THE UNITED KINGDOM SPELEOLOGICAL EXPEDITIONS TO THE HAWAIIAN VOLCANOES

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In 1979, a team of British cavers explored nearly 30 km of cave passage on Kilauea and Mauna Loa volcanoes, Hawaii Island. Detailed investigations of the lava flows produced during the 1969-74 Mauna Ulu flank eruption of Kilauea proved the existence of some respectable caves, one of which was an outstanding stalactite cave. The speleological work added significantly to the knowledge of the Mauna Ulu tube system, the formation and operation of which was previously observed by scientists from the Hawaiian Volcano Observatory. Exceedingly long lava tube caves were discovered to be very abundant elsewhere on Kilauea, particularly on the northeast flank. Here, Kazumura Cave was mapped to a length of 11.713 km, while Ainahou Ranch Cave on the south side of Kilauea was mapped to a length of 7.11 km. The expedition was left with the overwhelming impression that there is an enormous potential for very long caves on the Hawaiian volcanoes, and that these caves are full of geological, biological and archaeological interest. It is for this reason that a second expedition is being mounted from the UK to investigate more caves on Kilauea and Mauna Loa in 1982.

INTRODUCTION

Few cavers appreciate the speleological significance of the island of Hawaii. Entirely volcanic, and geologically very young, this island is likely to yield some of the world's longest and deepest caves. Its lava tube caves were little investigated until a party of UK cavers undertook a program of systematic exploration and mapping in 1979. In five weeks, the party explored 30 km of cave passage, of which 24 km were mapped. Important geological observations were made relating to the morphology and operation of lava tube systems. So successful was the 1979 UK expedition, and so abundant were the Hawaiian caves, that a second expedition to Hawaii Island is planned for 1982. This paper reports on this first comprehensive study of the Hawaiian caves, and outlines the proposals for the impending 1982 expedition.

BACKGROUND GEOLOGY

The Hawaiian Archipelago represents the southeastern end of a submarine mountain range, known as the Hawaiian Ridge. The ridge has been constructed above a melting zone in the earth's interior. It consists of a row of enormous volcanoes, some rising to as much as 9 km above the ocean floor. Volcanism has now ceased throughout most of the length of the ridge, except on the island of Hawaii at the extreme southeast. This island apparently lies closest to the modern melting zone. It is renowned world-wide for its active volcanoes; Mauna Loa and Kilauea.

The island of Hawaii may have been built from seven or eight volcanic edifices, though only five are apparent today. Listed in the order of oldest to youngest, with heights above sea level, these are Kohala (1,670 m), Mauna Kea (4,206 m), Hualalai (2,521 m), Mauna Loa (4,170 m), and Kilauea (1,228 m). Mauna Loa and Kilauea have been repeatedly active throughout the last century, with Mauna Loa erupting on *average* every 3.8 years, and Kilauea displaying some form of activity perhaps every 2-3 months.

The Hawaiian volcanoes are immense lava cones, each composed of many thousand thin basaltic (tholeiitic) lava flows. Mauna Loa is the archetypal "shield volcano;" its immense smooth, low-angled profile is indicative of a shield under development. The older Hawaiian volcanoes are capped with more alkaline and silica-rich lavas, ashes and cinder cones, making their profiles steeper and more irregular.

Kilauea is smaller than Mauna Loa, but it is nonetheless truly shield-like. Like its neighbor, it possesses such characteristic features as a large summit caldera, pit craters, and radiating eruptive fractures known as rift zones.

REASONS FOR THE 1979 EXPEDITION

What was the attraction that drew eight cavers half-way around the world to look for caves on the world's most active volcanoes?

A. **Reports in the Caving Literature:** The caving literature contains many indications that Hawaii could be fruitful speleologically. Halliday was making such comments as far back as 1955 (Halliday, 1955), while recently Mills (1979) listed 158 references to Hawaiian caves. Howarth (1972) described the 10 km-long Kazumura Cave, while Greeley's *Hawaiian Planetology Conference Guidebook* (Greeley, 1974) contains abundant evidence of a wealth of caves on Hawaii Island. Most recently, visits to Hawaii Island by the cavers Stephen Kempe (Kempe, 1978) and Jim and Libby Nieland (Nieland and Nieland, 1978) have shown that exciting caving can be done on the island with only limited resources.

B. **Scientific Reasoning:** In a thesis on lava tube systems completed in 1978 (Wood, 1978), this author proposed that equilibrium lava flow through lava tubes may account for the apparent anomaly of exceedingly long lava flows emplaced down very low-angled slopes. The proposal is far reaching, for

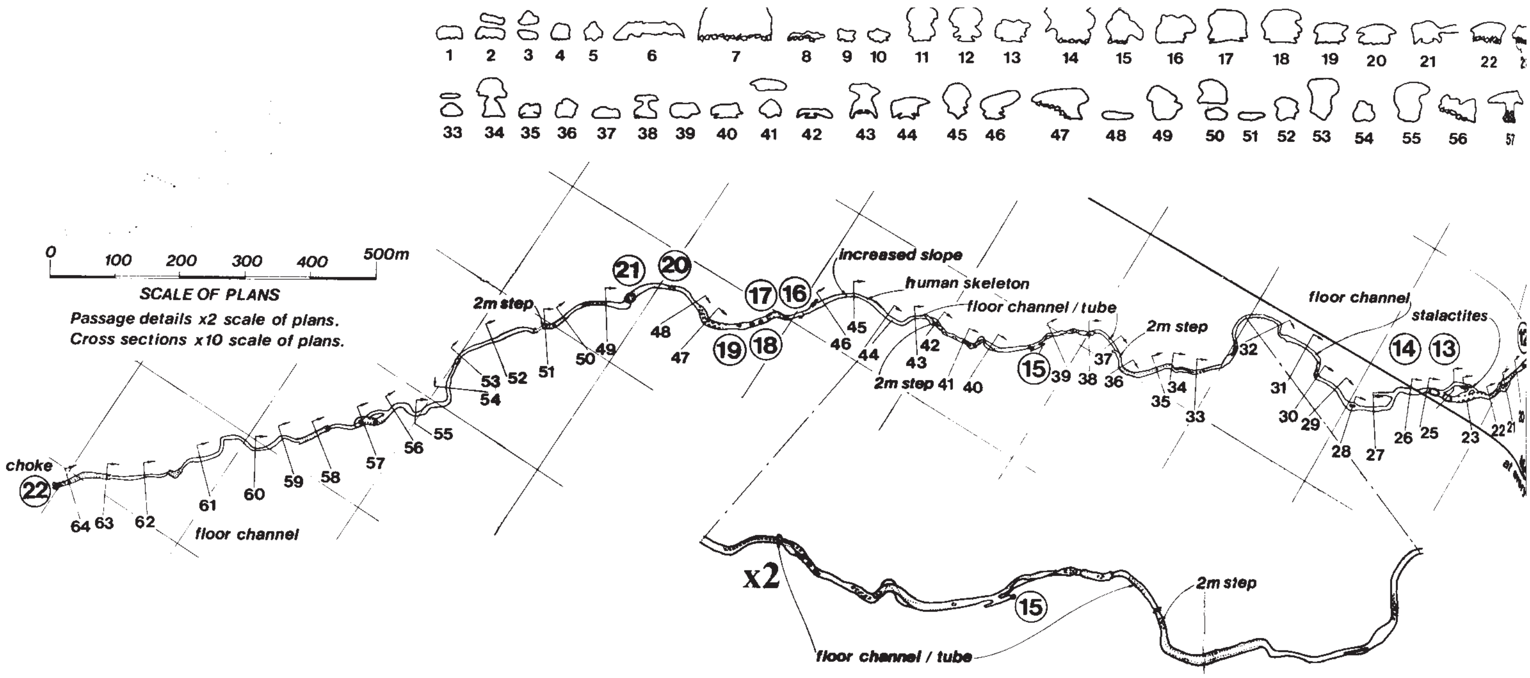
Figure 1. *Apua Cave is a principal feeder below major palis, and probably conveyed much of the lava that constructed a coastal delta.*

Figure 4. *Secondary mineralizations also are present in Apua Cave.*

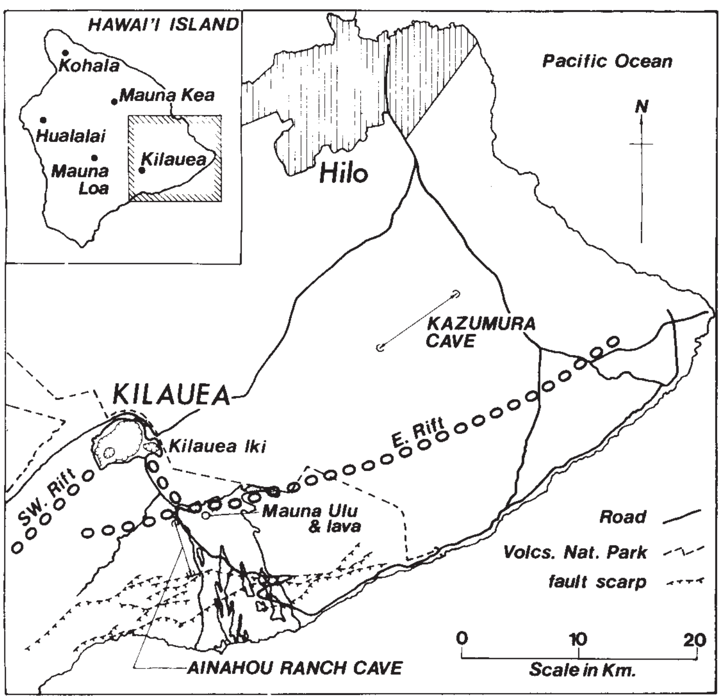
Figure 5. *In the Mauna Ulu flows, each major tongue-shaped unit contained a large axial feeder tube; the walls of the axial tubes were composed of many thin, superimposed sheet flow units which represent layered overflow from the channels from which the tubes evolved.*

Figure 6. *Away from the axial feeder tubes, toe extension appears to have been the major method of advance of the flow. Where the Chain of Craters Road has sliced through the Mauna Ulu lava, cross sections of many small lava tongues are visible and several have a small cave at their core.*

Figure 7. *Caves a considerable distance downflow from the vent have a wall structure composed of horizontal units ranging up to 2 or 3 m thick. Such a structure does not reflect tube construction from channel closure, and may result from evolution by tube enlargement and extension behind a steadily advancing flow front, with the axial feeder tube elongating across earlier delta zones and capturing dispersed flow. Photo by B. Weaver.*



Location map



Long Caves of Kilauea

ACKNOWLEDGEMENTS:

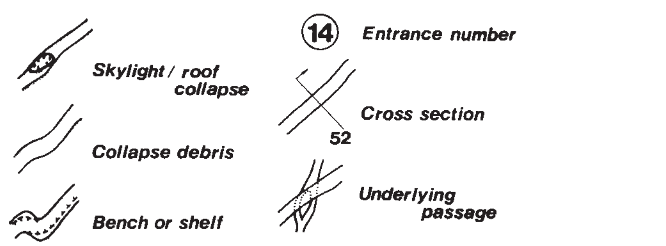
Mapped - Aug. 1979 by UK Speleological Expedition to Hawai'i.

Calculation of co-ordinates - Dec. 1979 & May 1980 by Ivan Young.

Plotted - Ainahou Ranch Cave, Feb. 1980 by M.T. Mills. Kazumura Cave, June 1980 by C. Wood.

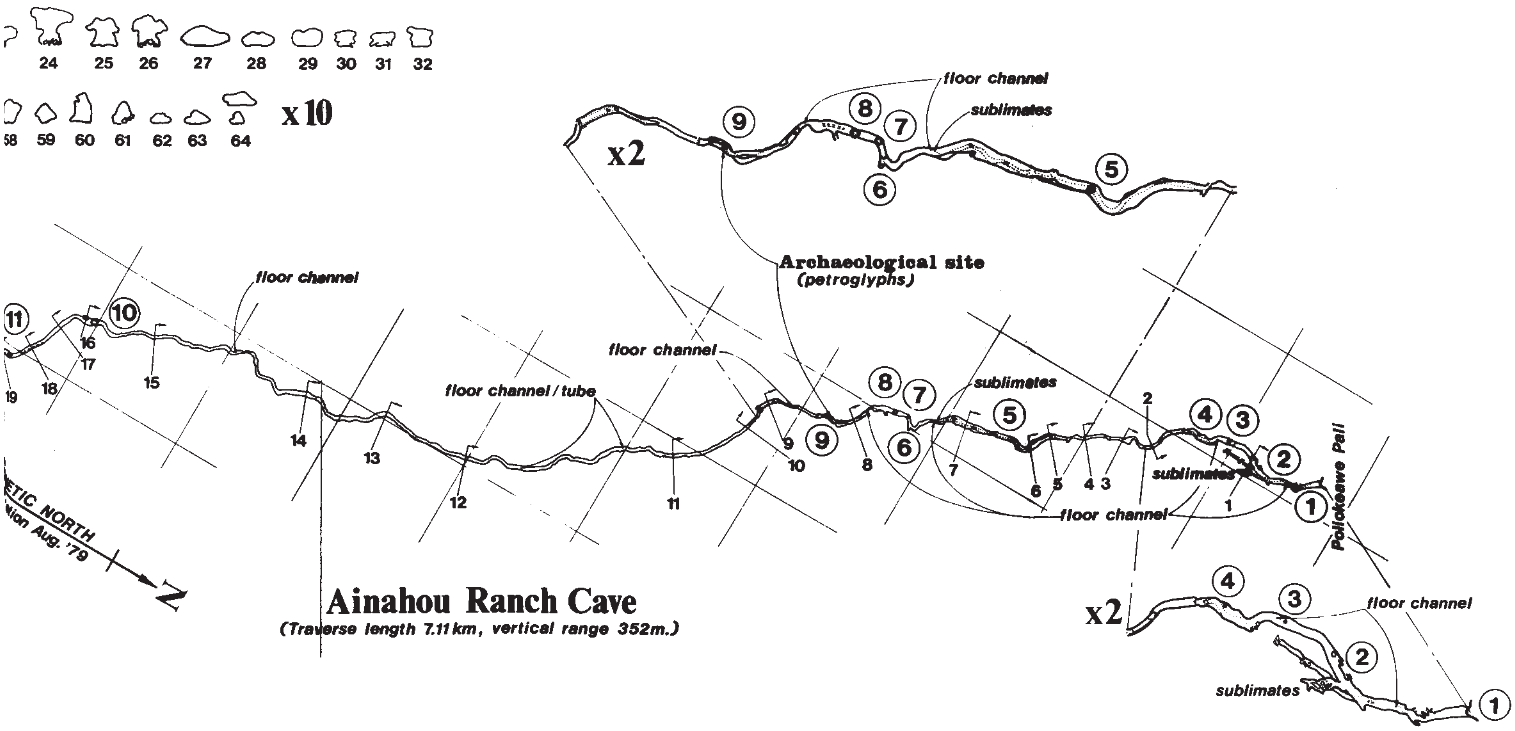
This map compiled and drawn July 1980 by C. Wood.

KEY:



in theory accumulations of tube-fed flows would form a shallow lava shield if they were erupted from a single vent, or form an expansive lava plain if erupted from multiple vents. To some extent, this was borne out by a photogeological study of the summit area of Mauna Loa by Greeley, Wilbur and Storm (1976), when it was estimated that 82% of the surface lava flows in the study area were either tube-fed or channel-fed. Clearly, a speleological expedition to the Hawaiian volcanoes would test this proposal further.

C. **The 1969-74 Mauna Ulu Flank Eruption of Kilauea:** Observations of the Mauna Ulu flank eruption of Kilauea confirmed much about the operation and construction of lava tube systems, and drew the attention of geologists to the important role played by lava tubes in the development of Hawaiian-type shield volcanoes (Greeley, 1971 and 1972; Cruikshank and Wood, 1972; Swanson and Tilling, 1974). Yet, because of the subsurface nature of functions of lava tubes, many important observations could not be made during the



olcano, Hawai'i Island.

Figure 9. Apua Cave is notable for its content of lava stalactites and stalagmites. Photos by A. C. Waltham.

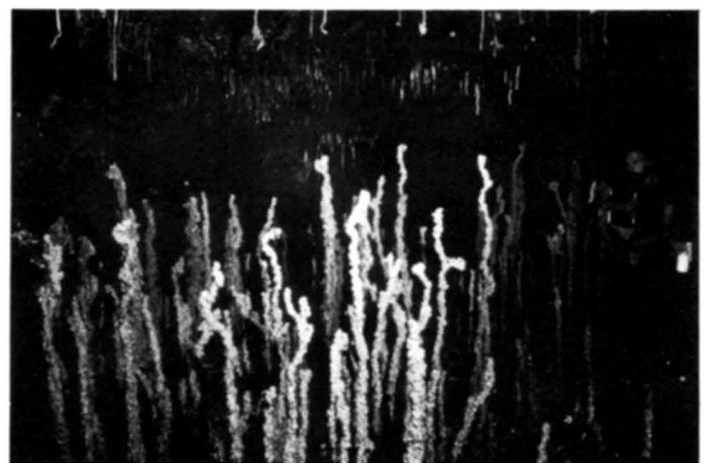


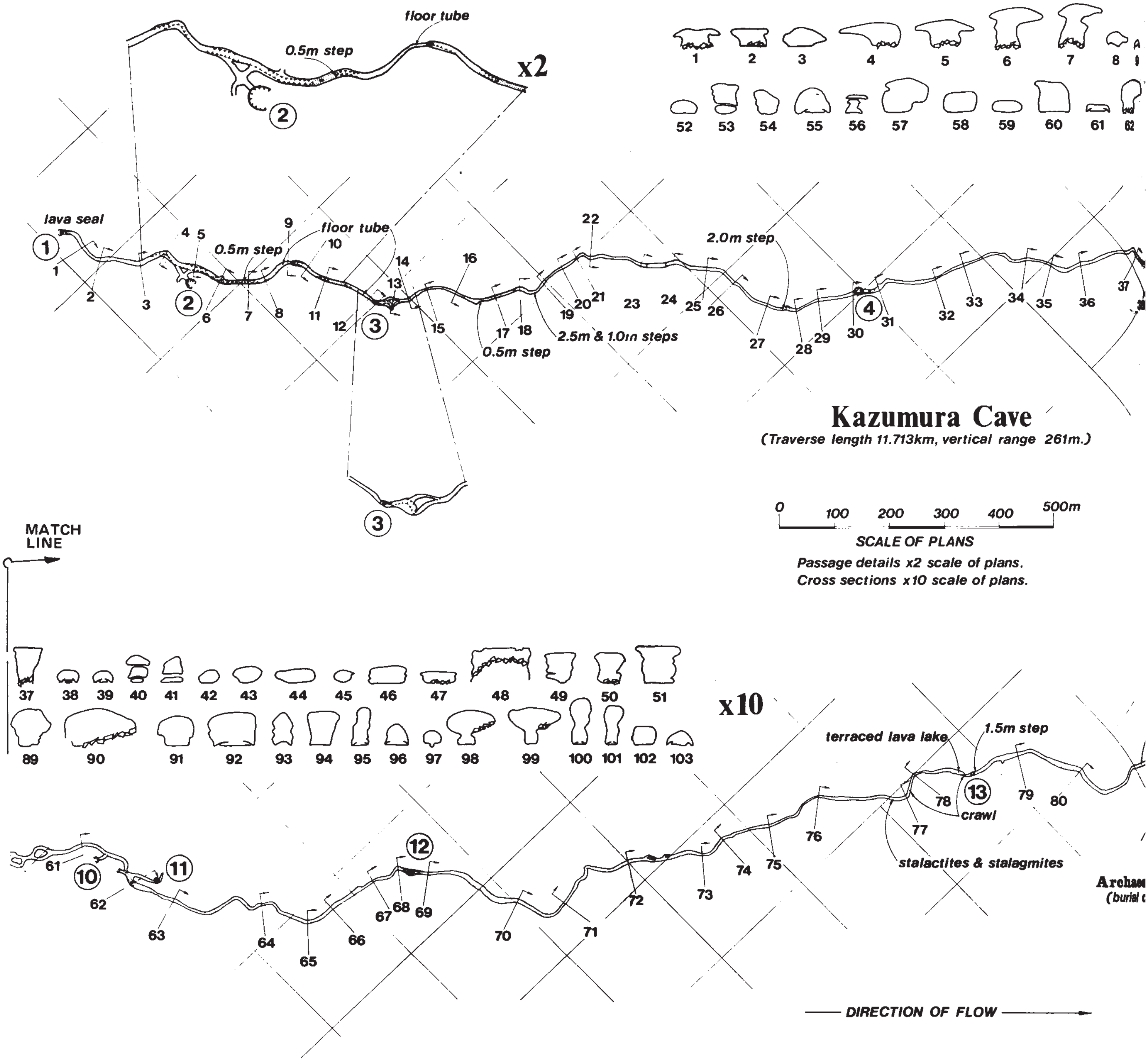
Figure 10. Apua Cave is notable for its content of lava stalactites and stalagmites. Photos by A. C. Waltham.

activity. If the Mauna Ulu tubes had drained and cooled, however, the resulting caves could be entered and mapped. The results, together with the previous observation of the liquid flow through these tubes, would provide a basis for an interpretation of the morphology of the tube system, and a partial understanding of the mechanics of the lava river it transported.

Here on Hawaii, then, was an unrivaled opportunity to undertake exploration in caves of probable world stature, and in so doing, to advance our knowledge of tube-fed lava flows and the formation of major basaltic landforms, such as shields and plains.

CAVE DESCRIPTIONS AND GEOLOGICAL OBSERVATIONS

Particularly important in an understanding of the development of the Hawaiian volcanoes, was the spectacular eruption from the upper east rift zone of Kilauea between 1969 and 1974. A new parasitic lava shield, eventually called Mauna Ulu, 120 m high and 2 km across, was constructed astride the rift. Lava flows, fed mainly by a complex system of lava tubes, tumbled down immense fault scarps (palis), before they entered the ocean 15 km distant from the vent. These flows ultimately covered 4,050 hectares of bush and forest within the Hawaii

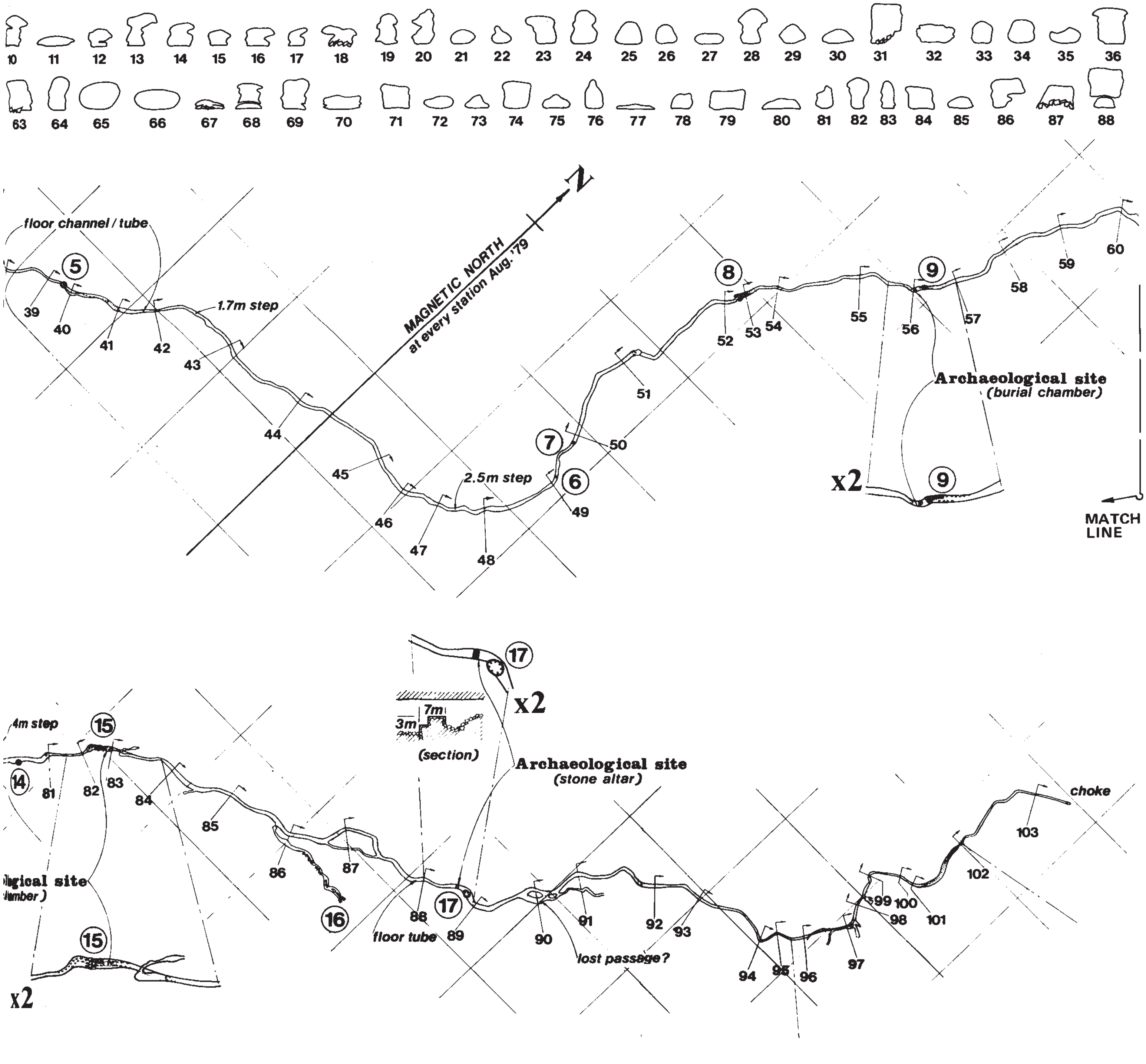


Volcanoes National Park, and added 80 hectares of new land at the coast.

During the activity, geologists were able to establish the routes of principal lava tubes from the lines of fume clouds emitted from skylights (roof collapses over an active tube). This information enabled Robin Holcomb to plot the position of the main tube-lines with some accuracy when constructing his map of the cooled flows (Holcomb, 1976). Holcomb's map, plus published observations of the eruption, formed the basis for cave hunting in 1979. The system we adopted each day was to follow a single tube-line from vent to coast, investigating each of the many skylights and post-activity collapses in the hopes of entering a significant cave.

The beautiful, glassy, contorted patterns of the surface of the Mauna Ulu lava must be seen to be believed. Vast seas of pahoehoe billow in the flows, at times overlain by aa clinker. Open and closed channels abound, and it was plain how the contorted patterns of the flow surface recorded the style of the emplacement of the lava. Yet, these beautiful expanses of glassy toes held danger, for reflected sunlight caused bad sunburn, and bodies became quickly dehydrated.

The party must have examined several hundred likely



looking holes in the surface of the flow. Many were very interesting, and one tube line in particular possessed over 30 spectacular skylights and post-activity collapses, overlying 2 km of segmented cave.

Nearly 3 km of cave passage was discovered in the Mauna Ulu lava by the expedition. Most of the parent lava tubes had drained off very little of their liquid flow, and many caves contained long crawls. Several were quite well decorated, although some of the caves are within 100 m of the Chain of Craters Road and future vandalism is expected.

Particularly outstanding was the largest cave we discovered in the Mauna Ulu lava. Apua Cave, as we called it, has a mapped length of 1.34 km, and two large collapse entrances are situated in its middle part. Its great dimensions indicate that the tube was a principal feeder, probably conveying much of the lava that constructed the coastal delta near Apua Point. What makes the cave so outstanding, however, is its notable display of lava stalactites and stalagmites.

What did our investigations of the Mauna Ulu tube system tell us about the geology of the lava flow? Firstly, cave explorations confirmed that each major tongue-shaped flow unit (the "arms" of the flow) contained a large, axial feeder tube, which divided into a mass of smaller tubes in the manner of a delta at the flow front.

Secondly, the walls of the axial tubes were composed of many thin, superimposed sheet flow units which obviously represented layered overflows of the walls of the channel from which the tube evolved. Sheets and lobes produced by overflows are easily identified on the fresh surface of the flow, bordering open lava channels or surrounding skylights. In my opinion, such evidence confirms the inappropriateness of exotic theories to explain layered wall structures in lava tube caves.

Figure 13. In the Mauna Ulu flows, lava which was fed by a complex system of lava tubes tumbled down immense fault scarps (palis) before they entered the ocean 15 km distant from the vent. These flows added 80 hectares of new land at the coast.

Away from the axial feeder tubes, toe extension appears to have been the major method of the flow. When the Chain of Craters Road has sliced through the Mauna Ulu lava, ellipsoidal cross sections of many small lava tongues are visible, many possessing a small cave at their core. Such internally developed tubes may also be observed in overflow units on the surface of the lava flow.

Yet, one very big problem concerning tube construction and operation remains that is not adequately explained by the structural evidence. Caves a considerable distance downflow from the vent (Apua Cave in the Mauna Ulu lava, and also other similar large remote cave segments in other lava flows) have a wall structure composed of horizontal units ranging up to 2 or 3 m thick. Such a structure does not reflect tube construction from channel closure, and thus I suspect that these caves evolved by means of a process of tube enlargement and extension behind a steadily advancing flow front. That is, as the lava front advances, the axial feeder tube elongates across earlier formed frontal deltaic zones, capturing the dispersed flow and developing an axial form that enables a more efficient transfer of heat and mechanical energy downflow.

Work on the Mauna Ulu lava lasted about two weeks, after which time the exploration net was cast wider and other caves were investigated. The potential for caving on the Hawaiian volcanoes is enormous. For example, some of the numerous pit craters on Kilauea may provide access to quite large caves. These spectacular pits in the Kau Desert, for example, are the subject of another paper in this symposium.

Also in the Kau Desert is an older parasitic lava shield of the Mauna Ulu type, known as Mauna Iki. The main outflow from this shield was fed by a large lava tube. Unfortunately, on a cursory visit to this site, we could find no entrance to the undoubted cave beneath the many great collapses.

Rifts and cracks on the volcanoes also make for exciting caving. They must be very deep. In 1973, National Park Service officers descended the SW Rift of Kilauea to a depth of about 100 m in order to rescue a man who fell by accident.

In 1978, Jim and Libby Nieland published an excellent account of their short, but productive caving jaunt to Hawaii Island. Especially interesting was their account of Ainahou Ranch Cave, situated on the southern slope of Kilauea. The Nielands explored abut two kilometers of the cave, and came to no termination upflow or downflow. We thought that we would undertake a full exploration of the cave. We discovered and mapped 7 km of the remarkable cave; this distance being broken in the center by an impenetrable collapse. Ainahou Ranch Cave extended from the Chain of Craters Road to a window high on the Poliokeawe Pali, but lines of collapses indicate that the cave continued from the base of the pali to the top of the lower Holei Pali, and even perhaps as far as the ocean. Geologically, the cave was unusually interesting. It was awesome in form, being truly conduit-like in many places. Frequently, it was unusually sinuous. Commonly, the passage would be divided into two or three tiers, with windows in the false floors connecting one tier with another. There were no significant side passages; the cave had the pattern of just one long snake, winding wildly down the gentle gradient to the pali top. Of great significance, bright orange clinker had invaded the cave were the walls had collapsed. Examination of the wall

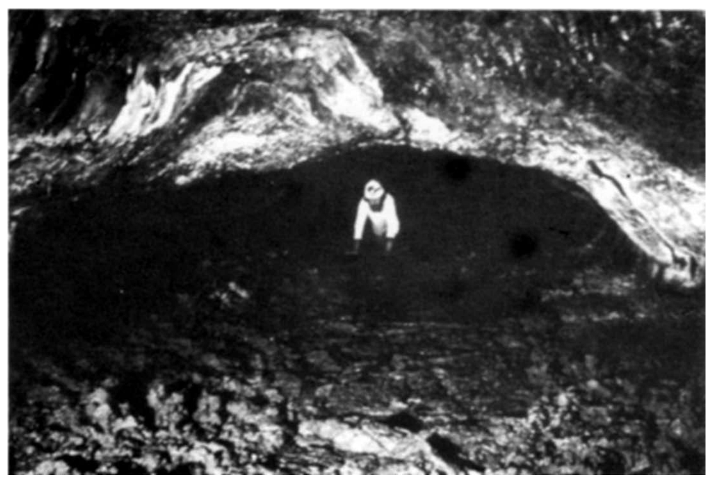


Figure 14. Although nearly 3 km of cave passage was found in the Mauna Ulu flows, most of the parent lava tubes had drained off very little of their liquid flow and many caves contained long crawls.

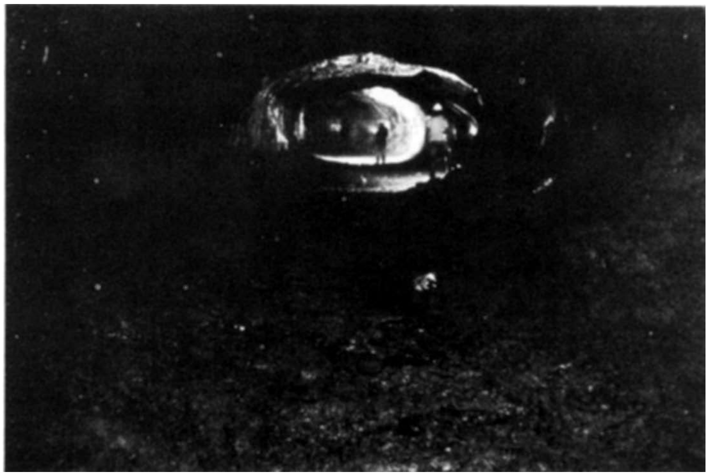


Figure 15. Ainahou Ranch Cave is conduit-like in many places.

itself showed that it was mainly very thin, sometimes as little as 3-5 cm thick! The clinker occupied about one-half of the vertical space behind the wall, and this was overlain by a thin layer of ash, which in turn was overlain in the upper half of the vertical space by typical, grey, stratified basalt, such as that found in all other lava tube caves. Clearly, the clinker was anomalous, and there was evidence to suggest that it was part of an aa flow that was older than the flow containing the cave, and into which the lava tube had been incised.

Ainahou Ranch Cave possessed some remains of ancient Hawaiian culture, including a skeleton, artifacts, and some outstanding petroglyphs (wall carvings).

The most important area for giant caves is the northeast flank. Robin Holcomb of the USGS, was on the island of Hawaii during the period of the expedition, completing his mapping of the surficial flows of Kilauea (Holcomb, 1980). His work has pointed to an important historic eruption site over the position of Thurston Lava Tube. His map of the lava flows emanating from this source postulates immensely long lava tubes, extending all the way down to the coast, south of Hilo. The lengths of some of these tube-fed flows must be 50 km or more, and the meandering tubes within them must have been much longer. Holcomb identified the tube lines from aligned collapse depressions seen on aerial photographs of the flows. I can vouch for the accuracy of this mapping; when investigated on the ground, these flows invariably yielded big caves. For example, caves such as Blair Cave, Kazumura Cave and John Martins Cave are members of this group.

Figure 1. In addition to steeply inclined "cascades" of lava, Kazamura Cave has several vertical lava falls.

Kazumura Cave had previously been explored by Frank Howarth, Hawaii's leading resident caver. He had estimated a total traverse length of 10 km. Our own survey, undertaken with Frank's assistance, resulted in a length of 11.713 km -- at the time making it longer than any other lava tube cave known. It has 17 skylight or collapse entrances, only three or four of which are enterable without tackle, and all of which are extremely difficult to locate in the boggy forest on this side of Kilauea.

Figure 16. Some sections of Kazamura Cave are impressive in diameter.

The cave is a single, at times enormous, sinuous passage. There are side passages, but mostly these are insignificant crawls. This long cave has many interesting features, including a location where the lava pooled to form a lake. Withdrawal of the liquid lava from this lake left a surrounding terrace. At other times, the lava cascaded down steep inclines or plunged over steps in the floor as lava falls. Conical ceiling stalactites abound, possibly indicating dripping off the roof as the tube emptied from a full-bore state. Lowering of the roof, and development of false floors is common in Kazumura Cave, and mainly indicates the position of former skylights. In the downflow part of the cave are some large loop passages.

Above all, Kazumura Cave is an illustration of the immensity and awesome form of the great lava conduits to be found on Kilauea's northeast flank. I have no doubt that the cave extends downflow for a considerable distance beyond the present terminal choke (which probably resulted from road building above this point), and if the choke is passed the length of Kazumura Cave, may possibly be extended to 15 km or more. And Kazumura is just one of the tens of parallel caves in the area, none of which

Figure 17. Conical stalactites possibly indicate dripping as the tube emptied.

have been adequately investigated.

The investigation of these caves is of fundamental importance to an understanding of the role played by lava tubes in the building of the Hawaiian shields. Probably nowhere else in the world is there such a collection of large lava tube caves, readily accessible to serious exploration and mapping. Robin Holcomb has demonstrated the quantity of tubes in the area, and it is now imperative for systematic cavers to map the cavernous portions of these tubes, in order to gain a comprehensive picture of the magnitude and geology of the tube-fed eruption style in this classical area. The task is big, but the accomplishments of the 1979 UK expedition illustrate what can be done during one short field season.

Figure 18. Large loop passage in Kazamura Cave.

One particular proposal for the use of map data is to attempt to calculate the volume of liquid movement through individual tubes. For example, conduit-like parts of the main passage of Kazumura Cave, with conical ceiling stalactites, strongly suggests to me that this part of Kazumura Cave transported a full-bore flow. I am intrigued by the apparent concentric banding on the walls, which, because of the low lighting, I never noticed whilst I was in the cave. Are these bands helical striations, caused by corkscrew motion of the passing fluid?

If, in fact, this part of the cave did carry full-bore flow, its dimensions could form a basis for the calculation of discharge of the former tube. With a larger sample of this passage type from one cave, these calculations of discharge could become more meaningful. Such knowledge of tube discharge, together with an estimate of the volume of the parent lave flow, would permit calculation of a figure for the duration of the vent effusion. Robin Holcomb has dated many of the lava flows on Kilauea's northeast flank, and if these calculations were done for many tubes, a comprehensive picture of the development of this part of Kilauea would be developed.

Figure 19. Are these helical striations? Kazamura Cave photo by C. Wood and A. C. Waltham.

This is just one example of the benefits to be gained from a close study of the caves on Kilauea's northeast flank. The UK team plans to contribute further to this work by returning to Hawaii Island in December, 1982. The plan is to seek out other long caves on Kilauea and Mauna Loa. Ten experienced cavers are currently reviewing aerial photographs, identifying long flows with lines of collapses. The idea is to compose a "hit list" of potentially rich cave sites, so that little time is wasted once

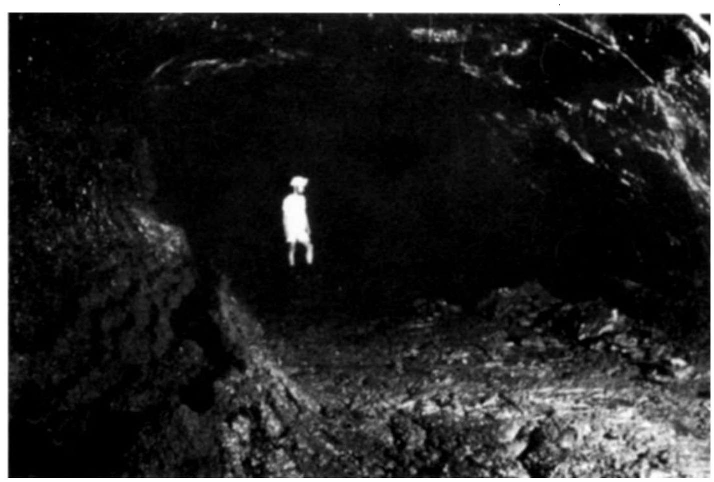


Figure 20. Multiple lateral crusts, Kazamura Cave.

we are on Hawaii. We are particularly excited about potential sites on Mauna Loa, and are preparing for the difficult problem of maintaining caving parties in remote areas of this mountain for long periods of time. Scientifically, we are very interested in understanding more about the morphology of long axial feeder tubes, and this is one reason for seeking caves longer than those currently known. For example, it would be interesting to know what form the feeder tube of the 1880-81 flow from Mauna Loa took and how the flow was maintained after a journey of 50-60 km down an average slope of less than 3-1/2°. This expedition will also be well equipped to record the biology of the caves visited, and parties are expected to discover further archaeological and geological features of note.

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