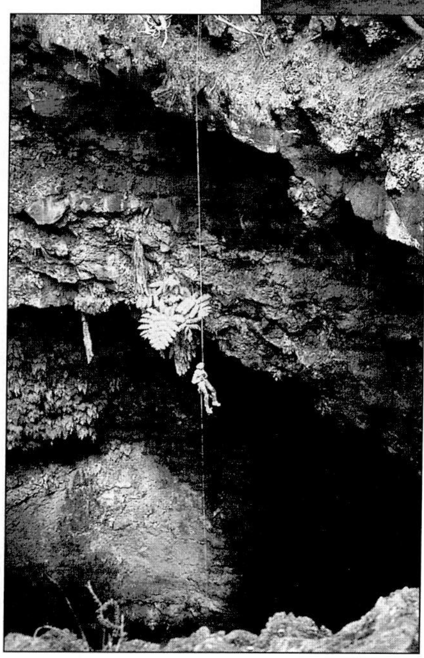


Fig. 7. Hapai Mamo Pit, southwest rift zone of Mauna Loa volcano. Photo by the author.

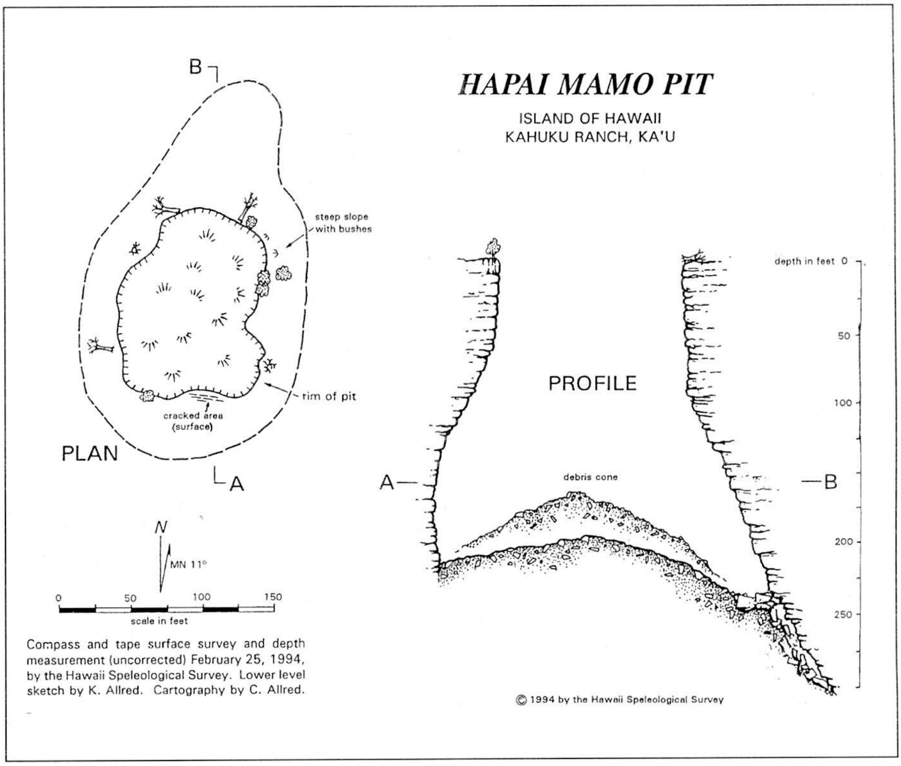


Fig. 8. Map of Hapai Mamo Pit, Island of Hawaii, Kahuku Ranch, Ka'u.

14) a rift tube 620 meters long exists about 85 meters below the surface, at the bottom of the pit structure (Favre, 1993). Upward stoping from this rift tube may well have caused this pit crater. At this time, it is unique in Hawaii.

SMALL VERTICAL CONDUITS

The present Glossary of Geology definition of pit crater technically could include much smaller vertical volcanic shafts than those commonly called pit craters. The most notable examples in Hawaii are at the head of the famous Kaupulehu xenolith nodule beds on Hualalai Volcano (Fig. 15-18). Some of these lead down to short horizontal passages terminating in small chambers with notable volcanic features. One is a more complex structure 30 m. deep (Fig. 15). These appear to be drained vents. Some occur in linear groups, separated by narrow septae or sills. The pahoehoe cap of one such vent is largely intact (Fig. 18). These are properly termed open vertical volcanic conduits (Skinner, 1993), not pit craters.

PIT CRATERS AS AN INTERFACE OF VOLCANOLOGY AND SPELEOLOGY

The term pit crater was first used before 1850 (Dana, 1849), and volcanologists' disagreements about their parameters are almost as old. This might seem to be an ideal

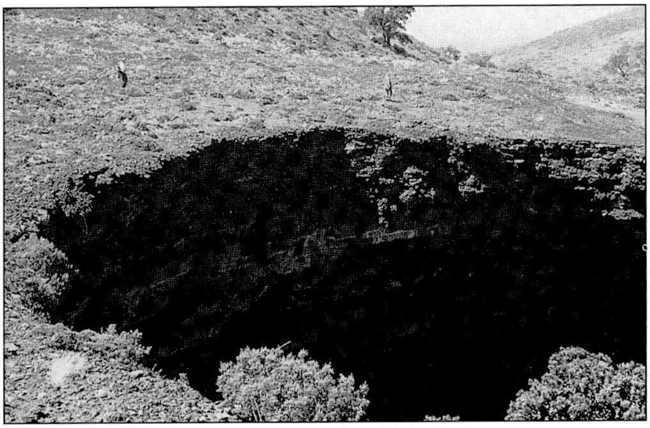


Fig. 9. Upslope end of one of the Malekule pit craters of Hualalai volcano, Hawaii. There is no raised rim of ejecta, but where the persons are walking, the ground is littered with small volcanic bombs. Photo by the author.

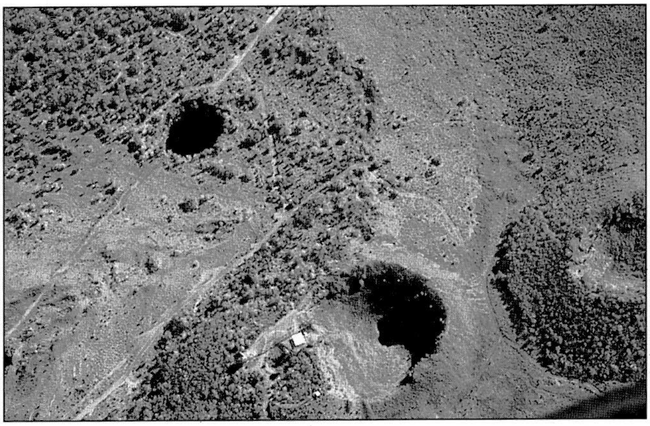


Fig. 10. Aerial view of bowl-shaped Kaupulehu Crater (bottom center) and "Parrot Pit", a "punched-out" pit crater, on the northwest rift zone of Hualalai Volcano. The inner open vertical volcanic conduit of Kaupulehu Crater is hidden in the shadow of the elevated rim. Photo by the author.

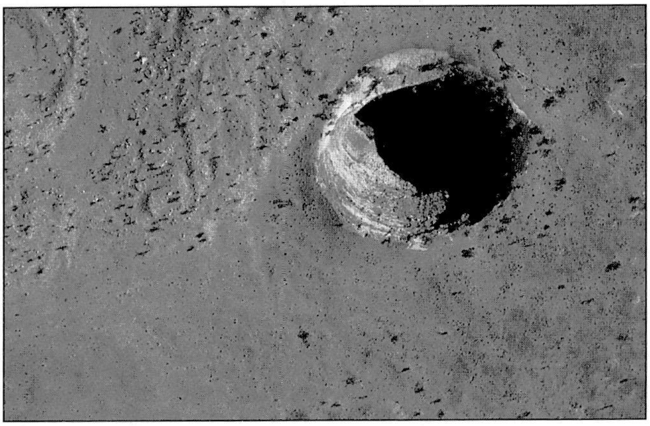


Fig. 11. Aerial view of Na One Pit, Hualalai volcano, showing small raised rim of ejecta. Because of this small raised rim, some volcanologists do not consider it a pit crater. The inner open vertical volcanic conduit is hidden in shadow. Photo by the author.

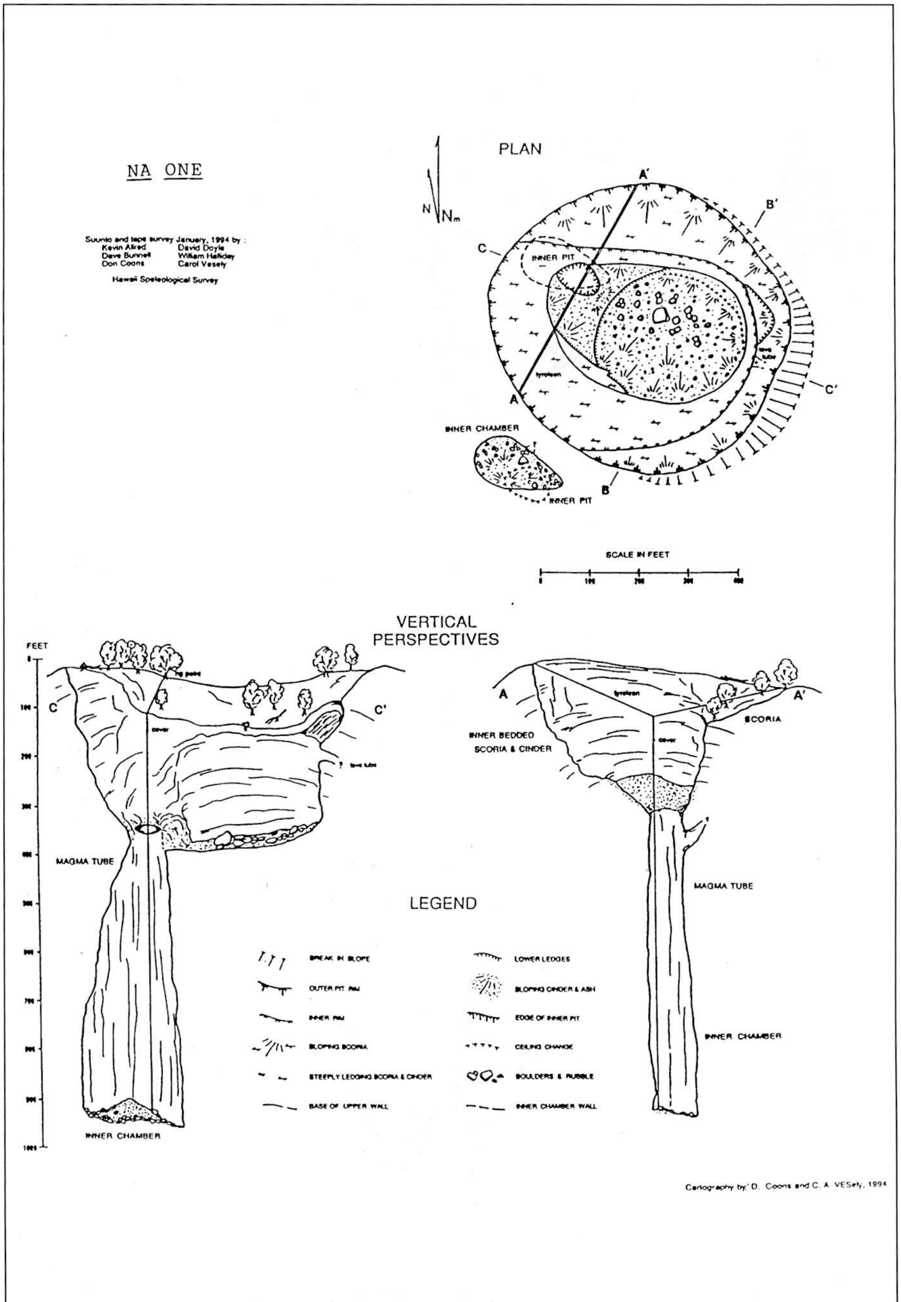


Fig. 12. Map of Na One Pit. Suunto and tape survey January 1994 by: Kevin Allred, Dave Bunnell, Don Coons, David Doyle, William Halliday, Carol Vesely. Hawaii Speleological Survey.

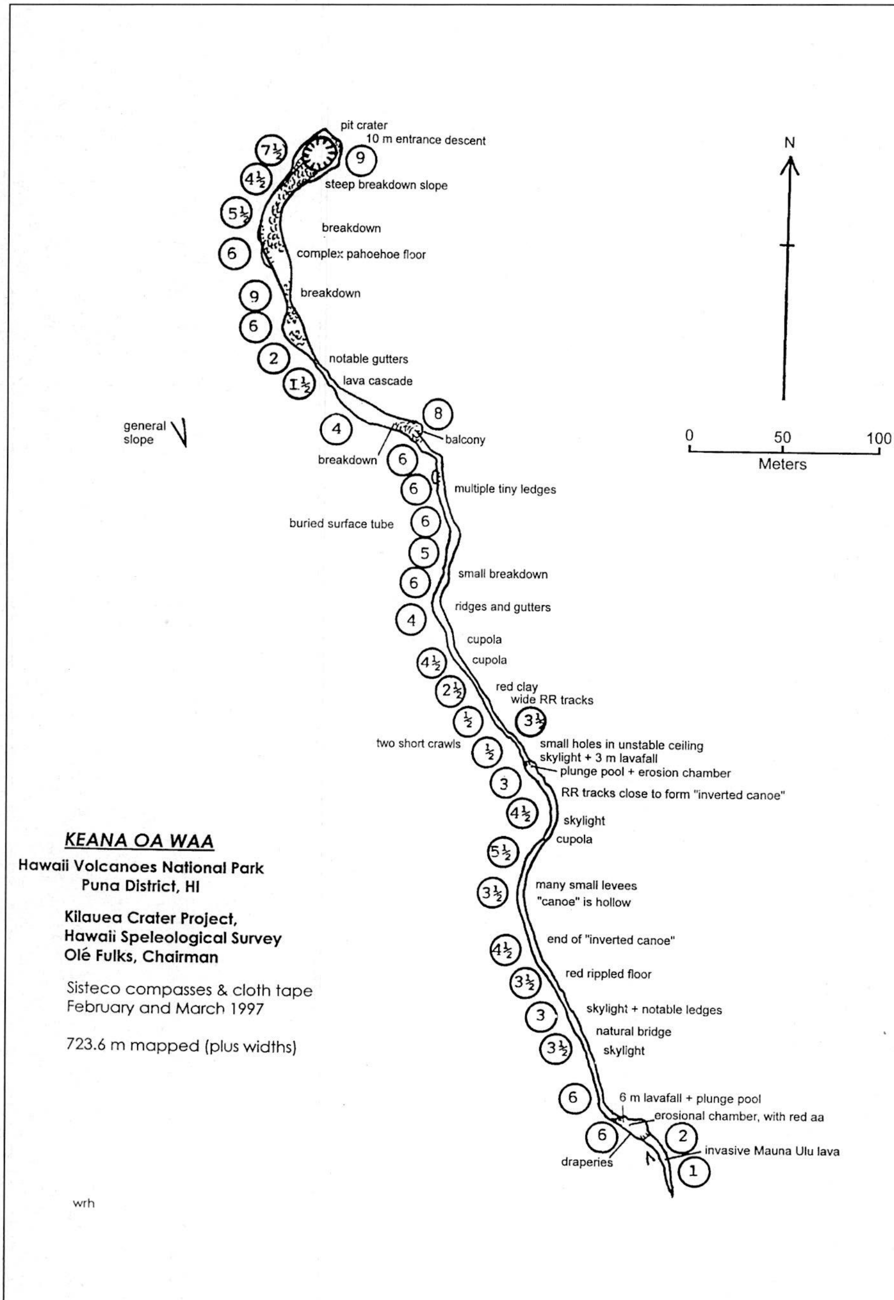


Fig. 13. Map of Keana Oa Waa, a complex consisting of a small pit crater with a localized rim of accreted plates plus a lava tube.

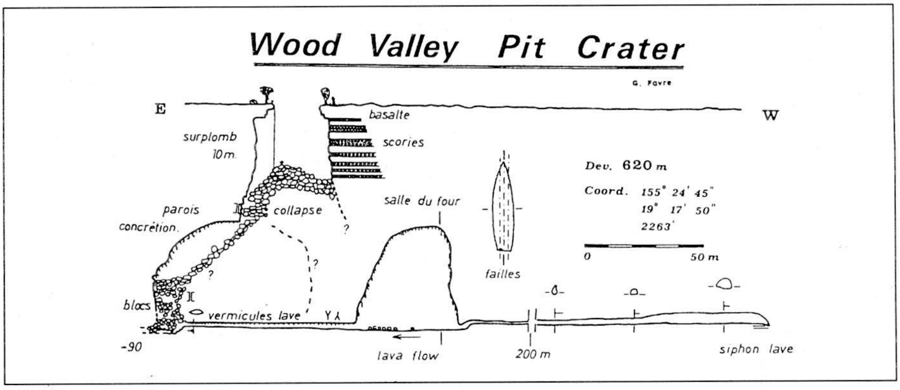


Fig. 14. Map of Wood Valley Pit Crater, from Favre, 1993.

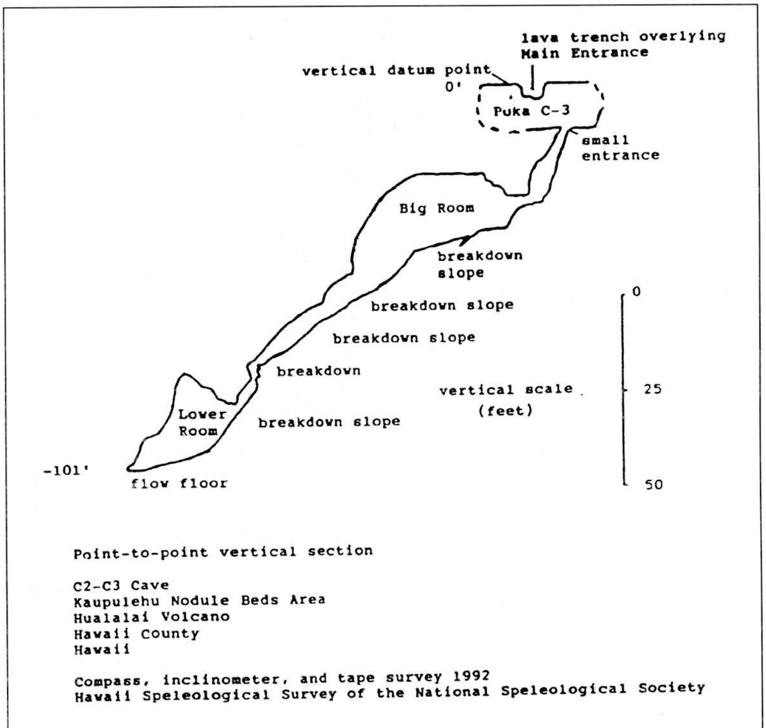


Fig. 15. Point-to-point vertical section of C2-C3 Cave, the deepest open vertical volcanic conduit known at the head of the Kaupulehu nodule beds. The ceiling and one wall of the Big Room are largely an accreted bed of dense lava containing ultramafic xenoliths of several mineralogical types. Nodule beds are present in several locations in this cave.

morass for speleologists to avoid. Yet, the confusion between roof features of ordinary lava tube caves and pit craters is clearly in the interface of vulcanospeleology and volcanology. Further, other vertical volcanic features are rapidly emerging as another interface. Cavers' "Nylon Highway" of single rope techniques makes many examples much more accessible for study by speleologists than by volcanologists. When using speleological expertise credibly, input by vulcanospeleologists already has been acceptable to editors of Glossary of Geology. Further input concerning the limited relationship between pit craters and lava tube caves is clearly appropriate. Future editions should specify that, except for very unusual deep-lying rift tubes, pit craters are NOT skylights nor collapse windows of passages of lava tube caves.

Some other supposed definitions in Glossary of Geology actually are non-definitions; an example is that of agglomerate. Its listing notes that agglomerate has been variously defined, and specifies that the term should be defined in context to avoid confusion. Provided that features of ordinary lava tube caves and open vertical volcanic conduits as defined by Skinner (1993) are specifically excluded, perhaps the same should be said for pit crater. I propose that the new President of the IUS Commission on Volcanic Caves suggest this to the editors of Glossary of Geology.

And I also propose that we as speleologists continue and expand our recent field support for volcanologists. Our special technical skills can be of great value in these vertical features, whatever they are called. Other open vertical volcanic features yet unplumbed will tax our combined knowledge and skills (Fig. 19) and require maximum cooperation in this interface of volcanology and speleology.

ACKNOWLEDGMENTS

Lengthy discussions with Chris Okubo and Charles V. Larson greatly clarified my thoughts on these and related matters. Studies in Hawaii Volcanoes National Park were made possible by Jim Martin (now Superintendent of that park) and Bobby Camara, its Cave Resource Specialist. Ron Greeley brought the Kaupulehu open vertical volcanic conduits to my attention and he and Steve Kadel joined in part of the subsurface studies. Jeff Taylor obtained permission for access to Bishop Estate lands. My thanks to all.

REFERENCES

Dana, J.D. 1849. Geology. Volume X, U.S. Exploring Expedition during the years 1838, 1839, 1840, 1841 and 1842, under the command of Charles Wilkes, USN. Philadelphia, printed by C. Sherman.

Doerr, J.E. Jr. n.d. (ca. 1930). Exploring the Devil's Throat. Hawaii National Park Nature Notes, Vol. 2, no. 3, P. 23.

Favre, G. 1993. Some observations on Hawaiian pit craters and relations with lava tubes. Proceedings, 3rd Internat. Symp. on Vulcanospeleology, Bend, OR, 1982. Seattle, International Speleological Foundation, p. 37.

Halliday, W. R. 1993. Kaluaiki and Thurston Lava Tube: an unrecognized jameo? Proceedings, 3rd Internat. Symp. on Vulcanospeleology, Bend, OR, 1982. Seattle, International Speleological Foundation, p. 52.

Jaggar, T.A. 1947. Origin and development of craters. Geol. Soc. of Amer. Memoir no. 21, 508 p. Plate X.

Jackson, J.A. (editor). 1997. Glossary of Geology, 4th Edition. Alexandria, VA, Amer. Geol. Inst., 769 p.

Moore, R.B. and D.A. Clague. 1991. Geological map of Hualalai Volcano. U.S. Geol. Survey Misc. Investigations Series Map 1-2213.

Skinner, C. 1993. Open vertical volcanic conduits: a preliminary investigation of an unusual volcanic form from Newberry Volcano and the central High Cascades of Oregon. Proceedings, 3rd International Symp. on Vulcanospeleology, Bend, OR, 1982. Seattle, International Speleological Foundation, p. 7.

Whitfield, P. 1980. Western Cone Crater, Hawaii, 19 and 20 December 1979. Cascade Caver, Vol. 19 no. 4 (April), p. 49.

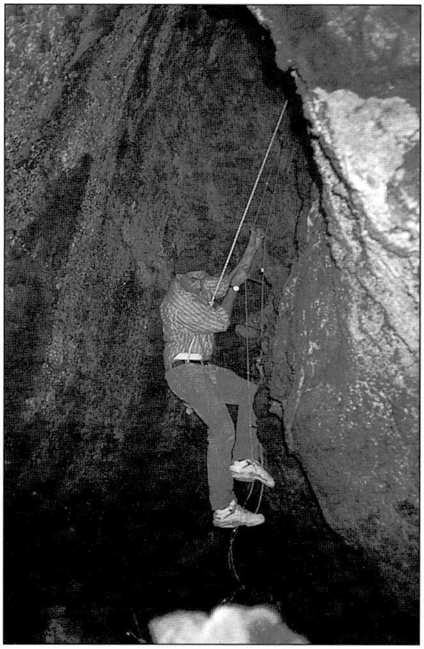
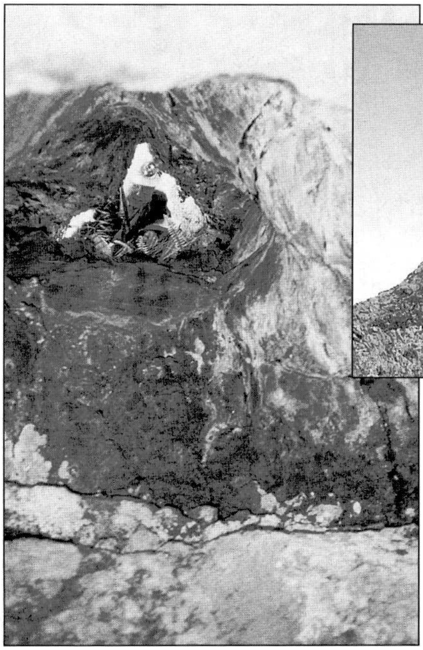


Fig. 16. Descending one of the open vertical volcanic conduits in the Kaupulehu xenolith nodule beds vent area. Photo by the author.

Fig. 17. Septum or sill separating open vertical volcanic conduits in Kaupulehu xenolith nodule beds vent area. Photo by the author.



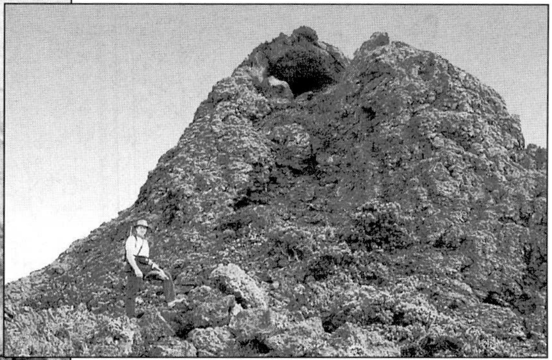


Fig. 19. One of several pahoehoe-coated cones on Hualalai volcano surmounting a deep, unexplored open vertical volcanic conduit. Photo by the author.

Fig. 18. a and b. Pahoehoe cap of open vertical volcanic con-duit in Kaupulehu xenolith nodule bed vent area. Photos by the author.

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LAVA TUBE REMELT BY RADIANT HEAT AND BURNING GASSES

Kevin Allred *

ABSTRACT

Some volcanologists assume that interior surfaces of hot lava tubes can commonly be remelted by burning gases and radiant heat. Pending further data, this appears to be unlikely.

Keywords: lava tubes, speleogenesis, radiant heat

INTRODUCTION

Country rock can be eroded by flowing lava. It occurs by partial melting accompanied by mechanical plucking of unmelted crystals (Cruikshank and Wood 1972, Coombs and others 1990, Allred and Allred 1997) and has been defined as "thermal erosion". The necessity of melting as a component of thermal erosion is particularly obvious with the recent recognition of the effect on buried lava tubes that are intersected by active flows. These older extraneous tubes had an air-cooled resistance to thermal erosion and caused the newer flow to divert around them, leaving a separating rind (Allred and Allred 1997a, Allred and Allred 1997b). There is also some evidence of convective gaseous turbulence melting country rock around the perimeters of lavafall plunge pools (Allred and Allred, 1997b). This paper primarily deals with the feasibility of burning gases and radiant heat in melting the interior surfaces of lava tubes.

DISCUSSION

The subject of remelt must begin with T.A. Jaggar, a pioneer in volcanology of Hawaii in the early 1900's. At Kilauea caldera, he undertook ingenious methods to study the little understood phenomena of volcanic eruption. An interesting feature observed above the crusted over, active lava lakes of the Caldera were hollow spatter or driblet cones (Jaggar 1917a, 1917b). When the surface of the lakes subsided, convection apparently caused a super-heated mixture of gas and air to blast up through these cones which he then called "blowing cones". These could have banners of flame above them and become "natural blow-pipes of burning sulfur and hydrogen"(1917a). The greatest heat occurred in the intense turbulence at the orifice itself. Jaggar estimated temperatures of at least 1130°C using seger cones. Based on relative glows and steel pipe oxidized to a dripping incandescence after being held only nine minutes in one flaming orifice, he estimated the burning flames reached 1350°C. These highest temperatures are far above the liquidus temperature of lava. An alternative explanation is

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that in the turbulence of super-heated air, an oxidation reaction occurred, making the steel melt at lower temperatures than what Jaggar supposed. Oxidation from commonly used oxygen-acetylene cutting torches is triggered with pure oxygen at temperatures as low as ~400°C (Oberg and Jones, 1972). In the blowing cones, oxygen concentrations would be less than that of air (20%), but in a turbulent, super-heated condition. Regardless of the cause or actual temperatures, the basalt of the blowing cones did melt away.

When Jaggar observed vermiform (tubular lava) stalactites in lava tubes, he concluded they also were products of remelt from burning gasses, even after the lava had ceased to flow in the tubes (Jaggar 1931, 1947). But, any source of the supposed gas is unexplained, and it is illogical for the thin delicate stalactites to survive a space occupied by a melting inferno of burning gasses. Despite obvious complications, this remelt view has been widely accepted (Hjelqvist 1932, Perret 1950, McClain 1974, Baird and others 1985). We have recently shown that these tubular lava stalactites are not remelt features at all, but segregations (differentiated residual liquid) extruded from partially crystallizing lava into the cooling lava tubes. The driving mechanism is thought to be the gas pressure of retrograde boiling (Allred and Allred, in press).

Incandescence, Glaze and Pendants

Sometimes lava remelt is inferred by the glow color of the lava tube walls (Macdonald, 1964). With the aid of an optical pyrometer, accuracy in readings depends on ones proximity to the tested lava (Swanson, 1973). Still more inaccuracy is incurred by trying to judge by sight alone under different lighting conditions. In incandescent steel, skilled observers may vary as much as 100°F (55°C) in their estimations of relatively low temperatures by color, and beyond 2200°F (1205°C) it is practically impossible to make estimations with any certainty (Oberg and Jones, 1972). Without an accurate measuring device, it would appear as difficult to estimate lava temperature as it is to describe the colors in charts designed to show us how (Oberg and Jones 1972, Beiser 1991). In one such chart (Fig. 1) the lava would be "yellow" to well below the crust-melt interface, the point at which cooling Kilauea lava can no longer flow.

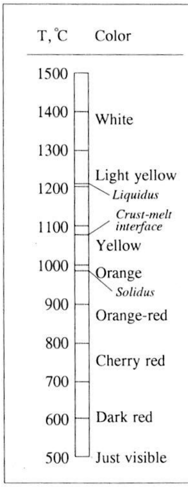

Fig. 1- The visible glow at various temperatures. Adapted from Beiser (1991) with lava crystalization data after Wright and Okamura (1977).

Investigators have claimed that common lava tube glaze and tapered shark tooth stalactites are also evidence of remelt by burning gases and radiant heat (Jaggar 1931, Macdonald 1964, Peterson and Swanson 1974, Harter 1971,1978,1993). Lava glaze is defined as "a thin, smooth, vitreous surface" (Larson, 1993). This definition is somewhat misleading, as glassy surfaces don't

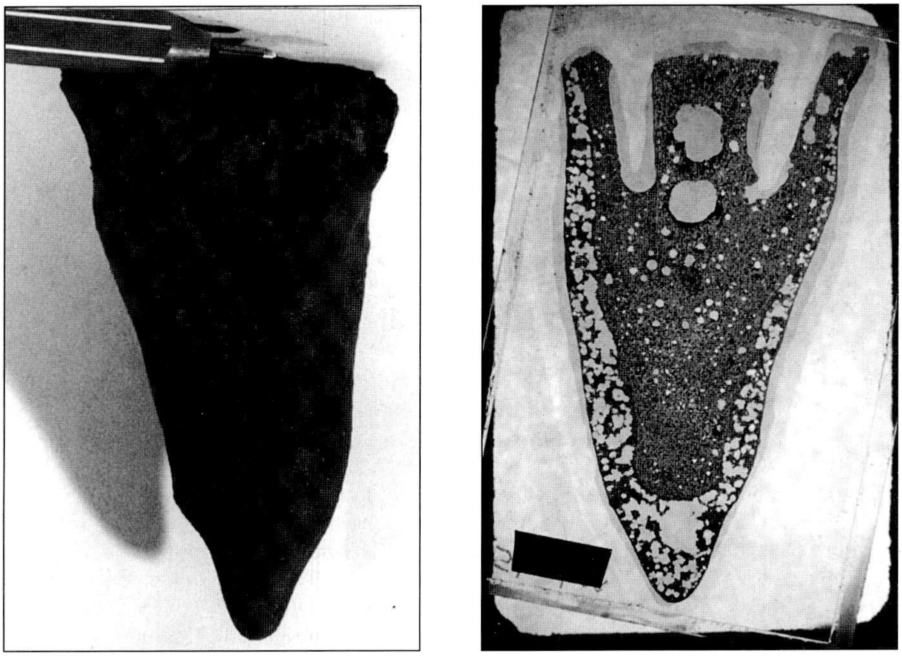

Fig. 2- Shark tooth stalactite and its thin section. Photos by Margaret Palmer.

occur in slowly cooling lava tubes. Here, glaze is defined as the silver luster (sometimes oxidized to reddish or brown) commonly covering the interior surfaces of lava tubes. It is not more than about 50mm thick, and its characteristic luster comes from light reflecting off of facets of tiny magnetite octahedrons. Magnetite crystallizes at temperatures below the crust-melt interface between 1030°C and 980°C (Wright and Okamura, 1977). Therefore, it is not proof of remelt.

Tapered pendants are commonly called shark tooth, or teat stalactites (Larson, 1993). They are often found in areas susceptible to splattering, or fluctuating lava levels. Many of these stalactites can be quite vesicular, and have a remarkable resemblance to the foamy peaks of the beaten egg-white of meringue.

A thin section was made of a shark tooth stalactite (Fig. 2). It had eight distinct layers or accreted linings ranging from 5µm to 2.5 cm thick (Allred and Allred in press). All of these were visible only with at least 100 power of a microscope. Such linings also commonly coat the ceiling between pendants. The magnetite glaze between these linings is continuous to discontinuous. It is unclear if the glaze along the transitions crystallized before each subsequent coating, or sometime later in the cooling process. However, it is safe to conclude that pendants are products of accreted lava and not remelt. If a pendant is only partially exposed between submerge cycles, it can become bulbous or teat-shaped. Transitional distinctions between linings will then end at the point of non-emergence or non-submergence. Tubular lava stalactites can sometimes grow out of pendants in favored conditions as in other linings (Allred and Allred, in press).

Using paraffin, my wife and I attempted to simulate stalactite formation according to the popular "remelt" hypothesis. Earlier we had successfully created tubular paraffin stalactites similar to those of lava (Allred and Allred, unpub.). But in this instance, we repeatedly flash heated a horizontal, flat, paraffin "ceiling". This only produced driblet projections less than three millimeters long. Any larger projections were quickly, and preferentially melted away when exposed to the heat. If the "ceiling" was inclined, not even the tiny driblets could be formed. After experimenting with this, we became even more convinced that these pendants must be products of accretion.

Radiant Heat

All objects have the property of absorbing as much radiation (electromagnetic waves) as they can emit. A theoretical black body has a surface texture which allows it to be a perfect emitter and absorber with an emissivity of 1. Matte black paint is .97 on the scale (Beiser, 1991). If it is assumed that lava or basalt are ~.9 emissivity, they are somewhat limited in their emissive and absorption capabilities. Yet, even though the transfer of heat is slower, the ceiling would eventually take on the temperature of the flowing lava, were it not for three things: First, conduction might sometimes exceed the radiant heat. Second, the conductive surface area of the arched ceiling and walls is larger than the radiating surface of flowing lava. Third, I propose that gas between the flowing lava and the walls and ceiling acts as a screen and the absorbing molecules reflect a portion of the radiation back towards the source. The thinner atmosphere of our earth functions in a similar way (Beiser, 1991). If there is a morphological change to the tube such as a new skylight to cause significant temperature differences, convective currents begin, and heated gas particles are dispersed to the cooler parts in the tube. When the temperatures are nearly the same in an area, the friction of the gas particles slows down or stops convection. The screen becomes more effective, and heat is conserved in the lava stream rather than causing a meltdown of the ceiling. Thus, as long as there is space between the two surfaces, the radiation reaching the slightly conductive ceiling will be less than the emission of the lava below. This can be illustrated by holding ones' hand near a very hot object, but not being able to safely touch it.

When convective currents are caused by mechanical means (lavafalls, or turbulent rapids) the balance may be upset, and heated gas can be blown against a surface where it otherwise would not. Over time, this heat flow may exceed the rock's conduction, specific heat, and enthalpy of fusion. Melting of the surface will occur as suggested by Allred and Allred (1997b). The shape of walls around the perimeters of plunge pools in lava tubes have the appearance of rounded forms of country rock under a very thin, or nonexistent lining, rather than unmelted broken surfaces. Some walls resemble ablation scallops commonly seen in glacier caves. Glaze covering these surfaces is identical to the surfaces elsewhere.

Do Burning Gasses Contribute to Remelt?

So, is it possible to use the present data collected from volcanologists to accurately predict if remelt can occur from burning gasses and radiant heat acting without convection? Not conclusively. There are still too many unknown values that must be supposed in order for any exact determination. For instance, how much atmospheric air is being drawn into cracks and skylights before expanding and being balanced with the gases? How much gas escapes through cracks? How much of the gases which can oxidize are present? Does higher heat allow lower concentrations of these gases to burn than at room temperature? Does the lighter hydrogen separate from gases, collect along the ceiling and "flow" to be burned where oxygen is available? What is the remelt temperature of basalt that has lost part of its water content, and do we Fig. a remelt starting from solidus or somewhere close to the crust-melt interface? Does radiant emissivity change during cooling textural changes?

Despite the obvious lack of data, below is a model of the theoretical possibility of remelt from burning gases in a lava tube. The chosen conditions greatly favor a remelt scenario. A theoretical lava tube is considered in two sections reflecting the recognized differences in loss of gas bubbles (Swanson 1973, Cashman and others 1994). For more simplicity, the negligible cooling of lava through the tube system was not considered, but is listed in the values below. The reader should understand the concept that the ceiling and wall linings accreted in the first place because the conduction of the ceiling rock exceeded the melting ability of the flowing lava against them.

In the model, all three common gases which oxidize (H_2, CO, H_2S) are drawn through a significant portion of a lava tube, then finally burn in one small area. The possibility of such complete oxidation is inferred by Greenland (1987a, pg. 762). However, considering the multitude of analyses showing low concentrations of these gases (Greenland, 1987a, 1987b), and their nearly consistent presence, in reality they usually remain diffused and mostly unburned. Not included here are trivial amounts of hydrogen liberated in oxidation of magnetite (Fe_3O_4) to hematite (Fe_2O_3) during advanced cooling. Gas exsolution has been found to be <5% volume in 11 km (Cashman and others, 1994), and is not included in the gas liberation value, "V" in the list below.

The sulfur concentrations are low in Kilauea and Mauna Loa basalt, averaging 153ppm (Franczyk and others, 1987). Of the portion carried away in gases, most of the loss is within 2 km of the vent. This follows the trend of overall gas loss. I observed elemental sulfur deposits around cracks atop the roofs of recently cooled lava tubes near Kupaianaha, Kilauea Volcano. This indicates that at least a portion did not oxidize, but condensed upon cooling. Sulfur is not considered here as a significant source of heat in lava tubes.

Basalt which has crystallized at virtual atmospheric pressure will require hotter temperatures to reverse the process and be melted at atmospheric pressure. This is because some water has been lost by exsolution, and without it the melting temperature is higher. Water cannot be forced back into the lava solution without pressure; its solubility at atmospheric pressure is zero (Charmichael and others, 1974). Greeley (1987) reported some minerals of a dacite block from the preflow terrain had been melted and flowed out through a wall collapse into a Mt. St. Helens lava tube. A sample of this dacite was heated gradually, and only showed signs of melting above 1200°C. It is not clear that these melted residuals were indeed from the preflow terrain, as they could also have been segregation drainage from the linings (Allred and Allred in press). At any rate, the high temperatures of this remelt experiment seems to confirm the higher temperatures required to melt a water deficient basalt (Carmichael and others, 1974, pg.8). In this paper I have chosen a rather modest 1100°C (Baird and others, 1985) as a flow temperature for remelt, even though it is only slightly above the crust-melt interface of primary basalt (Wright and Okamura, 1977). In this model, convection distributes radiant heat above the lava, balancing the ceiling temperature at 1070°C.

Useful Values

ΔHch heat of combustion of hydrogen ($2H_2 + O_2 \Rightarrow 2H_2O$ gas) to H_2O gas at 1070°C: Begin with -241.8kJ/mol at 25°C at constant pressure (Brown and others, 1991). At 1070°C, the volume of the gas is increased from heat expansion. Using Charles's Law, a mole (22.414L) at 0°C will take up a predictably larger volume at 1070°C. In this equation, V is the volume and T is the temperature in Kelvins. The minus value means that the reaction is exothermic:

$$\frac{V_1}{T1\ °K} = \frac{V_2}{T2\ °K} = -\ 241.8KJ/110.199\ \ L\ at\ 1070°C$$

ΔHcco heat of combustion of carbon monoxide ($2CO + O_2 \Rightarrow 2CO_2$) as in the equation above:
-283kJ/110.199 L at 1070°C.

ΔHchs heat of combustion of hydrogen sulfide ($2H_2S + 3O_2 \Rightarrow 2SO_2 + 2H_2O$ gas) as in the equation above: -518.53kJ/110.199 L at 1070°C.

H total lava heat lost from a 12 km lava tube: 2900 J/100g (Helz, 1993) = 6.931 cal/g.

Hc total cal. lost from lava per meter^3 in 12 km based on a density of 2.7g/cm^3: Hc = 6.931 cal/g x (2.7 x 10^6g/m^3) = 18,713,700 cal/m^3.

T1 crust/melt interface at 1070°C. Volume of crystals: 59% (Wright and Okamura, 1977, Fig. 16).

T2 lava begins to flow at 1100°C (Baird and others, 1985, pg.159). Volume of crystals: 38% (Wright and Okamura, 1977, Fig. 16).

ΔT3 (T2°-T1°).

ΔT4 change in temperature in 12km: 7°C (Helz, 1993).

c heat capacity of basalt: .3cal/g/°C/s (Jaeger, 1968).

ΔC change in crystal content in ΔT4 during flow of an 12km tube: 5.6% (Helz, 1993).

K thermal conductivity of basalt: From .0052cm^2/s/cm (cm^2/°C) (Weast and others, 1958) for a 3.09g/cm^3 basalt adjust for the density of ρ1 = .0032cm^2/s/cm (cm^2/°C).

ε enthalpy of fusion of basalt: 80cal/g. (Jaeger, 1968)).

ρ grain density of average basalt: 3.09g/cm^3 (Daly, 1944).

ρo fluid density of lava with 5% crystals: ρ -13% for expansion from total crystalline state (Daly, 1944), -5% of 13% to account for 5% crystals in erupting lava (Cashman and others, 1994) = 2.71g/cm^3.

ρ1 ceiling lining bulk density: 1.9g/cm^3 (Allred and Allred, 1997b, average of 10 lining samples).

Fr flow rate: 1.73m^3/s (Cashman and others, 1994, pg. 59).

D average stream depth (50-75cm): 62cm (Cashman and others, 1994, p.59).

f velocity of lava stream (1-2m/s): 1.5m/s (Hon and others, 1994).

V total gases liberated throughout an 11km tube/sec: .53 Fr (Cashman and others, 1994, pp. 59).

v1 gas loss in the first two km of 11km of tube/sec: .25 Fr (Cashman and others, 1994, Fig.8).

v2 gas loss in last nine km of 11km of tube/sec: .28 Fr (Cashman and others, 1994, Fig.8).

v3 H_2 percentage in gas: .48mol% of average of full gas analyses Greenland (1987a), Table 28.1 from Kilauea 1918-1919 and Greenland (1987b), Table 30.1 from Mauna Loa).

v4 CO percentage in gas: .21mol% (as in reference above).

v5 H_2S percentage in gas: .85mol% (as in reference above).

Remelt in the First Two Kilometers of an Active Lava Tube

1. ξ= volume of combustible gases available /s/km: A total of .25 Fr of the gas lost into the tube system are within 2 km from the vent. An average .0048, .0021, .0085 of the liberated gas content is H_2, CO, and H_2S respectably:

$$H_2\,\xi = \mathrm{v}3\left(\frac{\mathrm{v}1}{2}\right) = .0010\ m^3\,/s/km$$

$$CO\,\xi = \mathrm{v}4\left(\frac{\mathrm{v}1}{2}\right) = .00045\ m^3\,/s/km$$

$$H_2\,S\xi = \mathrm{v}5\left(\frac{\mathrm{v}1}{2}\right) = .0018\ m^3\,/s/km$$

2. Hb= Heat budget: Calories of burning H_2, CO, and H_2S versus calories drawn away by conduction per second into the ceiling. A hypothetical skylight one km upstream allows all released burnable gases of that km to ignite in an area 10m^2 near the skylight where oxygen is available. Heat of combustion for ΔHch(524400.860 cal/m^3), ΔHcco(613752.865 cal/m^3), and ΔHchs(1124555.738 cal/m^3) multiplied by their respective volume/s (ξ) equals heat given off below the affected area. Fig. that only 2/3 of the heat radiates upwards to the arched ceiling. Subtract the amount being conducted into the one meter thick roof of the affected area, figuring the difference between the crust-melt interface and the 20°C surface temperature to get the heat budget (Hb):

$$Hb = .666\ [(H_2\xi \times \Delta Hch) + (CO\xi \times \Delta Hcco) + (H_2\ S\xi \times \Delta Hchs)]$$

$$- \frac{K\ [10^5\ cm^2\ (T1 - 20)]}{100cm} = -\ 1478.692\ cal/s$$

The conduction into the ceiling exceeds the amount of heat given off from the burning gases.

3. Since conduction decreases as the roof is thickened, we can calculate the minimum roof thickness at which remelt begins:

$$\frac{K\ [10^5\ cm^2\ (T1 - 20)]}{.666\ [(H_2\xi \times \Delta Hch) + (CO\xi \times \Delta Hcco) + (H_2\ S\xi \times \Delta Hchs)]} = 1.78\ meters$$

Had the heat from burning gases been more than the conduction into the one meter-thick roof, we could have calculated the rate of remelt:

4. $\varepsilon 1$= Enthalpy of fusion of affected area: Fig. there are $10^5 cm^2$ (for an area $10m^2$ spanning the ceiling near an entrance). We are attempting to melt rock having a density of $\rho 1$, 1mm into the surface, multiplied by the enthalpy of fusion. Next, since the melting temperature of basaltic minerals covers a range of 980-1205°C, and we are only talking about the range from the crust-melt interface to 1100°C, we will adjust for this. Since 21 volume % crystals are all that need to be melted for the rock to begin flowing:

$$\varepsilon 1 = .21\varepsilon \left[\frac{1.9}{10}\ (10^5\ cm^2) \right] = 319{,}200\ calories$$

5. c1= heat capacity of affected area: Multiply the grams of rock to be melted by the heat capacity value, and then multiply the temperature change from 1070-1100°C:

$$c1 = (1.9 \times 10^4\ g \times c)\ \Delta T3 = 1.71 \times 10^5\ calories$$

6. t= time to melt 1mm deep of rock in the affected area:

$$t = \frac{\varepsilon 1 + c1}{Hb}$$

Remelt in an Actively Flowing Tube in the Lower Nine Kilometers

7. ξ= Combustible gas available s/km: .28 Fr of liberated gas was lost in the last 9 km of the tube. As in equation 1, only a portion of this gas is combustible:

$$H^2\xi = v3\left(\frac{v2}{9}\right) = .00025\ m^3\ /s/km$$

$$CO\xi = v4\left(\frac{v2}{9}\right) = .00011\ m^3\ /s/km$$

$$H^2\ S\xi = v5\left(\frac{v2}{9}\right) = .00045\ m^3\ /s/km$$

8. Hb= Heat budget of burning H_2, CO, and H_2S versus conduction under conditions as in equation 2:

$$Hb = .666\ [(H_2\ \xi \times \Delta Hch) + (CO\ \xi \times \Delta Hcco) + (H_2\ S\ \xi \times \Delta Hchs)]$$

$$- \frac{K\ [10^5\ cm^2\ (T1 - 20)]}{100\ cm} = -\ 2890.696\ \ cal/s$$

The conductivity of heat into the ceiling is 7 times the heat production from all burning gases. Using equation 3, the minimum roof thickness for remelt to begin is 7.1 meters.

CONCLUSIONS

In this modeling, remelt cannot occur from burning gases, unless the roof is at least 1.7m thick and near the vent. Gas analyses from other locales usually show consistent and minor amounts of diffused H_2, CO, and H_2S. Thus, complete oxidation of gases is unlikely, and partial oxidation may occur through many areas of a lava tube or after exiting. It was assumed convection distributed radiant heat to the ceiling and kept it at 1070°C. Similarly, even if burning could occur, the resulting heat would tend to be distributed by convection to adjacent cooler areas because of the temperature gradient. After lava flows about 12 km through a lava tube, estimated total heat lost/m^3 (H) is approximately 13,000 times more than potential heat from all flammable gas liberated from that lava. Burning gases would be negligible in the overall heat budget.

Despite the improbability, remelt in lava tubes from burning gasses and radiant heat, is likely to continue to be controversial until more is learned of the thermodynamics. A means should be found to accurately monitor the internal temperatures and gases of lava tubes away from the entrances. One way would be through drilling into the ceiling of an active tube. As pointed out by Jim Kauahikaua (pers. comm. 1996), it would be a potentially dangerous thing to do directly above the tube, since water would be used as a coolant. However, a tube could be pinpointed electromagnetically, then drilled diagonally to offer protection from potential collapse of the roof.

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REFERENCES

ALLRED, K., and C. ALLRED. 1997a. The December 1996 Allred Hawaii Expedition. Newsletter of the Hawaii Speleological Survey, July 1997, No.2, pp.3-7.

ALLRED, K. AND C. ALLRED. 1997b. Development and Morphology of Kazumura Cave, Hawaii. Journal of Cave and Karst Studies, Vol.59, No.2, pp.67-80.

ALLRED, K. AND C. ALLRED. in press, 1997. Tubular lava stalactites and other related segregations. Journal of Cave and Karst Studies.

BAIRD, A.K., D.C. MOHRIG and E.E. WELDAY. 1985. Vapor deposition in basaltic stalactite, Kilauea, Hawaii. Lithos, 18, pp.151-160.

BEISER, A.. 1991. Physics, fifth edition. Addison-Wesley Publishing Company, Mass. 930pp.
BROWN, T.L., H.E. LEMAY JR. and B.E. BURSTEN. 1991. Chemistry the Central Science, fifth edition. Prentice Hall, NJ, 1045pp.
CARMICHAEL, I.S.E., F.J. TURNER and J. VERHOOGEN. 1974. Igneous Petrology. McGraw Hill, New York, 739pp.
CASHMAN, K.V., M.T. MANGAN and S. NEWMAN. 1994. Surface degassing and modifications to vesicle size distributions in active basalt flows. Journal of Volcanology and Geothermal Research 61, pp.58,60.
COOMBS, C.R., B.R. HAWKE and L. WILSON. 1990. Terrestrial Analogs to Lunar Sinuous Rilles: Kauhako Crater and Channel, Kalaupapa, Molokai, and Other Hawaiian Lava Conduit Systems. Proceedings of the 20th Lunar and Planetary Science Conference, Lunar and Planetary Institute, Houston. pp.195-206.
CRUIKSHANK, D.P. and C.A. WOOD. 1972. Lunar Rilles and Hawaiian Features: Possible Analogues. The Moon, 3, pp.412-447.
DALY, R.A., 1944. Volcanism and petrogenesis as illustrated in the Hawaiian Islands. Bulletin of the Geological Society of America, vol.55, pp.1363-1400.
FRANCZYK, K.J., E.K. GIBSON, and R.I. TILLING. 1987. Sulfur and carbon abundances in Hawaiian tholeiite lavas: 1972-1975 eruptions of Kilauea and 1975 eruption of Mauna Loa. U.S. Geological Survey Professional Paper 1350. pp.791-803.
GREELEY, R., The role of lava tubes in Hawaiian volcanoes. U.S. Geological Survey Professional Paper 1350, pp.1589-1602.
GREENLAND, L.P. 1987a. Hawaiian Eruptive Gases. U.S. Geological Survey Professional Paper 1350, pp 759-770.
GREENLAND, L.P. 1987b. Composition of gases from the 1984 Eruption of Mauna Loa Volcano. U.S. Geological Survey Professional Paper 1350, pp.781-790.
HARTER, R. 1971. Lava Stalagmites in Government Cave. Plateau, a quarterly of the Museum of Northern Arizona vol.4, no.1, pp.14-17.
HARTER, R.G. 1978. Strata of Lava Tube Roofs. NSS Bulletin 40, pp.118-122.
HARTER, R. 1993. Lava stalactites: terminology, shape and possible origins. Proceedings of the Third International Symposium on Vulcanospeleology, pp.111-112.
HELZ, R.T. and C. HELIKER. 1993. Thermal efficiency of lava tubes at Kilauea Volcano, Hawaii. (abstract) IAVCEI General Assembly, Canberra, pg.47.
HJELMQVIST, S. 1932. Uber Lavastalaktiten aus einer Lavhohle auf Sud-Island. Kungl. Fysiografiska Sallskapets I Lund Forhandlingar, BD2. Nr. 2. pp.6-13. (in German)
HON, K., J. KAUAHIKAUA, R. DENLINGER AND K. MACKAY. 1994. Emplacement and inflation of pahoehoe sheet flows: Observations and measurements of active lava flows on Kilauea Volcano, Hawaii. Geological Society of America Bulletin, vol.106, pp.351-370.
JAEGER, J.C. 1968. Cooling and solidification of Igneous Rocks. pp. 503-536, Basalts, vol.2. by H.H. Hess and Arie Poldervaart. Interscience Publishers, New York, 862pp.
JAGGAR, T.A. 1917a. Thermal gradient of Kilauea Lava Lake. Journal of the Washington Academy of Science, vol. VII, no. 13, pp.397-405.
JAGGAR, T.A. 1917b. Volcanologic Investigations at Kilauea. vol.44, pp. 200-216.
JAGGAR, T.A. 1931. Lava Stalactites, Stalagmites, Toes, and "Squeeze-ups". The Volcano Letter, No. 345, pp.1-3.
JAGGAR, T.A. 1947. Origin and development of craters. Waverly Press Inc., Baltimore, MD.
KAUAHIKAUA, J. 1996. personal communication, U.S. Geological Survey Hawaiian Volcano Observatory.
LARSON, C.V. 1993. An Illustrated Glossary of Lava Tube Features. Western Speleological Survey Bulletin 87.
MACDONALD, G.A. 1964. Hawaiian Volcanoes during 1955. U.S. Geological Survey Bulletin 1171, 170pp.
MCCLAIN, D.W. 1974. Geology of Lavacicle Cave Geological Area. a thesis for the University of Oregon.
OBERG, E. and F.D JONES. 1972. Machinery's Handbook. Industrial Press, New York, 2420pp.
PERRET, F.A. 1950. Volcanological Observations. Publication 549, Carnegie Institution of Washington, pp.74-77.
PETERSON, D.W. and D.A. SWANSON. 1974. Observed Formation of Lava Tubes During 1970-71 at Kilauea Volcano, Hawaii. Studies in Speleology, Vol.2, Part 6.
SWANSON, D.A. 1973. Pahoehoe Flows from the 1969-1971 Mauna Ulu Eruption, Kilauea Volcano, Hawaii. Geological Society of America Bulletin, v.84, pp.615-626, 13 Figs.
WEAST, R.C., M.J. ASTTE and W.H. BEYER. 1958. Handbook of Chemistry and Physics, Fortieth Edition. Chemical Rubber Company, Cleveland Ohio, 3456 pp.
WRIGHT, T.L. and R.T.OKAMURA. 1977. Cooling and Crystallization of Tholeiitic Basalt, 1965 Makaopuhi Lava Lake, Hawaii. U.S. Geological Survey Professional Paper 1004, 78 pp.

Int. J. Speleol., 27 B (1/4), (1998): 135-145.

THE ORIGIN OF TUBULAR LAVA STALACTITES** AND OTHER RELATED FORMS

Kevin Allred * and Carlene Allred *

ABSTRACT

Tubular lava stalactites are often found in lava tubes. Field observations, sample analysis, and comparative studies indicate that these are segregations extruded during cooling from partially crystallized lava at about 1,070 - 1,000 °C. Retrograde boiling (gas pressure) within the lava provides a mechanism to expel the interstitial liquid. In addition to tubular lava stalactites, a variety of other lava features can also result, such as lava helictites, lava coralloids, barnacle-like stretched lava, runners, runner channels, and some lava blisters and squeeze-ups.

Keywords: lava speleothems, soda straws, experimental growth

INTRODUCTION

The study sites for this paper are four lava tubes totaling approximately 71 km of mapped passages located on Kilauea volcano, Hawaii (Fig. 1). Here, as in other well preserved lava tubes we investigated in Hawaii and the western United States, interior surfaces are commonly coated with "a thin, smooth, vitreous surface" known as glaze (Larson, 1993). This is sometimes underlain by a variable layer of dark-hued rock on either broken or smooth surfaces. Where thick, the dark deposits are usually associated with slender, worm-like lava stalactites (Fig. 2,3). These are called tubular lava stalactites, and can be straight, branching, eccentric, or even deflated. Their interiors are usually an entrainment of elongated vesicles and septa, but some examples are completely solid or hollow (Larson, 1993). Where these stalactites drain, globular stalagmites might be built (Fig. 2,3). Previous investigators have theorized these stalactites originated from: 1. water vapor (Dana 1849, Brigham 1868, Dana 1889), 2. remelt (Jaggar 1931, Hjelmqvist 1932, Perret 1950, McClain 1974, Baird, Mohrig and Welday 1985), and 3. other means (Williams 1923, Harter 1993, Favre 1993, Ogawa 1993, Allred 1994).

METHODS

Some tubular lava stalactites and ceiling lining samples were crushed and then tested for grain density using kerosene as a displacement medium. Eight thin sections were made of stalactite and ceiling lining samples. X-ray analyses were done on a Philips X-

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** After the submission of the paper, the Authors regrettably decided to print it in the "Journal of Cave and Karst Studies", Vol. 60, n. 3: 131-140.
In order to supply the participants to the Symposium with a complete set of the papers presented at the Sympsium, the Editor decided to keep in these Proceedings such a paper.
Nevertheless it must be stressed that any effort to avoid these double printings should always be done.

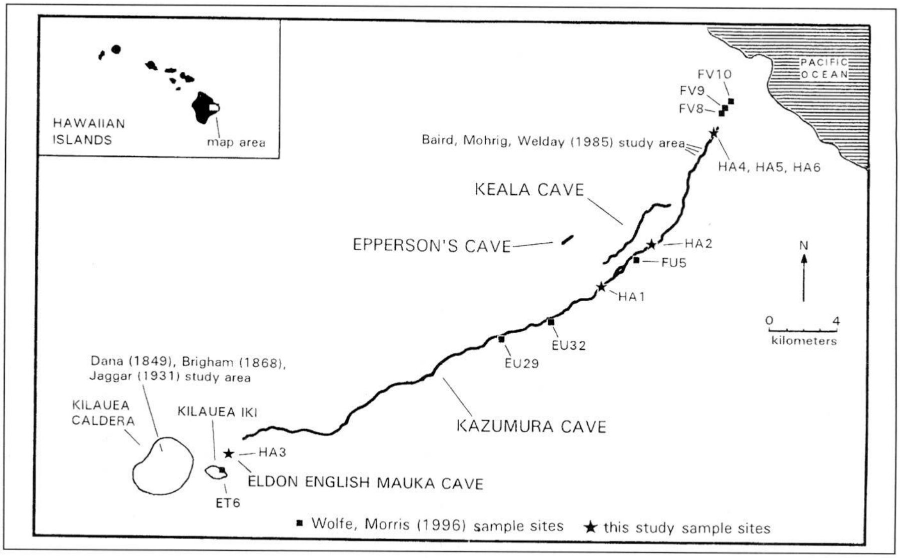

Fig. 1. study caves. Keala from S. Kempe, (pers. comm.). Eppersons from W.R. Halliday (pers. comm.). Kazumura and Eldon English Mauka Caves after Hawaii Speleological Survey (NSS) files. Bulk rock samples from Wolfe and Morris (1996).

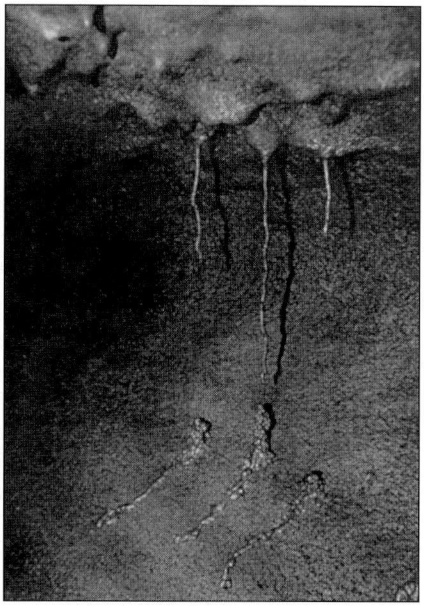

Fig. 2. Tubular lava stalactites, stalagmites and runners. The Marriage Passage (an extraneous lava tube) in Kazumura Cave. Photo by Mike Shambaugh.

ray diffractometer for modal composition. Chemical analyses of 69 elements were made of a group of small tubular lava stalactites and the parent lining 1 - 3 cm above the stalactites. This was done primarily by ICP-AES (inductively coupled plasma emission spectrometry), INAA (instrumental neutron activation analysis), ICP/MS (inductively coupled plasma-mass spectrometry), and XRF (X-ray fluorescence spectroscopy).

Field observations in 1995 and 1996 were correlated with paraffin models used to simulate tubular lava stalactite growth. A caldron of liquid paraffin drained through a coarse filter, valve, and tube, into a small cooling reservoir. The paraffin then seeped through a sponge filter and out a final tube. Temperature was monitored with thermometers in both containers.

DISCUSSION

Field observations give us some clues as to the origins of tubular lava stalactites and related forms. In some instances it can clearly be seen that their fluids originated from within the rock itself, as manifest by tiny conduits directly above their uppermost portions. Most tubular lava stalactites we found tended to be eccentric and kinky nearer their ends (Fig. 3). Others had formed only as an incipient coralloid shape (Halliday, 1994). They are called runners (Larson, 1993) where they are found against a surface

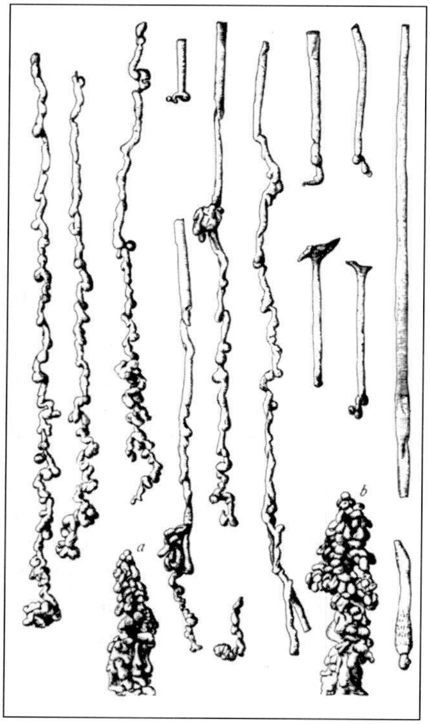

Fig. 3. Tubular lava stalactites and lava stalagmites thought to be from Kaumana Cave near Hilo, Hawaii (Dana, 1889). The lower ends of the stalactites tend to be more eccentric. As is typical, stalagmites show signs of more fluidity nearer their bases.

Fig. 4. Squeeze-up, Keala Cave. This erupted lava is suspected of being extruded in a similar fashion to tubular lava stalactites. The battery above the rounded cap is 5 cm long. Photo by Carlene Allred.

(Fig. 2). If runners flowed down a tubular lava stalactite, the original free-dripping portion can be identified by its annular growth rings.

The globular structures of the stalagmites tend to be more runny, and less distinct at their bases (Fig.2,3). The stalagmites were usually deposited after the floor of the tube had stopped moving. Rarely a line of driblets had fallen on a slowly moving floor before a stalagmite was finally formed.

Other kinds of lava features result from extrusions similar to those described above. Dripped "lava roses" (Larson, 1993) can form by falling masses and sheets of lava originating from within ceilings. "miniature volcanoes" (Jaggar, 1931), or "small spatter cone[s]" (McClain, 1974) were forced upwards from ledges or floors. Those we observed often had rounded caps (Fig. 4) and runners around their robust perimeters. Others had crater-like depressions at their tops and resembled miniature volcanos. Lava blisters are sometimes found associated with tubular stalactites and the squeeze-ups. Jaggar (1931) described "barnacle stalactites". We sometimes found these stretched, grooved, forms associated with tubular lava stalactites behind slumped ceiling linings (Fig. 5). They are also common around contracted perimeters of subsided plunge pools.

Concepts of Filter Pressed Segregation

Wright and Okamura (1977) explained that lava can "segregate" from a partially crystallized melt at temperatures between 1,030 and 1,070°(°C). This results in veins of "relatively coarse grained, glassy, vesicular rock" differing in composition from the main body of lava. They aptly describe this process, which is called filter pressed segregation, in lava lakes of Kilauea Volcano:

"The crystal framework of the crust behaves as a filter, through which the liquid fraction moves into the open fracture. The efficiency of the filtration process is variable. Some segregations carry in crystals, so that the bulk composition of the segregation does not lie on the liquid line of descent for the lake as a whole, whereas other segregations are virtually free of early-formed crystals".

Wright and Helz (1987) concluded that highly differentiated segregations can occur in contraction cracks of these lakes between temperatures of 1,060 - 1,000(C, even when interstitial liquid becomes 10% or less. They were inferred to be gas-driven.

We submit that tubular lava stalactites and other related forms are actually segregations ejected by expanding gas into the cave passages. Like the cracks in the cooling lava lakes of Kilauea, some lava tube contraction cracks had been injected with interstitial liquid from both opposing surfaces after they split apart. This material did not come from flowing parent lava of the lava tube. If cracks were widening during the extrusions, stretched barnacle-like forms grew (Fig. 5). It is important to note that the majority of lava tube cracks lack segregations because of improper conditions, or may have opened nearer or below solidus, given as 980°(°C) by Wright and Okamura (1977). Not all extrusive phenomena are filter pressed segregations. For example, settling of crusts may have extruded some parent lava as blisters and squeeze-ups.

Segregation emergence

Why and how did the lava tube segregation extrusions occur only after the lava had reached an advanced stage in crystallization? Rounded bubbles, or vesicles are formed from volatile exsolution at a time when only a small percentage of lava has crystallized.

When 50 to 55% of the lava becomes crystallized at about 1070 °C-1065 °C, it ceases to flow (Wright and Okamura 1977, Peck 1978). This transition is called the crust-melt interface. With more progressed crystallization, interstitial liquids can effervesce between crystal faces to form irregular vugs (Peck, 1978). This is because as crystallization becomes more advanced, volatiles (chiefly H_2O) will be concentrated in the residual melt and retrograde boiling occurs (Best 1995, pg. 246, 292). It is significant that we observed more intense vuggy fabric in linings having higher concentrations of tubular stalactites and other segregations (Fig. 6). In such fabric, vesicle surfaces can become honeycombed with vugs until only their general spherical shapes remain. At least some of the interstitial melt is forced out into the cave to form tubular stalactites (Fig. 7).

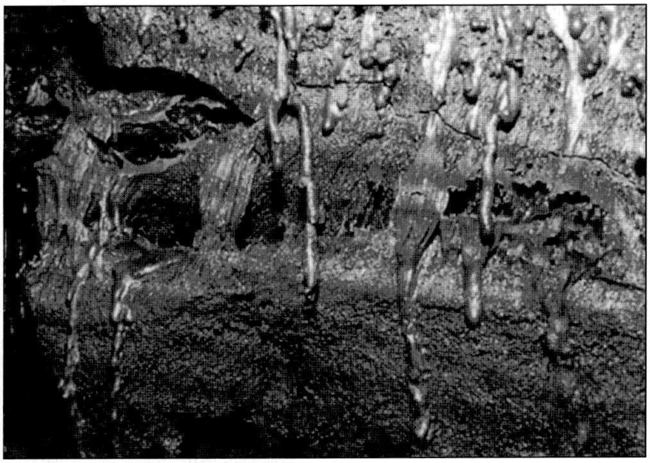

Fig. 5. Barnacle-like stretched lava, Kazumura Cave. Lava forming these was extruded as the crack widened. If the lower part fell away, only the "stalactite" portion remains. Photo by Mike Shambaugh.

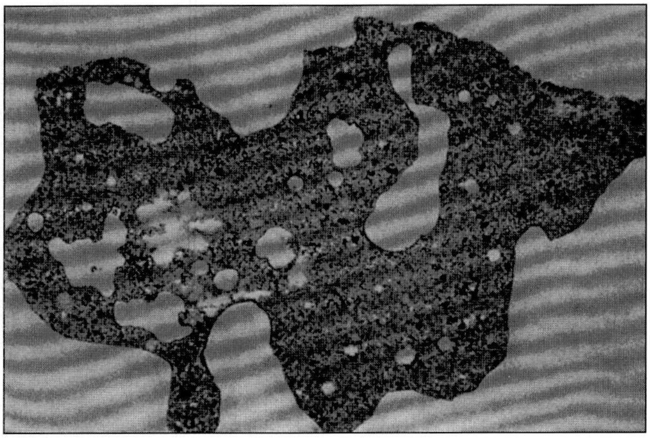

Fig. 6. Vuggy fabric in HA2 lining above a small darker tubular lava stalactite. The stalactite is 8 mm long. Photo by Margaret Palmer.

The occurrence of coarse grains in segregations is evidence of increased diffusion of atoms from high H_2O content. Low viscosity of residual liquid may result from some water molecules combining with O in Si-O tetrahedra to break their chains. Addition of K_2O and Na_2O to silicate melts plays a similar role (Best 1995, pg. 232, 293). With this in mind, we observed a tendency of brownish colored segregation material to have once been very fluid with almost none of the magnetite prevalent in the more common dark gray samples. This may indicate extensive oxidation to hematite under high H_2O conditions that would cause retrograde boiling. Vesiculation in segregations (Anderson et al., 1984) is further evidence that the driving force was retrograde boiling. Even later retrograde boiling can form vugs in tubular lava stalactites and stalagmites to extrude helictites or coralloids (Fig. 8). None of these second order segregations have yet been analyzed.

Comparisons with paraffin models

To help understand the origin of tubular lava stalactites, we were able to simulate their growth using paraffin at approximately 65-70 °C. Paraffin flow was regulated by inserting a sponge plug into the drainage tube which fed the stalactites. This is similar to the process of filter pressed segregation in lava, but where gravity takes the place of gas pressure. The resulting paraffin stalactites were 3 - 4 mm in diameter, and up to 15 cm long. As driblets drained quickly through a stalactite and dripped from the growing tip

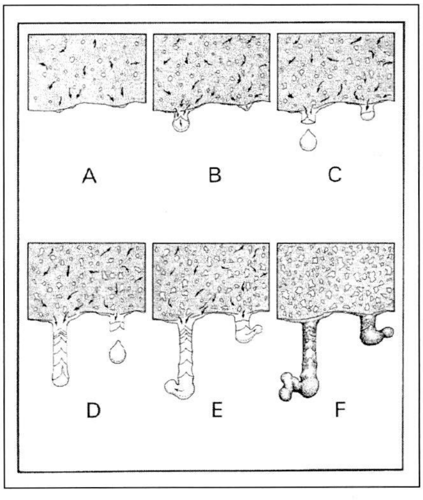

Fig. 7. Proposed extrusion of tubular lava stalactites.
A. Retrograde boiling in the lining creates vugs and begins extruding a thin discontinuous layer of residual melt.
B. Continued residual outpourings collect in some discrete points.
C. Incipient tubular shapes become more apparent, and vugs continue to form in the lining.
D. Continued addition of drip segments creates growth rings. Splitting of the newest skin is perpetuated to additional segments as new driblets emerge.
E. Cooling promotes crystallization of the bottom part of emerging driblets, forcing the liquid to the side or upward into eccentric shapes. Vesicle surfaces have become honeycombed by vuggy fabric.
F. Cooled stalactites.

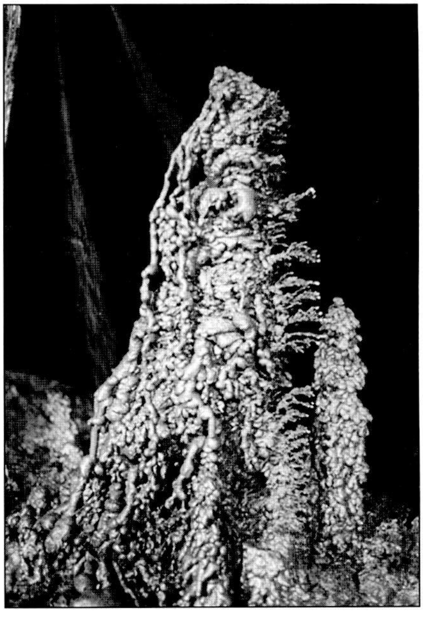

Fig. 8. Lava coralloids (second-order segregations) extruded from a large lava stalagmite, Eppersons Cave. During the cooling of the lava tube the coralloids formed on the upstream side, and probably leeward of a breeze. The stalagmite is 50 cm high. Photo by Mike Shambaugh.

(Fig. 9), a thin flexible skin extended in segments. We sometimes observed the skins of newest segments splitting open and closing repeatedly parallel to the axis during cyclic driblet movement. This segmenting and splitting is reminiscent of growth rings and linear seams on some tubular lava stalactites.

The paraffin stalactites could be diverted into eccentric directions. Paraffin has high solidification contraction of 14.89% volume. Since the solids will be heavier, they tend to congeal in the bottom of the emerging driblet. The driblet is held to the last segment by surface tension, and the skin is thinnest around the sides of the driblet where spreading is occurring. If the drainage is allowed to cool sufficiently (due to convection farther down the stalactite, or from diminished flow), pressured liquid pushes out or upwards from the side of the driblet, beginning an eccentric form. These breakouts can also occur nearer the attachment point of a stalactite resulting in a compound form. If a breeze is present, preferential growth is leeward. We believe a similar process is involved in the formation of eccentric tubular lava stalactites since lava contracts about 13% (Daly, 1944) (compare Fig. 3, 10). If the paraffin temperature was too hot, a stalactite could not form, and all of each driblet fell into puddles below.

Petrographic Analysis and Density

Our sectioned samples (Table 1) were generally similar to tubular stalactites of previous petrographic studies (Dana 1889, Hjelmqvist 1932, McClain 1974, Baird and oth-

Sample	Olivine	Pyroxene	Plagioclase	Ilmentite	Magnetite	Hematite	Glass, Zeolite[4]	Apatite	Total
HA1 shark tooth stalactite composed of seven linings	?	36.04	31.39	1.16	12.79	1.16	17.44		99.98
HA2 lining portion directly above tubular stalactite		29.16	30.55		15.27	5.55	19.44		99.97
HA2 tabular stalactite portion of sample		16.00	25.00	2.00	19.00	11	27.00[6]		100.000
HA3 both tubular stalactites and portion above are segregations		12.24	16.32		23.46		47.95[6]		99.97
HA4 stalagmite, transverse cross section		32.46	23.37		29.87	3.89	10.38		99.97
HA4 stalagmite, axial cross section		28.41	15.90	1.13	32.96	2.27	18.17	1.13	99.97
HA5 outer portion of HA6, directly above a small tubular stalactite	*	49.99	30.48		12.19	1.22		6.09	99.97
HA5 small tubular stalactite of HA6		39.60	22.77		24.75		8.91	3.96	99.99
HA6 lining from which tubular stalactites had grown	*	66.66	16.00		10.66	2.66		4.00	99.98
Hj[1] tubular stalactite, Raufarholshellir Cave, Iceland		19.00	19.80		7.90	17.90[2]	35.40[3]		100.00
MLL[5] Chemical mode for average Makaopuhi basalt	6.50	39.80	42.50	4.20	1.00		5.00[3]		100.00

Table 1. Modal compositions (volume percent). Segregations are shaded. [1], from Hjelmquist (1932); [2], the outer crust of the stalactite, and includes both hematite and magnetite; [3], all glass; [4], undetermined amounts of zeolite were detected in the glass; [5], uncorrected modes (Wright and Okamura, 1977, Table 14); [6], includes minor amounts of clay deposited on the exterior surfaces of stalactites after they were formed; *, olivine was visible in lining and may have been included in point counts for pyroxene.

ers 1985). The segregations are of darker hue, more coarsely grained, and are higher in magnetite and glass content, than the linings from which they extruded. We found that tubular stalactites can often easily be picked up with a magnet, due to high magnetite content throughout.

Glaze is a <50 micron thick magnetite skin which has a characteristic silver luster from light reflecting off facets of tiny octahedrons. This magnetite ornamentation appears to have grown after the greenish pyroxene-rich surface had begun to crystallize on many lava tube surfaces. We found rare sites of greenish colored linings and tubular stalactites lacking much of the magnetite ornamentation. A reddish color can result when glaze has been oxidized to hematite. The magnetite indicates low temperature crystallization between 1030 °C and solidus (Wright and Okamura, 1977). Thus, we question the prevailing assumption that glaze is evidence of remelt (Jaggar 1931, Peterson and Swanson 1974, Harter 1978, Allred and Allred 1997). As for the darker-hued, coarsely grained, layer sometimes found under some glaze of our samples, this is segregated material. The chemical compositions of tubular lava stalactites and lining above them are found in Table 2. Table 3 shows that many incompatible trace elements are concentrated to nearly 200% in the stalactites. This is another indication that the segregations occurred at about the crust-melt interface. Other elements are compatible with the early formed mineral, olivine, and have lesser concentrations in the stalactites.

In lining/tubular stalactite samples, the transitions between the linings and segregations were much less distinct than between typical layered linings. In the lining/stalactite samples, pyroxene crystals and laths of plagioclase often extended deep into either side of the transition zone, indicating segregation drainage through the crystalline framework.

Runner Channels

Sometimes shallow, incised, "runner" channels are found which extend vertically

Oxide	Tubular stalactite, Kilauea Caldera. (1868)[1]	Tubular stalactite, Kazumura Cave. (1985)[2]	Tubular stalactite HA6, Kazumura Cave. (this study)[6]	Parent lining of tubular stalactite HA6, (this study)[6]	Average parent lava flow. (1996)[3] of the Kazumura upper flow	lower flow	Segregation vein, Makaopuhi Lava Lake. (1977)[4]	Average Makaopuhi basalt. (1977)[5]
SiO_2	51.9	53.3	49.14	48.74	50.70	50.70	50.77	50.18
Al_2O_3	13.4	13.8	12.49	13.70	13.13	13.00	12.27	13.26
Fe_2O_3	15.5		15.33	12.07	12.66	2.87	4.26	1.48
FeO		10.4			--	8.65	10.45	9.86
MgO	4.8	5.5	5.23	8.37	7.85	8.42	4.23	8.27
CaO	9.6	10.9	9.37	11.07	11.33	11.02	8.47	10.82
Na_2O	3.0	2.8	3.05	2.46	2.08	2.10	2.75	2.32
K_2O	1.1	.5	.65	.33	.38	.39	1.11	.54
TiO_2		2.8	3.63	2.08	2.52	2.30	4.49	2.64
P_2O_5			.35	.19	.23	.25	.52	.27
MnO	.8		.20	.17	.17	.20	.20	.17

Table 2. Chemical composition of segregations and Kilauean parent lavas (weight percent). Segregations are shaded. [1], silica oxide and sodium oxide were designated as SiO3 and NaO respectively (Brigham, 1868); [2], collected from Kazumura Cave (Baird, Mohrig and Welday, 1985), total Fe calculated as FeO; [3], from Wolfe and Morris (1996); [4], segregation vein from Makaopuhi lava lake sample 68-2-10 (Wright and Okamura, 1977); [5], Wright and Okamura (1977), Table 12; [6], detection limit of 0.01%.

Element	Au	As	Ba	Br	Co	Cr	Cs	Hf	Ir	Rb	Sb	Sc
detection limit/unit	1 ppb	1 ppm	1 ppm	0.5 ppm	0.1 ppm	0.5 ppm	0.2 ppm	0.2 ppm	1 ppb	10 ppm	0.1 ppm	0.01 ppm
HA6 lining	-2	2	105	-0.5	45.1	695	-0.2	7.6	-1	-10	0.4	29.1
HA6 tubular stalactites	8	2	173	-0.5	42.1	351	-0.2	7	-1	-10	0.7	27.5

Element	Se	Ta	Th	U	W	La	Ce	Nd	Sm	Eu	Tb	Yb
detection limit/unit	0.5 ppm	0.3 ppm	0.1 ppm	0.1 ppm	1 ppm	0.1 ppm	1 ppm	1 ppm	0.01 ppm	0.05 ppm	0.1 ppm	0.05 ppm
HA6 lining	-0.5	0.6	0.7	-0.1	-1	8.4	21	15	4	1.43	0.7	1.76
HA6 tubular stalactites	-0.5	1	1.2	0.5	2	16.9	42	30	7.29	2.46	1.3	3.01

Element	Lu	Sr	Y	Zr	V	Mo	Cu	Pb	Zn	Ag	Ni	Cd	Bi	Be
detection limit/unit	0.01 ppm	1 ppm	1 ppm	1 ppm	1 ppm	2 ppm	1 ppm	5 ppm	1 ppm	0.5 ppm	1 ppm	0.5 ppm	5 ppm	2 ppm
Ha6 lining	0.25	308	23	122	270	3	118	14	87	2.4	151	-0.5	25	-2
HA6 tubular stalactites	0.42	341	41	234	390	3	235	-5	129	2.9	58	-0.5	15	-2

Table 3. Trace and rare earth elements of HA6 lining and stalactites. (-) Indicates below detection limits.

down the cave walls. Those we observed were up to 20 mm wide, 5 mm deep, and up to a meter long (Fig. 11). These "appear" to have been melted into the already solidified walls by hotter lava extruded into the cave through tiny holes in the walls. We believe the volatile-supersaturated segregations pouring from the orifices reacted with the residual liquid of the hot wall lining. This caused some residual liquid to become less viscous and flow away with the segregations. Best (1995, pg. 234) calls this process "depolymerization". In such circumstances, previously crystallized olivine and other minerals would be undermined and wash down the channels with the liquid. Exit holes and internal conduits above the channels seem to have been enlarged as well. Indeed, it may be that "roots" observed to extend above some tubular stalactites (Harter, 1971, 1993) were formed by residual melts depolymerizing along the paths of segregations. As with the other segregated features, the depolymerization occurred during cooling of the lava tube. It is important to emphasize that none of these processes have anything to do with a "remelt" scenario. Although the eventual solidus temperature might be lowered by increased H2O in residual melts, there is no change from crystalline to melt.

CONCLUSIONS

Based on evidence stated above, we conclude that tubular lava stalactites and some other extrusions in lava tubes are filter pressed segregations extruded by retrograde boiling from partially crystallized lava. They occur at or below the crust-melt interface between about 1070 and 1000(C. Segregations differ from their parent linings in density, texture, mineral ratios, and chemical composition. In some cases, segregations depolymerized residual liquid in partially crystallized linings.

Genetically, the outer shells of tubular stalactites function like the insulative linings of the lava tubes in which they grow. The great varieties of these and related features are influenced by composition of the parent lavas, when the segregations occur, the efficiency of filtering, and the complex, open environments under which they cool.

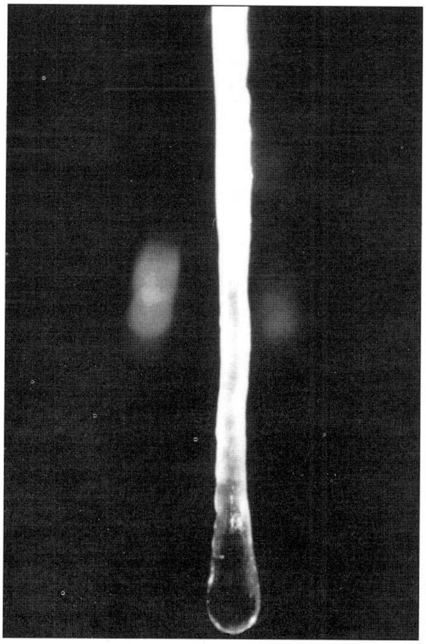

Fig. 9. Tubular paraffin stalactite during growth. The stalactite diameter is 3 mm. Photo by Carlene Allred.

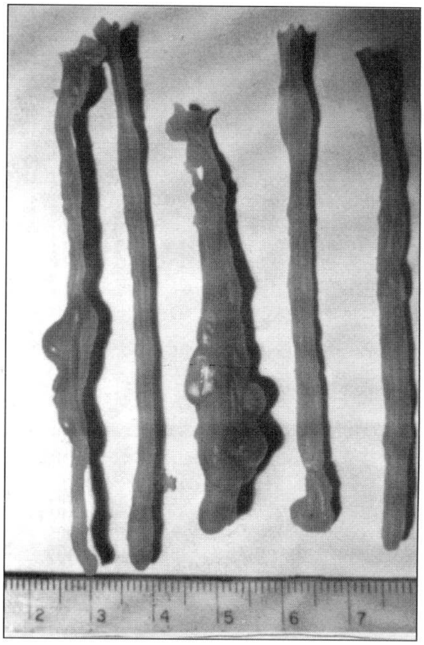

Fig. 10. Some tubular paraffin stalactites. The stalactite diameters are >3 mm. Photo by Carlene Allred.

Fig. 11. Runner channels with subsequent runners, Keala Cave. The scale is 15 cm long. Photo by Kevin Allred.

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REFERENCES

Allred, K. 1994. A Possible Explanation for the Formation of Tubular Lava Stalactites. Hawaii Grotto News, vol.3, No. 2, pg.10.

Allred, K. and C. Allred. 1997. Development and morphology of Kazumura Cave, Hawaii. Journal of Cave and Karst Studies, vol.59, No.2, pp.67-80.

Anderson, A.T. Jr., G.H. Swihart, A. Giberto and C.A. Geiger. 1984. Segregation vesicles, gas filter-pressing, and igneous differentiation. Journal of Geology, vol. 92, pp. 55-72.

Baird, A.K., D.C. Mohrig and E.E. Welday. 1985. Vapor Deposition in Basaltic Stalactites, Kilauea, Hawaii. Lithos, 18, pp. 151-160.

Best, M.G. 1995. Igneous and Metamorphic Petrology. Blackwell Science. Cambridge, Massachusetts. 630 pp.

Brigham, W.T. 1868. Notes on the Volcanic Phenomena of the Hawaiian Islands, with a description of the modern Eruptions. Memoirs, Boston Society of Natural History, vol.1, part III pp.341-472.

Daly, R. A. 1944. Volcanism and petrogenesis as illustrated in the Hawaiian Islands. Bulletin of the Geological Society of America, vol. 55, pp. 1363-1400.

Dana, E.S. 1889. Contributions to the Petrography of the Sandwich Islands, Art. XLVI, American Journal of Science, pp. 441-459 and plate XIV.

Dana, J.D. 1849. United States Exploring Expedition During the Years 1838, 1839, 1840, 1841, 1842. Vol. 10, pg. 177, 201. C. Sherman, Philadelphia.

Favre, G. 1993. Some Observations on Hawaiian Pit Craters and Relations with Lava Tubes. Proceedings of the Third International Symposium on Vulcanospeleology, pp. 37-41.

Halliday, W.R. 1994. Extrusion of lava coralloids and dripstone. Hawaii Grotto News, vol.3, No. 2, pg.10.

Harter, R. 1971. Lava Stalagmites in Government Cave. Plateau, The Quarterly of the Museum of Northern Arizona, vol. 44, no.1, pp. 14-17.

Harter, R.G. 1978. Strata of Lava Tube Roofs. NSS Bulletin 40: pp.118-122.

Harter, R. 1993. Lava Stalactites: Terminology, Shape, and Possible Origins. Proceedings of the Third International Symposium on Vulcanospeleology. pp. 111-112.

Hjelmqvist, S. 1932. Uber Lavastalaktiten aus einer Lavahohle auf Sud-Island. Kungl. Fysiografiska Sallskapets I Lund Forhandlingar, Bd 2, Nr 3, pp. 6-13. (in German)

Jaggar, T.A. 1931. Lava stalactites, stalagmites, toes, and "squeeze-ups". The Volcano Letter, Hawaiian Volcano Observatory, National Park, Hawaii, No. 345: 1-3.

Larson, C.V. 1993. An Illustrated Glossary of Lava Tube Features. Western Speleological Survey Bulletin 87, pg. 16.

McClain, D.W. 1974. Geology of Lavacicle Cave Geological Area. a thesis for the University of Oregon.

Naughton, J.J. 1975. Fiber-containing and Crystal-lined Basaltic Vesicles: Possible Lunar Analogs. American Mineralogist, Volume 60, pp. 1118-1121.

Ogawa, T. 1993. On Lava Caves in Japan and Vicinity. Proceedings of the Third International Symposium on Vulcanospeleology, pp. 56-73.

Peck, D.L. 1978. Cooling and Vesiculation of Alae Lava Lake, Hawaii. U.S. Geological Survey Professional Paper 935-B, 59 pp.

Perret, F.A. 1950. Volcanological Observations. Publication 549, Carnegie Institute of Washington. pp.74-77.

Peterson, D.W. Swanson, D.A., 1974. Observed Formation of Lava Tubes. Studies In Speleology, vol.2, part 6, pp.209-222.

Williams, I.A. 1923. The Lava River Tunnel. Natural History, vol.23, pp.162-171.

Wolfe, E.W. and J. Morris. 1996. Sample data from the geological map of Hawaii. U.S. Geological Survey Professional Paper 1004, 78pp.

Wright, T.L. and R.S. Fiske. 1971. Origin of the Differentiated and Hybrid Lavas of Kilauea Volcano, Hawaii. Journal of Petrology, vol.12, No.1, pp.1-65.

Wright, T.L. and R.T. Okamura. 1977. Cooling and Crystallization of Tholeiitic Basalt, 1965 Makaopuhi Lava Lake, Hawaii. U.S. Geological Survey Professional Paper 1004, 78 pp.

Wright, T.L. and R.T. Helz. 1987. Recent Advances in Hawaiian Petrology and Geochemistry. U.S. Geological Survey Professional Paper 1350, pp. 625-640.

Int. J. Speleol., 27 B (1/4), (1998): 147-153.

THE 1981 ERUPTIVE FISSURE ON MT. ETNA: CONSIDERATIONS ON ITS EXPLORATION AND GENESIS

Angelo Leotta * and Marco Liuzzo *

ABSTRACT

This paper is targeted to an analysis of features common to various fissure caves on Mt. Etna, Sicily. The Authors report the preliminary results of the exploration carried out in the 1981 eruptive fissure, the technical problems met during the exploration, the flow trends and the different courses of the molten material inside the fissure, the particular morphologies. A genetic model is proposed, different from those characterising the lava tube cave genesis, and links are suggested between the various fissures and the main tectonic stress systems operating on Mt. Etna, as well as the morpho-structural conditions of the volcanic edifice of Mt. Etna.

Keywords: speleogenesis; eruptive fissure; Mt. Etna, Italy

FOREWORD

The eruptive fissures of Mt. Etna have been carefully and systematically investigated in the last decade. Starting from a limited knowledge of the upper segment of some fissures, this study brought to a list of eight fissure caves completely surveyed (table 1):

N	NAME OF THE CAVE(S)	ERUPTION YEAR	INVOLVED FLANK
1	Abisso di PROFONDO-NERO (Deep-Black Abyss)	1923	North-East
2	Abisso del GHIACCIO (Ice Abyss)	1947	North-East
3	Buca della MARINITE (Marinite Hole)	1928	East
4	Grotta delle PALOMBE (Doves Cave)	1669	South-East
5	Grotta MARASCA (Marasca Cave)	1986	East
6	Grotte di SERRACOZZO I-II (Serracozzo I-II Caves)	1971	East
7	Bocche Eruttive di Ripa della Naca (Eruptive Vents at Ripa della Naca)	1928	East
8	Fratture del 1981 (1981 Eruptive Fissures)	1981	North

Some cavities, e.g. the Palombe, the Serracozzo, the Marasca and the Marinite caves, are partially fissure and partially lava tube caves; other caves, e.g. the 1780 fissure cave, have been sealed by subsequent eruptions and cannot be further investigated. The first two caves in the list resulted more than 100 m deep, with several hundreds of meters length, whereas our survey ascertained much smaller dimensions in the remainder caves.

It must be also considered that each lateral eruption outcrops from a fissure opened in the volcano flanks, which means that much more fissure caves than the known ones are potentially existing on Mt. Etna, although several fissures are actually inaccessible.

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GEOLOGIC PATTERNS

Mt. Etna rises to more than 3300 m North of the Plain of Catania, in the western Mediterranean area; it is the highest active volcano in Europe. The first volcanic evidences date back to 500.000 years ago: traces of submarine intrusions have been ascertained at Acicastello (Romano, 1982), a coastal village close to Catania. During the subsequent phases of the volcanic activity, the volcanic axes migrated from the SE sea bottom to NW, shifting from submarine to subaerial conditions, up to the present position.

Mt. Etna presently produces a generally basic magmatism, featured by low viscosity lava, which in turn facilitates the lava cave formation, witnessed by over 200 caves known and surveyed on the volcano (AA. VV., 1994).

The classic volcanology outlines two main kinds of eruption: the summit eruptions and the lateral ones. The first type outpours from the central eruptive apparatuses of the volcano. The central eruptions on Mt. Etna did not generate significant caves from a speleological point of view, due to several reasons; Mt. Etnas eruptive style and prevailing morphology are worth consideration among them.

The latter type, i.e. the lateral eruptions, can outpour from whichever side of the volcano, at whichever height, through a breach in the surface crust. Such a gap allows the magma to raise toward the surface, forming one or more ephemeral cones, wherefrom explosive and effusive products are thrown all around. The molten lava effusions govern the formation of the well known lava tube caves, whereas the eruptive fissures and the related overlying cones (through which the access to the hollow could be possible) support the genesis of the fissure caves (fig. 1).

The magma flows inside the fissure by a composite motion, which can be temporally altered, since the local surfacial topography governs vertical mouvements (upward and downward) and lateral downflows. The fissure is first invaded by gases, which open the preexisting weakness planes by their high temperature and pressure, and prepare the path for the hot molten material. Gases themselves govern the upward magma motion: the deep magma chambers hold the gases completely dissolved in the molten body, and volcanologists name "hypomagma" this phase. The opening of the fissure generates a reduction in the hydrostatic pressure affecting the magma; this in turn induces a segregation of the gases into bubbles exerting their own internal pressure, and this latter phase is named "pyromagma" by volcanologists. Due to their reduced density in comparison with the molten material, the bubbles trend upward, and their velocity is directly proportional to the square of their radius and inversely proportional to the viscosity of the molten stuff (Stokes Law). The loss of hydrostatic pressure causes an adiabatic dilatation of the bubbles, which increase their ascensional velocity and share their motion with the engulfing fluid.

When a bubble reaches the surface, the gases explode and can throw molten spatters even at a distance of hundreds of meters (Rittmann, 1967). The spatters falling around the fissure build up welded spatter cones named hornitos, often aligned with the direction of the fissure (Fig. 2), whereas the effusive vent, named oven mouth, is placed at the lower end of the fissure. The environment beyond the oven mouth is wider and no more saturated by magma, and lava can freely degas to the air. This passage couples the one from phreatic into vadose or subaerial circulation in a carstic environment. In other words the magma comes to surface under gases push, and outpours from the lower end of the fissure. This determines a fluids lateral motion, to be added to the previously described vertical motion. Yet magma rate of discharge vary continuously during the eruption, and this governs in turn a downward variable motion inside the fissure.

The resulting motion of magma inside the fissure, governed by the named factors,

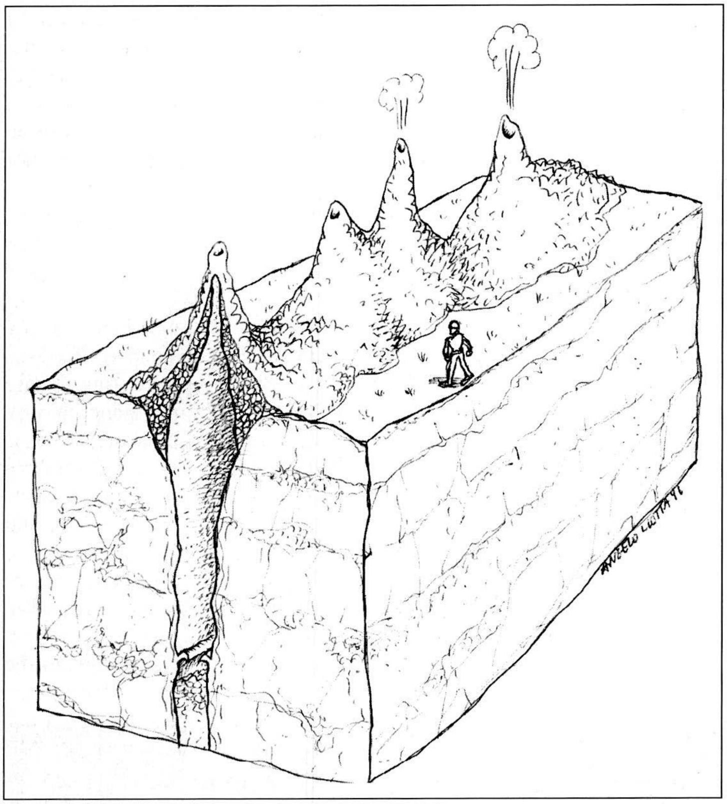

Fig. 1 - Ipotetic tridimensional sketch with hornitos, fissure and, inside, small horizontal shelves.

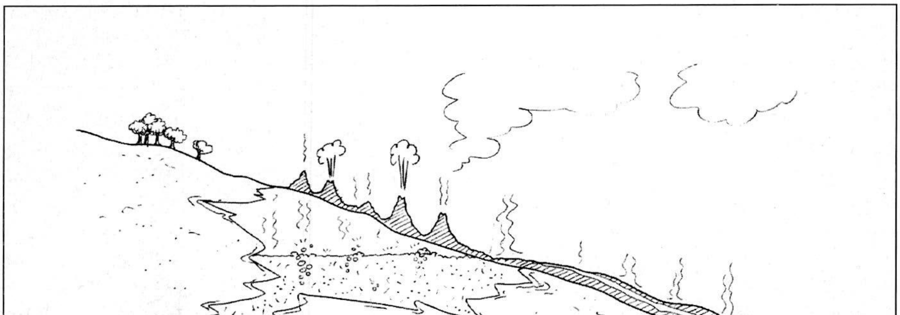

Fig. 2 - Hornitos aligned with the direction of the fissure: at the lower end is placed the effusive vents, named "oven mouth".

should involve a slantwise trend, though no witness can be found, since a diminution of the upward push results into a fall down of the discharge rate and this induces in turn a downward vertical motion of the fluid inside the fissure, up to the end of the eruption. Any possible slanting trace produced on the still plastic walls of the fissure, is only a relic, generally effaced by the most usual vertical groves produced by the last motion (Fig. 3). The decreased flow rate induces the formation of a hollow in the upper part of the fissure, which can be eventually explored by the speleologists (Fig. 4).

GENETIC MODEL AND CAVES MORPHOLOGY

According to Anderson and Grews theory (stress corrosion cracking theory, 1977), the ascending magma exerts an excess of pressure on the lithostatic load in the area close to the surface, and this generates an upward trending gap. No preexisting fissure is required for implementing this mechanism. Yet some weakness trends, generated by the regional tectonics, could supply a path to the ascending magma. A pressure increase inside the magma chamber allows the gases to segregate from the fluid and start an upward push by widening a preexisting fissure, or opening a new one in a weaker area. Then the gases squeeze themselves inside the fissure, and implement an additional widening by corrosion. At this stage the molten material, pushed upward by the gases, bursts into the gap and breaks out the actual path of the effusion toward the surface.

The first batch of the fluid becomes immediately chilled for the abrupt thermal fall in the contact area with the engulfing rocks. Thus a non-conducting pad prevents further heath losses during the fluids upward motion. The chilling of the fluid inside the

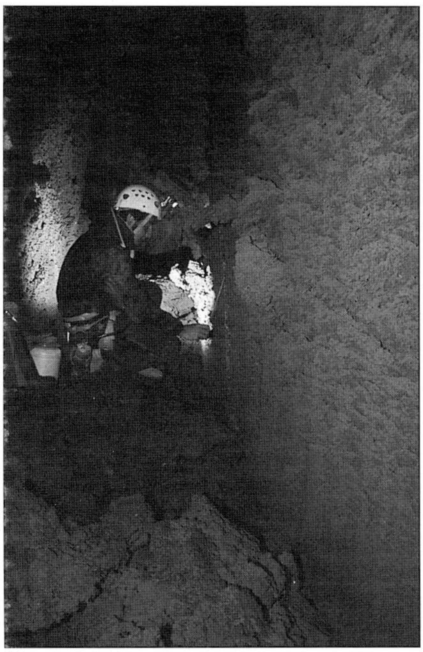

Fig. 3 - Trace produced by the last motion.

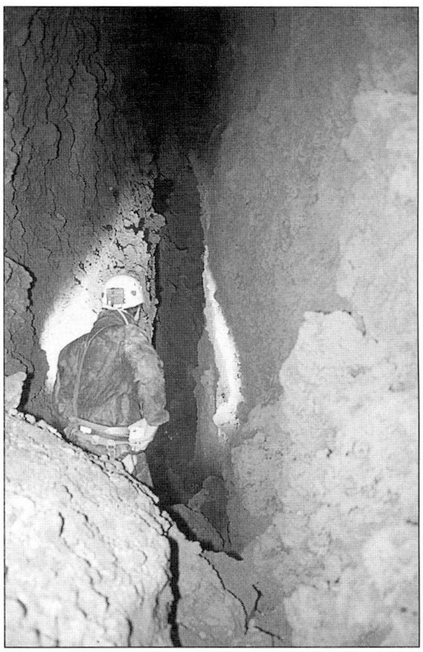

Fig. 4 - The upper part of the fissure which can be explored.

fissure is centripetal: therefore subsequent concentric plaster layers are formed, starting from the fissure inner surface.

A remarkable feature observed inside the eruptive fissures is that they consist of a train of hollows spaced by intermediate oven mouths, rather than a single vertical hollow. A parallelism can be suggested, between the outer ephemeral vents and the inner oven mouths, according to the age and the position of the fissure, by observing the external morphology of the lava flows. The eruptive fissures are therefore extremely jointed hollows which develop downward through a train of levels increasingly deep spaced by inner oven mouths; these latter are distributed according to a kind of regressive migration, with an increasingly low level inside the fissure, from the outermost mouth downslope to the increasingly innermost ones, whose height is topographically lower.

The hollow inside the examined fissure has not a linear trend: the inner wave-shaped surfaces governed the magmatic flow influencing local slackenings and chillings and final obstructions contrasting the linear magmas path. The recurrent ups and downs in the inner course of the fissure witnesses this mechanism: small rooms generated by collapsed walls, showing the engulfing rocks (Fig. 5), are often followed by climbs along obstruction by chilled magma.

The walls also display horizontal wrinkles due to the temporary magma standings, whereas some vertical strias have been supposed to be the result of an alternance between standing and subsequent reduction in magmas discharge rate. This governs the formation of small horizontal shelves as the still plastic wall, missing the support of its filling, slips downward and folds prior to its final chilling (Fig. 6); in the meantime more viscous or solid parts of the lowering fluid carve vertical grooves into the walls. Somewhere else a new surge and subsequent re-lowering of the lava filling can be supposed to have determined a flattening of the observed horizontal shelves with vertical strias.

The horizontal shelves at small intervals (about one meter) could witness a remarkable periodical alternance of standings and lowering of the fluid filling (Fig. 7). This probable periodicity is surely implemented by some unknown mechanism of the magma chamber.

The trend of the shelves in some segments of the cave follow the ups and downs commanded by the local topography, though they remain essentially parallel one another. Lateral rolls can also be observed along the lower gallery, similar to those found in the lava tube caves and most likely generated by the same mechanism: during its activity the fluid deposits layers of plaster on the fissure walls, which are affected by centripetal chilling. An abrupt reduction in the rate of discharge, and the consequent lowering of the filling, deprive the inner layer of a valid support, thus probably implementing its curling down and reaching the final roll shape.

ERUPTIVE FISSURES AND REGIONAL TECTONICS

A basic question is whether we can correlate the lateral eruptions with the main tectonic trends of Mt. Etnas edifice, which in turn are related with the regional tectonics. If we can affirm that a fissure in the rock is the reply to an external stress, we can even try and understand the relationship between the examined caves and the tensional system ruling the eastern side of Sicily. A mere check of the direction of the surveyed fissures, for example, shows that the Profondo-nero abyss, the Marasca cave, the Marinite hole and the caves at Ripa della Naca display a uniform ENE-WSW trend; this trend, limited to some selected areas of the volcano, follows the main fault system named "Acate-Caltagirone-Ponte Barca system" (Ghisetti & Vezzani, 1981) and "Messina-Fiumefreddo

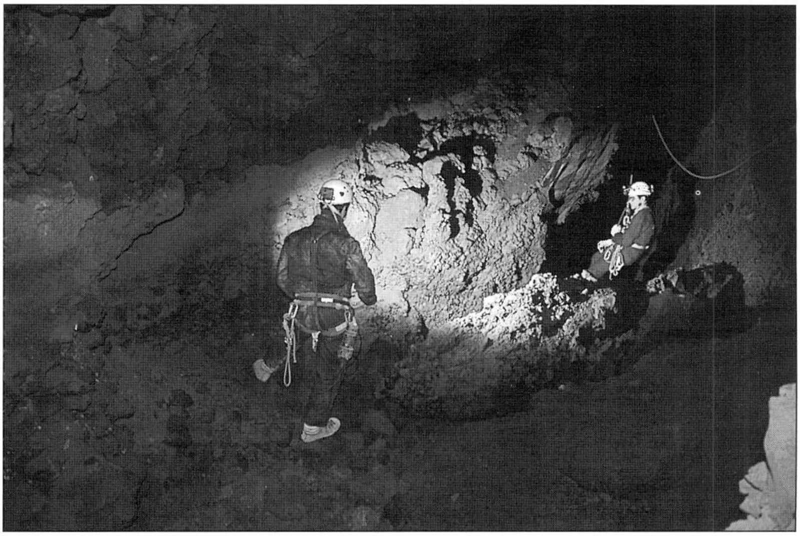

Fig. 5 - Small room generated by collapsed walls.

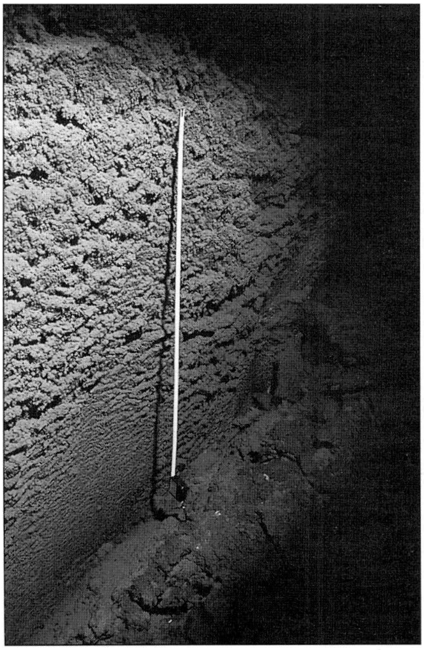

Fig. 6 - Horizontal trace due to the temporary magma standings.

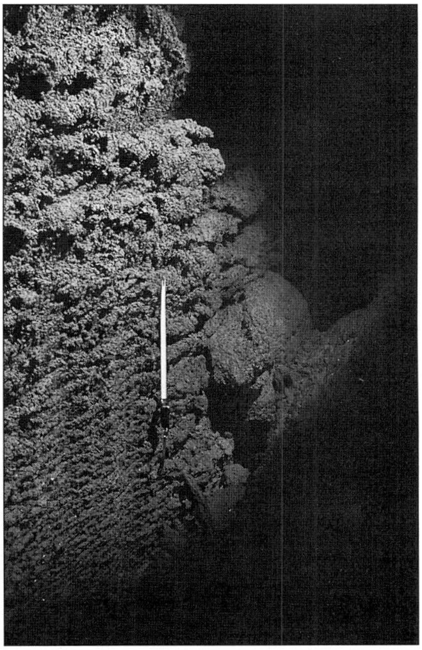

Fig. 7 - Horizontal shelves: periodical alternance of magma standings.

system" (Ghisetti, 1979) by the geologists, the Ice abyss is NNE-SSW oriented, just like the Central Chasm and the NE Crater of Mt. Etna, whereas the Doves Cave trend is aligned NNW-SSE, in accordance with the Ibleo-Maltese scarp.

In other words, a lava tube cave can display whichever trend, somehow governed only by the preexisting topography, whereas the orientation of the eruptive fissures are most likely linked with regional tectonic phenomena, which govern and implement their opening. This in turn can explain why a fissure genesis is not directly implemented by the magma surge, but is governed by multiple interacting factors.

CONCLUSIONS

Fissure caves display several differences, though they share many features with the lava tube caves: these latter are usually built up on the preexisting ground, whereas the former ones usually lay at a lower level, entirely contained by the engulfing rock. Tectonic stresses must be considered a basic factor in their genesis, as they implement the weakness trends through which the increased pressure pushes gases and fluid material.

Magmas motion inside the fissure is influenced by heavy changes in the discharge rate (abrupt downflows, etc.), which implement a regressive shift of the oven mouths, and by light changes, witnessed by small wall shelves featured by some periodicity.

The correspondence between the main tectonic trends of the Mt. Etna region and the orientation of the observed fissures is evident. Yet we deem that the quantity of acquired data doesn't yet account for a firm correlation between the two phenomena. In any case we suppose that the field evidences supply some hints worth of consideration, to be investigated and compared with similar situations in other volcanic areas.

Fissure surveys are not as affordable as other cave surveys, since they require specific technical cautions which cannot be arranged on the spot. Yet we deem that their investigation and study is worth a steady commitment which can solve many questions and can supply many and very interesting data.

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REFERENCES

AA.VV., 1994. Atti del II Congresso Regionale di Speleologia, Catania 8-11 Novembre 1994.Boll.Accad.Gioenia Sci. Nat., Vol. 27, N. 348 Catania 1994.

ANDERSON, O. L. & GREW, P.C., 1977. Stress corrosion theory of crack propagation with applications to geophysics. Rev. Geophys. Space Phys., 15, 77-104.

GHISETTI, F. 1979. Evoluzione neotettonica dei principali sistemi di faglie della Calabria centrale. Boll. Soc. Geol. It., 98, 387-430.

GHISETTI, F. & VEZZANI, L. 1981. Contribution of structural analysis to understanding the geodynamic evolution of the Calabrian arc (Southern Italy). Journal Struct. Geol., 3, 371-381.

RITTMANN, A. 1967. I vulcani e la loro attività. Cappelli Editore, 1967.

ROMANO, R. 1982. Succession of the volcanic activity in the etnean area. Mem. Soc. Geol. Ital., 23, 27-48.

Int. J. Speleol., 27 B (1/4), (1998): 155-162.

CHEMICAL DEPOSITS IN VOLCANIC CAVES OF ARGENTINA

Carlos Benedetto *, Paolo Forti **, Ermanno Galli ***, Antonio Rossi ***

ABSTRACT

During the last Conference of the FEALC (Speleological Federation of Latin America and Caribbean Islands) which was held in the town of Malargue, Mendoza, in February 1997, two volcanic caves not far from that town were visited and sampled for cave mineral studies.

The first cave (Cueva del Tigre) opens close to the Llancanelo lake, some 40 kms far from Malargue and it is a classical lava tube. Part of the walls and of the fallen lava blocks are covered by white translucent fibres and grains.

The second visited cave is a small tectonic cavity opened in a lava bed some 100 km southward of Malargue. The cave "El Abrigo de el Manzano" is long no more than 10-12 meters with an average width of 3 meters and it hosts several bird nests, the larger of which is characterized by the presence of a relatively thick pale yellow, pale pink flowstone.

Small broken or fallen samples of the secondary chemical deposits of both these caves have been collected in order to detect their mineralogical composition.

In the present paper the results of the detailed mineralogical analyses carried out on the sampled material are shortly reported.

In the Cueva del Tigre lava tube the main detected minerals are Sylvite, Thenardite, Bloedite and Kieserite, all related to the peculiar dry climate of that area.

The flowstone of "El Abrigo de el Manzano" consists of a rather complex admixture of several minerals, the large majority of which are phosphates but also sulfates and silicates, not all yet identified. The origin of all these minerals is related to the interaction between bird guano and volcanic rock.

Keywords: cave minerals, volcanic caves, Argentina

INTRODUCTION

During the last Conference of the FEALC (Speleological Federation of Latin America and Caribbean Islands) which was held in the town of Malargue, Mendoza, in February 1997 (Forti & Rivalta 1997), two volcanic caves not far from that town have been visited (Fig. 1).

The first cave (Cueva del Tigre) opens close to the Llancanelo lake, some 40 kms far from Malargue, its geographical co-ordinates being 69°19'02" W and 35°45'48" S; and it is a classical lava tube consisting of a subhorizontal gallery with a total length of about 300 meters and an average diameter of 6-8 meters (Fig. 2). The entrance of the cave is a vertical pit of 6-7 meters reaching the central part of the tube and it has been adapted for the tourism by fixing metallic ladders to its wall: unfortunately the tourist activity inside the cave led to its heavy pollution at least in the first tens of meters from the entrance. In the inner part of the cave portions of the walls and of the fallen lava blocks are covered by white translucent fibres and grains (Fig. 3) of bitter salty minerals.

The second visited cave (El Abrigo de el Manzano) is a small tectonic cavity

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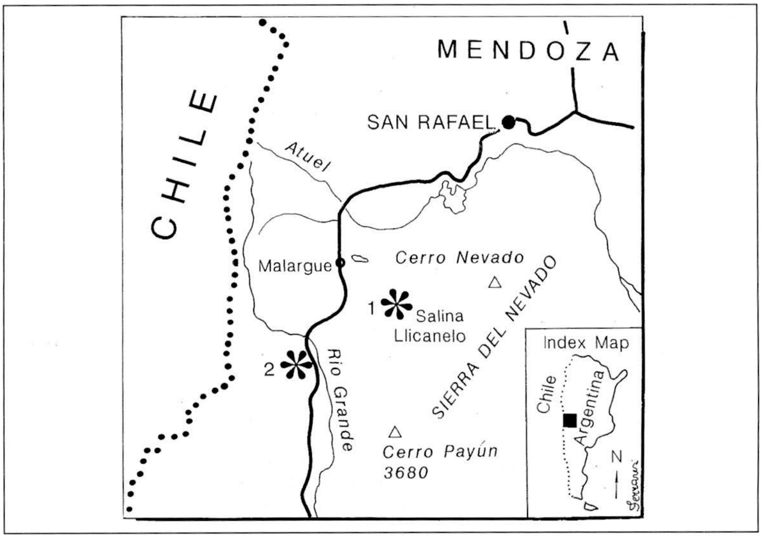


Fig. 1 - Location map for the two volcanic caves : 1 Cueva del Tigre ; 2- El Abrigo de el Manzano.

opened in a lava bed of about 20 meters of high few meters apart of the National Route 40 some 100 km southward of Malargue (Fig. 4): its geographical co-ordinates are 69°43'06" W and 35°04'24" S. The hosting rock is a basalt with a transitional composition between alcaline and sub-alcaline rocks, which may be defined as trachibasalt (Irvine & Baragar 1971). The cave (Fig. 5) is long no more than 10-12 meters with an average width of 3-4 meters and it's known for hosting a small red painting, which is not in good condition nowadays. The cavity is presently a shelter for different animals and in particular it hosts several bird nests, the larger of which is characterized by the presence of a relatively thick pale yellow-pale pink flowstone some tens of centimeters long (Fig. 6).

Small broken or fallen samples of the secondary chemical deposits have been collected from both these caves in order to detect their mineralogical composition.

In the present paper the results of the detailed mineralogical analyses (still in progress) of the sampled materials are shortly reported.

SAMPLE ANALYSES

Samples from the Cueva del Tigre lava tube consist of well crystalline materials therefore it was sufficient to analyze them by means of X-ray powder diffraction in order to detect their mineralogical composition.

Beside gypsum, which was known from that cave long since, the detected minerals are : Sylvite, Thenardite, Bloedite and Kieserite. All these minerals have been already known from lava tubes and their origin is related to the peculiar dry climate of that area, which allow a fast evaporation of the seeping water reaching the cave, while all the involved ions come from the weathering of the lava bed (Hill and Forti, 1997).

More complex resulted the analysis of the flowstone found in the "El Abrigo de el

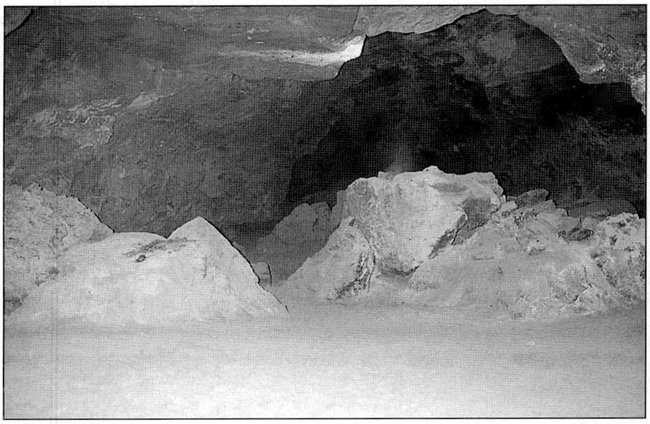
Manzano" which consists of a rather complex admixture of several minerals, the large majority of which are phosphates.

At the naked eye this flowstone consist of several thin layers, the color of which may greatly change following their chemical variance : from whitish to pale ivory to pink to reddish-brown.

The observation with the binocular microscope put in evidence that the different layers often have a different structure (globular, terrigenous, fibrous, strongly to weakly cemented).

The observation of thin sections perpendicular to the layers shown the presence of

Fig. 2 - Inside the Cueva del Tigre lava tube.



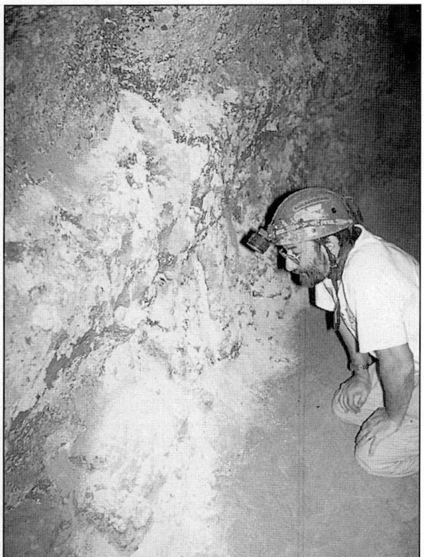


Fig. 3 - The white crystalline powder of the Cueva del Tigre lava tube.

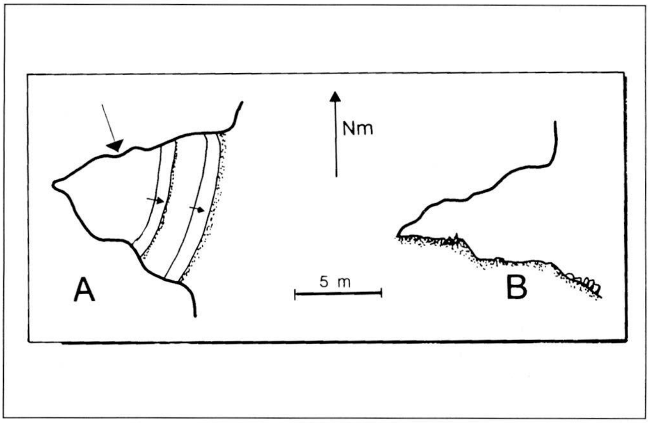


Fig. 4 - Plan and vertical section of the El Abrigo de el Manzano cave (after Urbani & Benedetto 1998).

widespread tension cracks, the existence zones rich in spherical cavities, and areas with redissolutional and/or corrosional features.

The X-ray diffraction over powdered samples selected by using the binocular microscope to reduce their compositional variability gave scarce results due to the impossibility to have enough pure materials and due to the presence of scarcely crystalline compounds.

Better results were achieved by combining the X-ray diffraction (obtained by the Gandolfi camera) over a few of single crystals selected under the binocular microscope with the SEM observation and EDS semiquantitative analyses.

Up to now over 500 samples have been selected for the SEM and EDS analyses, 40 of which have been also used for the X-ray diffraction.

The SEM analyses shown that the speleothem sometimes consists of an admixture of very small (few microns or few tens of microns) euhedral crystals of different minerals even if more frequently it is composed by spherical or tubular structures which are clearly remnants of the microbiological activity inside the guano.

The EDS analyses put in evidence that most of the speleothem consists of phosphates with some sulfates, urates, chlorides and silicates ; some organic compounds are also present.

The presently identified minerals are listed in Tab. 1 together with their chemical composition and peculiar characteristics.

Tab. 1- The presently identified minerals of the volcanic cave "El Abrigo de el Manzano"

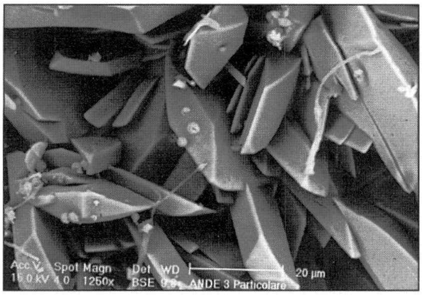
Mineral	Chemical composition	Occurrence
Carbonate-hydroxilapatite	$Ca_5(PO_4, CO_3)_3(OH)$	in a pale-yellow layered crust mixed to syngenite
Brushite (Fig.7A)	$CaHPO_4.2H_2O$	stocky tabular monoclinic crystals
Hannayite (Fig.7B)	$(NH_4)_2Mg_3H_4(PO_4)_4.8H_2O$	transparent, vitreous crystals
Monetite (Fig.7C)	$CaHPO_4$	tabular whitish elongated prismatic euhedral crystals
Sulfur (Fig.7D)	S	yellow crypto-crystalline aggregates
Syngenite (Fig.7E)	$K_2Ca(SO_4)_2.H_2O$	tabular transparent vitreous euhedral prismatic crystals
Uricite (Fig. 7F-G)	$C_5H_4N_4O_3$	small aggregates of transparent monoclinic crystals

Fig. 5 - Overview on the Rio Grande valley from El Abrigo de el Manzano.

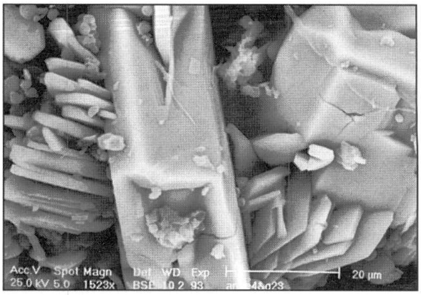
Fig. 6 - The flowstone found in the bottom of El Abrigo de el Manzano.

Fairly common are also aggregates of small spheres (Fig. 7H), the chemical composition of which is variable from spot to spot, being always high in organic matter. They seem to be produced by the chemical precipitation of different minerals over some living microorganisms, which has been identified as colonies of coccoidal bacteria, similar to those living over ancient glasses (Krumbein et al. 1991). These bacteria evidently live not only over artificial glass but also over natural (volcanic) glass: the El Abrigo de el Manzano is the first place in which coccoidal colonies are surely identified in a cave environment.

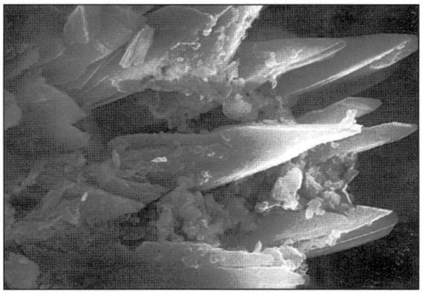
Inside the speleothems several elongated organic fibers related to other bacteria or fungi have been also observed.



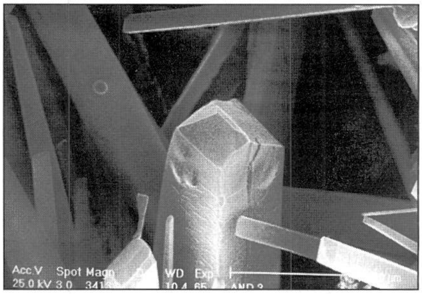
A) Brushite with some organic filaments.



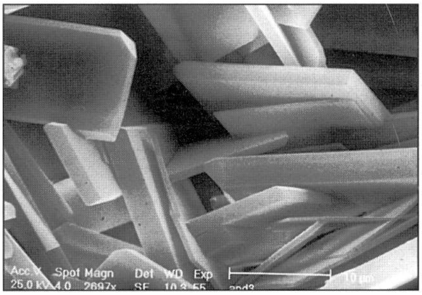
B) Hannayte.



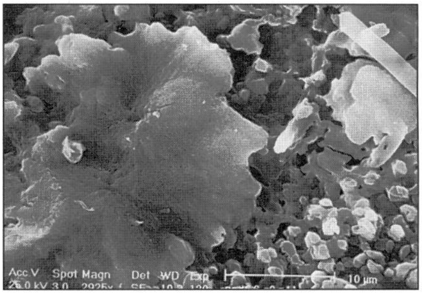
C) Monetite.



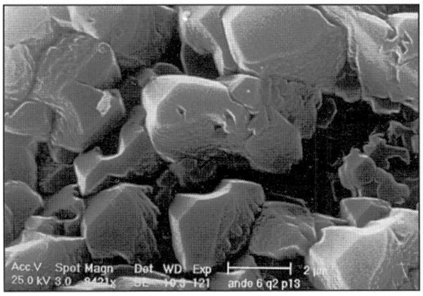
D) Single crystal of Sulfur.



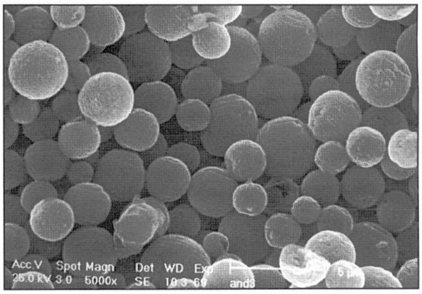
E) Syngenite.



F) Uricite.

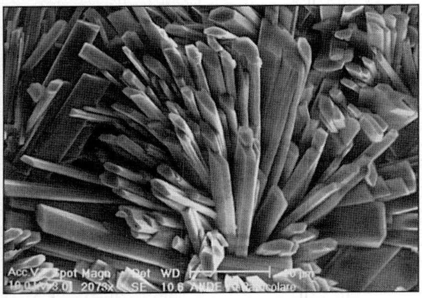


G) Enlargement of F.



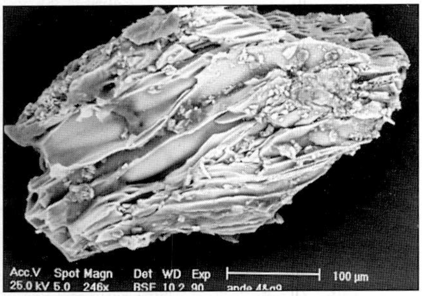
H) Coccoidal bacteria.

Fig. 7- SEM images from el Abrigo de el Manzano.



A) Organic compound.

B) Organic compound.



C) Amorphous silicate.

Fig. 8 - SEM images of unidentified materials from El Abrigo de el Manzano.

Beside these minerals identified structures the flowstone is built up by someeveral other compounds not yet definitively identified.

Among them a potash and sodium phosphate two organic compounds, the first of which forms bidimensional radial aggregates of elongated prismatic greasy crystals (Fig. 8A), and the second of which consists of spheroidal aggregates of acycular crystals (Fig. 8B). Finally some part of the flowstone is composed by an amorphous potash sodium aluminum silicate, which forms vitreous weakly transparent layered uncemented structures (Fig. 8C).

Fairly common are also aggregates of small spheres, the chemical composition of which is variable from spot to spot : they seem to be produced by the chemical precipitation of different minerals over some living microorganisms.

Finally several other uncommon phases and crystals are waiting to be understood.

Anyway the origin of all the presently detected minerals, as well as that of those still not completely identified, is surely simply related to the interaction between bird guano and volcanic rock often controlled by micro-organisms as testified by SEM images of biogenic structures close to the well crystallized secondary minerals.

FINAL REMARKS

Even if the analyses are still in progress the achieved results allow to state that these two caves are already very important from the mineralogical point of view for Argentina, moreover the "El Abrigo de el Manzano" will probably become one of the richest caves in the world of different well crystallized cave phosphates and organic compounds.

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REFERENCES

FORTI P., and G. Rivalta 1997 Dagli Appennini alle Ande - ovvero: le peregrinazioni carsico-scientifico-turistiche-collezionistiche di due speleologi di Bologna a Malargue. Sottoterra 104, p.20-25

HILL C.A. and P. Forti P. 1997 Cave Minerals of the World (second edition). National Speleological Society, 464 pp.

IRVINE T. N., and W. R. A. Baragar., 1971 A guide to the chemical classification of the common volcanic rocks. Can. J. Eath Sc., 8, p.523-528

KRUMBEIN W. E., C.E. Urzì and C. Gehrmann. 1991 Biocorrosion and Biodegradation of Antique and Medieval Glass. Geomicrobiology J. v.9, p.139-160

URBANI F., and C. Benedetto. 1998 Apuntes Mineralogicos sobre Algunas Cuevas del Departemente de Malargue, Mendoza, Argentina. Bull. Soc. Venez. Espel. In press.

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