
Lava Tube Systems of the Hilina Pali Area, Ka'u District, Hawaii

Stephan Kempe
*Institute for Biogeochemistry and Marine Chemistry
University of Hamburg, Bundesstr. 55, Hamburg 13, Fed. Rep. Germany*

Christhild Ketz-Kempe
Barmbeker Ring 52b, D-2054 Geesthacht, Fed. Rep. Germany

Hawaii Speleological Survey

Abstract

Two lava tube systems have been investigated in lavas of the Kilauea volcano in the Hilina Pali area, Ka'u Desert, Island of Hawaii. The longer one is the Charcoal Cave System, composed of four caves, with a total mapped length of over 1,500 meters. It is the central feeding tube of a clearly outlined flow lobe probably belonging to the Kalue flow group (500-750 yr BP). The Earthquake Cave System is a canyonlike tube, mapped for 338 meters, running perpendicular to the pali. It probably belongs to the lavas of the Kipuka Nene flow group (1,000-1,500 yr BP). It is not associated with a flow lobe and must have attained its large depth (six meters) by erosion into the underlying strata. This conclusion is substantiated by the fact that a soil layer is exposed in the walls of the cave. Both cave systems were modified not only by extensive breakdown, but also by aeolian and fluvial ash deposits which fill cave entrances and which clog passages.

Introduction

Lava tube caves are a common phenomenon within the pahoehoe lavas of the Mauna Loa and Kilauea volcanoes on the Island of Hawaii. The world-wide longest mapped tube system, Kazumura Cave (e.g., Wood, 1980), is developed in lavas which flowed from the Kilauea summit caldera eastwards, 350 to 550 years ago. Many other caves are known to rangers, residents, speleologists, geologists, biologists, and archaeologists, but apart from cave descriptions in the speleological literature little has been done to study their geology and speleogenesis systematically.

This paper deals with the tubes of the Hilina Pali area located within the Hawaii Volcanoes National Park. The area is situated in the center of the Ka'u Desert Quadrangle of the 7.5 minute series U.S. Geological Survey topographic map (*circa* 1918'N and 15519'W). The area is called Kipuka Keana Bihopa, i.e. the vegetation island (kipuka) of Bishops (a family name) Cave (keana). It is not quite clear whether the term keana designates one of the cave systems described later (Charcoal Cave Sys-

tem ?) or a cave system as yet undiscovered or one of the large breakout scars along the pali (where the term Keana Bihopa appears again in small print on the topographic map). The most important surface features of the study area are given in Figure 1. They are based on color aerial photographs taken 1988 and were made available to the authors by James F. Martin, chief ranger of the Hawaii Volcanoes National Park.

It should be noted that access to the described caves is regulated in order to protect them and they may be entered only with a valid caving permit from the National Park Service.

Geological Setting of the Hilina Pali Area

The Hilina Pali is an escarpment which is a series of west-southwest to east-northeast striking, nearly vertical, high angle slip faults south of the Kilauea caldera. They are reached by the Hilina Pali road of the Hawaii Volcanoes National Park which ends at a shelter at 700 meters above sea level overlooking the faults (Figure 1, P at end of

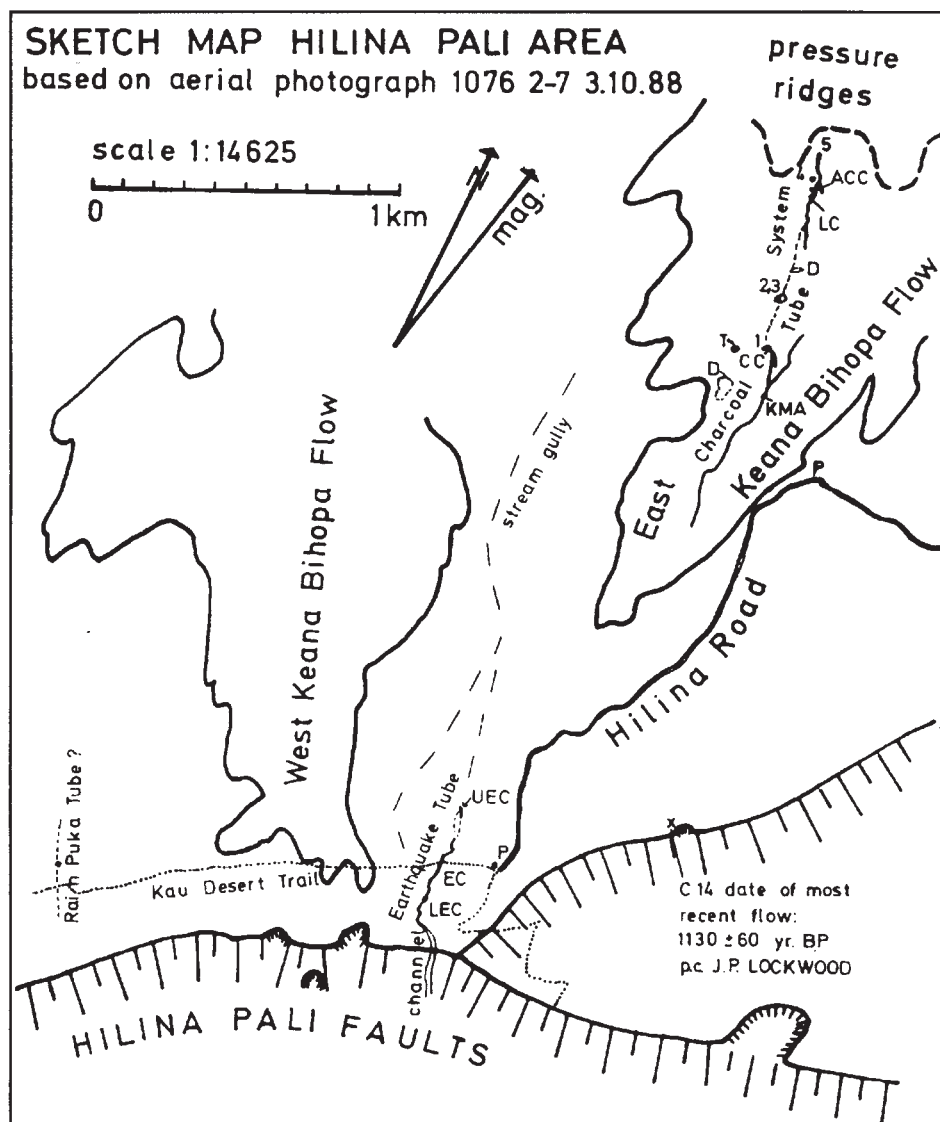


Figure 1—Sketch map of the Hilina Pali area giving flow lobe boundaries according to aerial photographs and lava tubes according to own surveys. Abbreviations: P = pullouts, D = dunes of Keanakakoi ash, T = tumulus, KMA = Entrance of Keana Momoku Ahi (Charcoal Cave), CC = Entrance of Calabash Cave, LC = Entrance of Ledge Cave, ACC = Entrance of Ash Crawl Cave, number 1-5: aeolian ash plugs sustaining kipukas, UEC = Upper Earthquake Cave, EC = Earthquake Cave, LEC = Lower Earthquake Cave.

road). Along the pali (the fault) the seaward block has subsided several hundred meters (maximum 550 meters) exposing the oldest accessible rocks of the Kilauea volcano edifice. Table 1 shows the local idealized stratigraphy as derived from the publications of Rubin *et al.*, 1987, Holcomb, 1987 and Easton, 1987. The lower sequence of caldera basalts (Hilina Basalt, 100 meters thick) is capped by the Pahala ash (nine meters thick) which must

have been deposited before the major movements of the faults occurred. Radiocarbon dating shows that the ash was deposited between 11,000 and 25,000 years Before Present (yr BP). On top of the ash, thin members of the Holocene Puna Basalt series were deposited. These members are separated by soil and/or ash layers, 4,800, 3,500 and 1,130 (Uwekahuna ash) years old (Rubin *et al.*, 1987; Easton, 1987). The latest ash is covering the surface in the Hilina Pali area partially and belongs to the historic 1790 A.D. ash eruption of Kilauea (Keanakakoi member).

This seemingly simple stratigraphy becomes complicated as soon as one tries to assign dates to certain lava flows at the surface. In the paper of Holcomb (Figure 12.5 D), the Kipuka Nene flows and the surface of the lava at the end of the Hilina Pali road are grouped into different time slices (i.e. 1,000 to 1,500 yr BP versus 1,500 to 10,000 yr BP, respectively). Furthermore Holcomb puts the Uwekahuna ash into the latter time slice even though the ^{14}C date

(W 3827, collector J. Lockwood; Rubin *et al.*, 1987) suggest an age of only $1,130 \pm 60$ years as correctly cited in Easton's Figure 11.14. We therefore reinterpreted the stratigraphy using the published ^{14}C dates and suggest that the Kipuka Nene flows (dated with sample W5135 to $1,150 \pm 70$ years, collector N.G. Banks; Rubin *et al.*, 1987) and the surface around the end of the Hilina Pali road belong to the same group of flows roughly 1,100

years old (not withstanding the fact, that older strata outcrop at the brink of the pali). To the north of the Hilina Pali shelter a large lobe (termed East Keana Bihopa Flow in Figure 1) transgresses the older flows. Holcomb groups this lobe with the Kalue flows which separate the Hilina Pali and the Kipuka Nene areas. The Kalue flow is not well dated and Holcomb suggests an age of 500 to 750 years. To the west of the Hilina Pali shelter another lobe extends almost to the brink of the Pali (termed West Keana Bihopa Flow in Figure 1). Holcomb groups it with the 250-350 years old Observatory Flows. However, Holcomb overlooks two ^{14}C dates which may indicate that this lobe is older, i.e. the samples W5152 = 660 ± 70 yr BP and W4402 = 700 ± 70 yr BP (collector N.G. Banks; Rubin *et al.*, 1987, Figure 10. 5). The description of site W4402, (325 meters west of the Hilina Pali shelter) suggests that it may have been collected from under the eastern rim of the West Keana Bihopa Flow (Figure 1). The West Keana Bihopa Flow could therefore be also of the age of the Kalue flow group, i.e. 700 years old. The appearance of the east and west Keana Bihopa Flows on the aerial photographs is rather similar in color, surface structure and with regard to the thin rim of vegetation (which probably taps the water reservoir provided by the heat-cracked lava beneath the flow rims). They could therefore very well be of the same age.

Description of Tube Systems

Within the area three tube systems exist, two of which are accessible and have been mapped in

detail. These are the caves within the East Keana Bihopa Flow collectively called Charcoal Cave System and the Earthquake Cave System east of the Hilina Pali shelter (Figure 1). A third system exists west of the West Keana Bihopa Flow. On the aerial photograph we noticed a breakdown hole (puka) shortly north of the Ka'u Desert Trail (Rain Puka, Figure 1). S. Werner and S. Kempe explored it July 13, 1991, but found that the underlying tube cannot be entered. The tube must be rather deeply seated and is buried in breakdown both upslope and downslope. On the aerial photographs no other pukas were noticed which could give access to this tube. Also in the center of the West Keana Bihopa Flow lobe no entrances were noted on the aerial photographs and none are known from surface excursions even though this lobe potentially contains a tube system.

Table 2 compares the speleological data of the two systems mapped. The Charcoal System is the longer of the two, but its gradient is less than that of the Earthquake System. The Charcoal Systems follows the center of the East Keana Bihopa Flow throughout most of the length of the lobe (Figure 1). Four caves and at least five ash-plugged breakdown holes (marked 1 to 5 in Figure 1) belong to the system. The presumed vertical section of the system is given in Figure 2. The ash-plugged pukas keep water in their thick ash deposits which therefore carry isolated stands of ohia trees and are visible as small kipukas on the aerial photographs. At least two dunes and the only large tumulus on the lobe also carry isolated stands of trees so that

Years BP	Member	Thickness (m)
1790 A.D.	Keanakakoi Ash	0 to > 2
700	Kalue Flows (including Keana Bihopa Lobe)	0 to 8
1,100	Kipuka Nene Flows (Including Earthquake Tube System)	2
1,130	Uwekahuna Ash	0.2
3,500	Puna Basalt	2
3,500	Soil	0.1 to 0.3
4,800	Puna Basalt	5
4,800	Ash on Top of Soil	1.5
10,700	Puna Basalt	4
11,000-25,000	Pahala Ash	9

Table 1: Stratigraphy of the Hilina Pali area (revised according to Holcomb, 1987 and Easton, 1987).

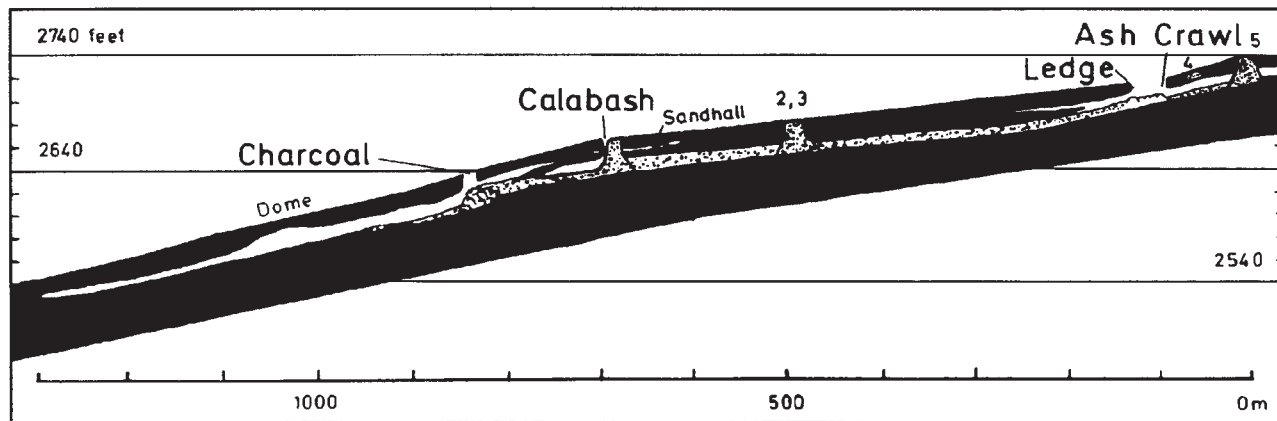


Figure 2—Longitudinal profile through the Charcoal Cave System in the East Keana Bihopa Flow lobe indicating entrances, main passages and ash deposits. Elevation of surface is according to topo map, sheet Ka'u Desert. Depth and size of caves are schematic only.

trees as such are not an infallible sign of buried tubes.

The East Keana Bihopa Flow is superimposed upslope by another flow lobe which is characterized by many large pressure ridges (tumuli). Shortly below, we encounter the first evidence of the East Keana Bihopa Flow tube system, an ash filled breakdown hole (No. 5, Figure 1). It is accessible underground in Ash Crawl Cave (Figure 3). The

total mapped length of Ash Crawl Cave is 117 meters, with a horizontal extension of 100 meters. It is entered through the upslope opening of an elongated shallow breakdown feature. The crawl on ash leads to a passage which turns back (The Delta) and ends in a fluvial ash plug. Upslope the ash-floored passage encounters breakdown before the passage opens up to standing height (Dining Hall), the end of which is formed by the ash cone

Parameter	Charcoal Cave System	Earthquake Cave System
horizontal extension (m)	> 1,300	> 400
mapped (m)	1,500	338
elevation (feet)	2,740 to 2,540	2,300 to 2,200
vertical extension (m)	60	33
gradient	1/22 (2.6°)	1/12 (4.7°)
age of flow (years yr BP)	700 (?)	1,100 (?)
total number of caves	4 Charcoal C. Calabash C. Ledge C. Ash Crawl C.	3 Upper EC EC Lower EC
system	braided, tributary	single canyon
archaeological remains	stone settings charcoal	none
destruction	aeolian ash plugs, fluvial ash plugs, breakdown	fluvial ash plug, breakdown, ponds during floods

Table 2: Comparison of speleological data for the two tube systems mapped.

of plug 5. The cave must continue upslope beyond the obstruction.

Plug 4 is encountered north of the entrance breakdown hole illustrating that a passage (marked by plug 4 and the entrance sinkhole) parallel to Ash Crawl Cave must exist. It continues downslope as Ledge Cave (Figure 4) from the southern end of the elongated entrance sinkhole. Ledge Cave can be followed for 171 meters downslope and has a total length of 185 meters. The entrance is a low, wide crawl on fluviially deposited ash, then one has to squirm through breakdown before a walking size tube is encountered. The pahoehoe floor becomes visible under a shallow ash cover and ledges accompany the sides. In Ledge Room, the tube splits. The main passage is blocked by a fluvial ash plug, the side passage, a slightly elevated older overflow, is free of ash. The passage decreases in size and contains pahoehoe flow features, rafted blocks and magnificent lava forma-

tions. These stalagmites and stalactites show that hot gas flowed through the tube and could have caused partial melting at the ceiling of the tube, probably while the main passage still conducted lava (flowing at a level below the ledges). The side tube ends in loose breakdown, but an air draft indicates that the cave continues. Bits of charcoal show that Polynesian explorers have visited this cave as far as Candle City. Torches have been cleaned on a block in

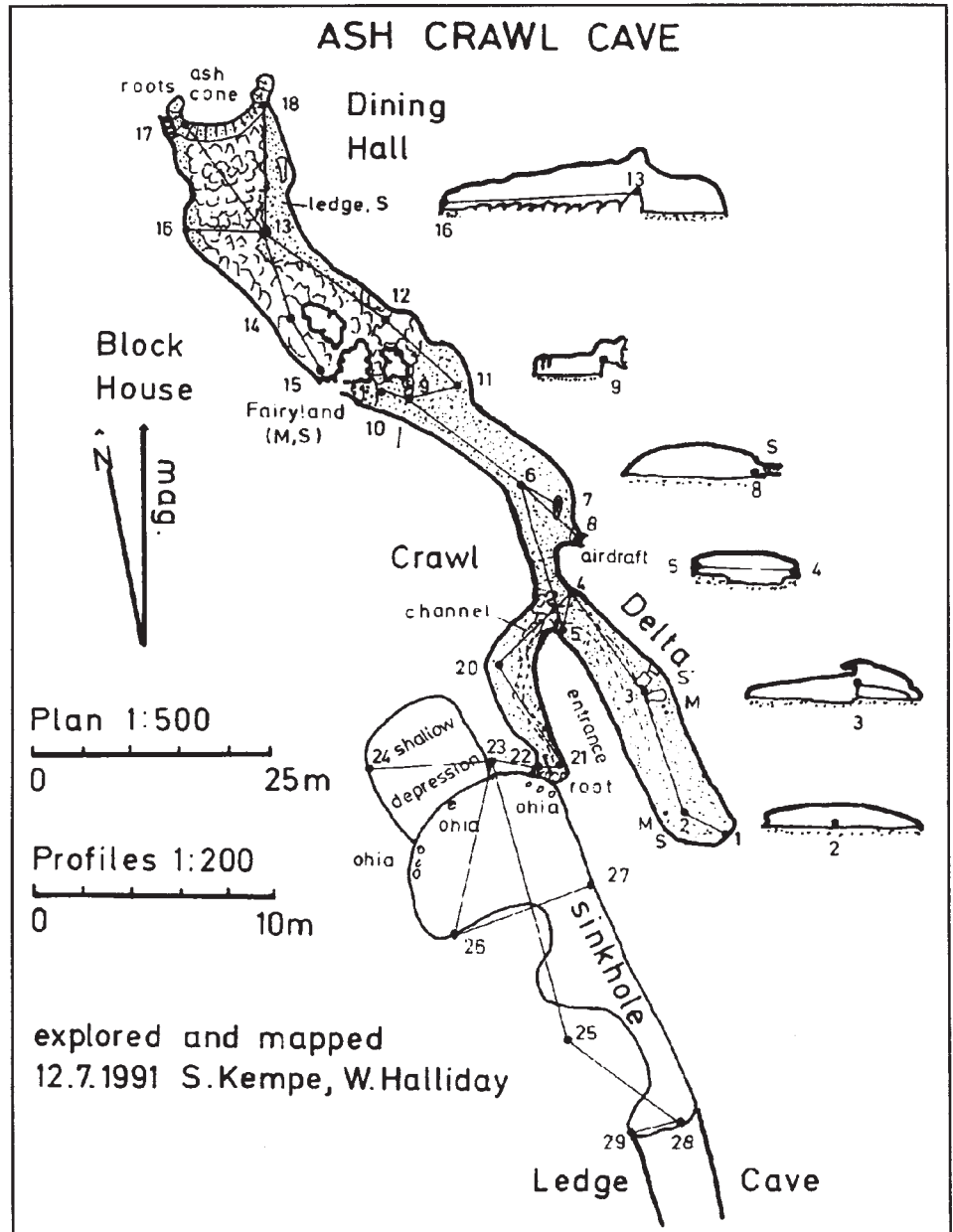


Figure 3—Map of Ash Crawl Cave, East Keana Bihopa Flow, Hilina Pali, Ka'u District, Island of Hawaii. M = lava stalagmites, S = lava stalactites.

Ledge Room. No charcoal was found in Ash Crawl Cave. However, recent fluvial ash layers may have covered any remains of prehistoric visitors.

The tubes in the upper part of the East Keana Bihopa Flow are all near the surface, the roof is not more than one or two meters thick, the size of the passages is moderate, wider than high and often trapezoid or rectangular in cross-section. Several passages appear to have developed parallel to each other.

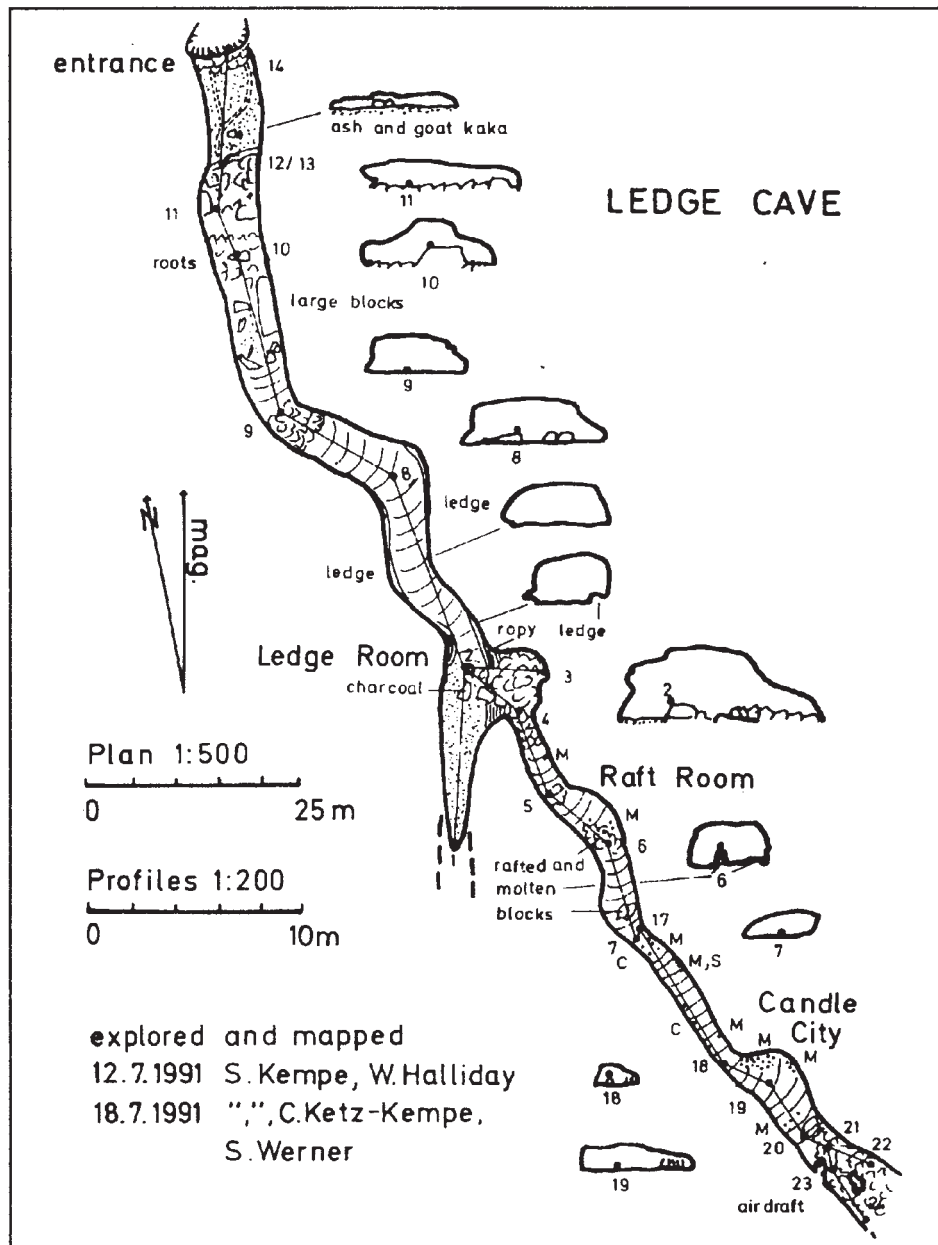


Figure 4—Map of Ledge Cave, East Keana Bihopa Flow, Hilina Pali, Ka'u District, Island of Hawaii. M = lava stalagmites, S = lava stalactites, C = charcoal.

The next few hundred meters of the tube system cannot be followed underground, but the ash-plugged twin breakdown holes 2 and 3 show that the cave continues with a wide passage. The next ash-plugged breakdown hole (No. 1) downslope has partly been eroded and provides access to Calabash Cave, the beginning of the Charcoal Cave System (Kempe and Ketz-Kempe, 1979). Here we encounter a huge passage which, after 80 meters, is clogged by fluvial ash (Figure 6). On an elevated

and ash-free loop, stone settings were found which were used to hold drip water collecting calabashes. A few piled-up stones served as stepping stones up the ledge. In the ceiling a very narrow near-surface tube is intersected, a nasty belly crawl interconnecting with the Charcoal Cave (Keana Momoku Ahi) proper. The cave system has been mapped (1978) by the authors and was described in detail already. The map published here does however include the L-series passage below Junction Hall mapped December 9, 1988, by S. Kempe and G. Landmann.

The entrance hole of the Keana Momoku Ahi is planted with ti (a Polynesian plant with large leaves which spreads only by planting), shaded by a few ohia trees and offers the most spectacular entrance setting in the area. Downslope it gives access to the same large tube as in Calabash Cave. Upslope however, the fluvial ash is ponded behind the breakdown pile clogging the main passage completely. The breakdown occurred at a place where three tubes

met, (i) the large trunk passage, now filled with ash, (ii) the belly crawl connecting from Calabash Cave and (iii) a small tributary upslope tube. This tube can be followed for more than 250 meters upslope before it ends in breakdown. In Sand Hall a small ash cone enters through an inconspicuous hole, showing that this tube runs near the surface. It may be the same tube as encountered in the Candle City passage in Ledge Cave, but actual proof for this hypothesis cannot be offered. Below

the Keana Momoku Ahi entrance the tube is six meters high and four meters wide and gives the impression of a gently meandering canyon. Washed-in ash covers the floor. Throughout the next 300 meters the trunk tube is accompanied mostly by narrow side tubes. The trunk opens up into the enormous Dome of Darkness which is 50 meters long, 12 meters wide and 6 meters high and is littered with large breakdown blocks. Beyond the dome the pahoehoe floor becomes accessible for the first time. Behind Junction Hall breakdown blocks the passage. Only a nasty crawl or a climb up into an intersected loop gives access to the lower section of the tube. The loop features stalagmites. Again they must have formed while the deeper main tube was still active so that rising heat could cause partial melting at the roof in the drained loop. The cave continues for another 250 meters (L-series). But it is now much smaller, hardly walking size and the ceiling becomes low toward the end leaving just a few centimeters for air to pass. The floor is composed of clinkery pahoehoe, grading into small aa blocks. Charcoal is found as far as behind Junction Hall, but the L-series was never entered by Polynesian explorers.

The accessible tube ends 450 meters above the lowest tip of the East Keana Bihopa Flow. Its central position in the flow lobe shows that it must be in fact the main feeding tube for the flow.

The East Keana Bihopa Flow transgresses on older lava (Kipuka Nene Series). The surface is composed of both aa and pahoehoe flows. The pahoehoe is visibly more deeply weathered than on the East Keana Bihopa Flow. Enough vegetation exists on the surface of this lava so that it was able to hold wind-driven ash of the Keanakakoi member. Today the plain is grown with exotic (i.e. post-Cook imports) grasses and a few ohia trees, most of which were burnt in a fire some years ago. This portion of the Kipuka has the appearance of a savanna. The ash cover is eroded along stream channels. During the depression in the 1930s, public works programs were used to fortify the ash against further erosion. Stones line the gullies keeping the ash from being washed into the stream. Many small dams were erected from local stones, some of which have been washed away already, evidence of occasional torrential rain storms during the last fifty years in this otherwise rather dry section of Hawaii.

In one of these streams a hole, 2.1 x 1.8 meters wide, opens up into the Upper Earthquake Cave (Figure 5). It is a 38-meter-long section of a canyon type tube, closed to our dismay upslope by break-

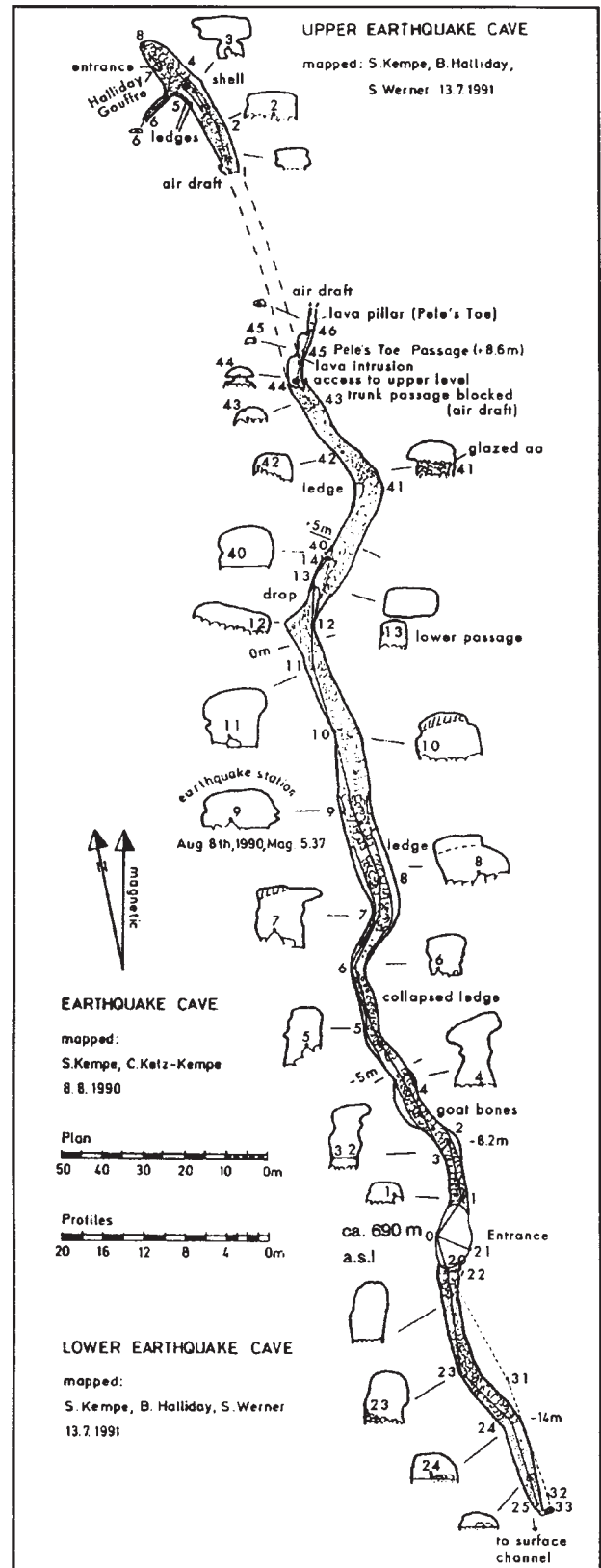


Figure 5 – Map of Earthquake Cave Tube System, Hilini Pali, Ka'u District, Hawaii.

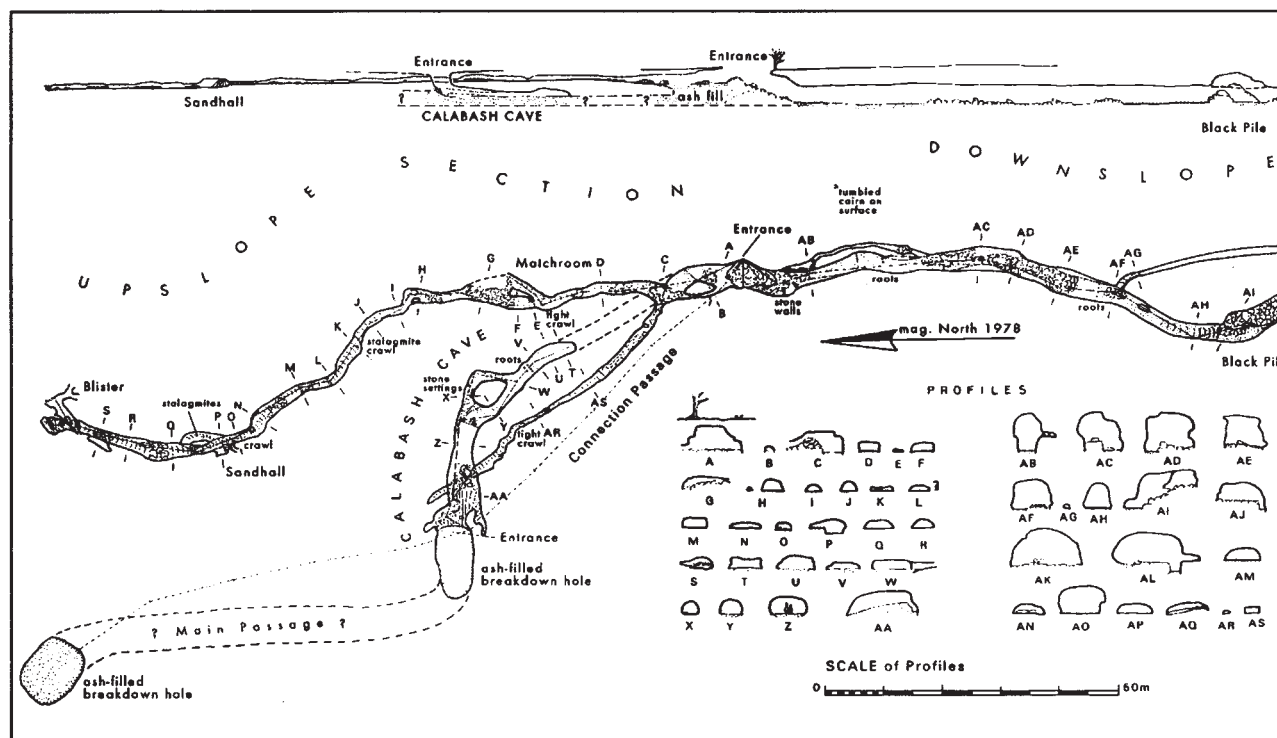


Figure 6—Map of the Keana Momoku Ahi (Charcoal)—Calabash Cave System, East Keana Bihopa Flow, Hilina Pali, Ka'u District, Island of Hawaii. Compared with the map published by Kempe & Ketz-Kempe

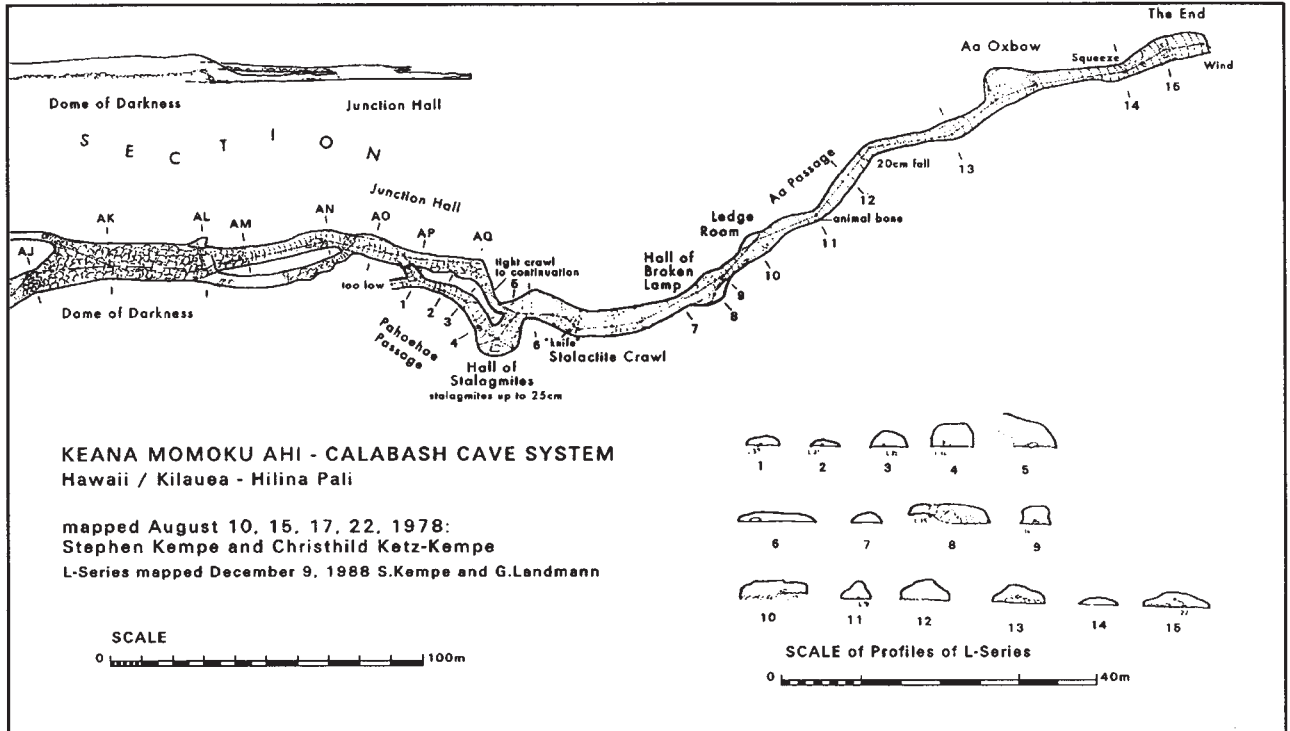
down. Downslope the tube is also closed by breakdown, but another, larger breakdown hole, *circa* 200 meters southwest of the Hilina Pali shelter, gives access to the same tube system. Upslope the Earthquake Cave extends for 228 meters, ending a few dozen meters below Upper Earthquake Cave. The passages is mostly higher (up to six meters) than wide with a canyonlike appearance and a meandering course. The cave is characterized by intensive breakdown from ceiling and walls, the original floor is only rarely seen. Evidence of washed-in plant material and charcoal shows that the cave floods more or less completely during rain storms, serving as a pseudokarst drain. Downslope, the Lower Earthquake Cave can be followed for 64 meters before the canyon is clogged by a deep fluvial ash plug. Beyond, the tube is discontinued and the lava entered into an open trench before it plunged over the pali several hundred meters down. An extended description of the cave is found in our paper, this volume.

Speleological Conclusions

The two cave system are quite different. The Charcoal System features parallel tubes—up to

three in the section between Calabash Cave and Keana Momoku Ahi—while the Earthquake System consists of only one tube. The Charcoal System is clearly associated with a large flow lobe and appears to diminish in size towards the end of the lobe. The flow lobe has a height of three to five meters above the surrounding terrain and shows convex isohypses on the topographical map. In short, the Charcoal System is at a position where one would expect a tube.

In contrast, the Earthquake tube is not associated with any recognizable flow lobe and appears to have served as a fast lava transport route toward the pali without much local lava buildup. In fact, even today a stream gully follows roughly its course, underscoring nicely the missing buildup which should have deflected any stream course to the side of the tube position. At the pali, no lava strata are visible with a thickness comparable to the depth of the Earthquake Cave. One can only conclude that the Earthquake tube must have cut downward into the older Puna Basalts in order to obtain the clearly canyonlike character. There is further evidence of this hypothesis in the cave. Where the vertically layered wall lining fell away, one can clearly see thick horizontally stratified lava



(1979) this map includes the lowermost L-series. Note that the cross-sections of the L-series are plotted in a different scale than the other cross-sections.

beds, a structure unlike what one would expect in a tube which was formed by levee buildup and roofing. In fact, in Lower Earthquake Cave an oxidized clayey soil layer is exposed between horizontal lava beds. Clearly such a layer cannot be an integral part of a pahoehoe flow. The existence of this soil layer also shows that the tube was not a streambed canyon which was just incidentally occupied by the lava and roofed over. In a watercourse, the soft material of the former soil would have been removed by lateral erosion. In a downcutting lava flow, material not hot enough to be remelted cannot be easily eroded, in fact it could be more difficult to erode a wet soil thermally than solid lava. Figure 7B shows how the observed soil may fit into the local stratigraphy and how far the tube probably cut down into older strata. Clearly more dating has to be done before both the age of the Earthquake Cave flow and the local stratigraphy can be resolved. The outcrops in the caves may, however, provide a place to look for suitable ^{14}C samples.

With this discussion in mind, let us consider the trunk passage of the Charcoal System once more. At the Keana Momoku Ahi entrance the roof has a thickness of four to six meters and the passage a

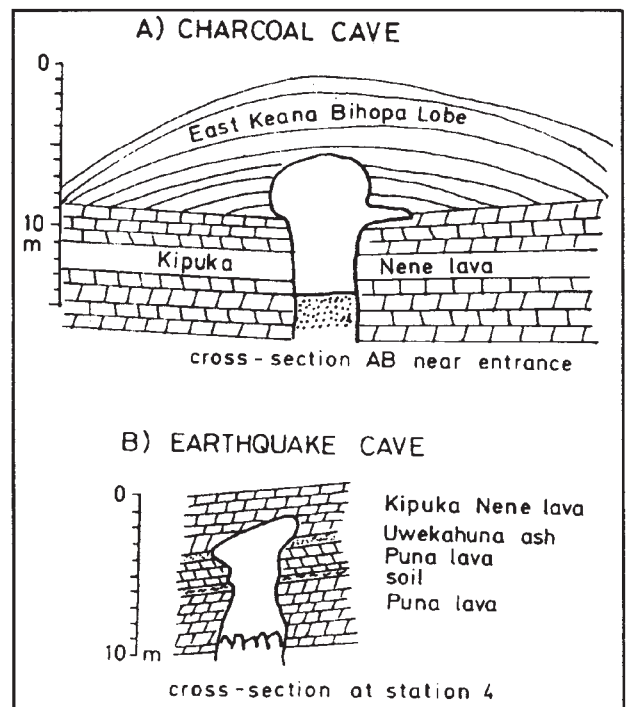


Figure 7—Conceptual models of the stratigraphic situation of the canyonlike sections of the two cave systems illustrating the downcutting of the lava flow into older rocks.

depth of six to seven meters. This is clearly more than the apparent topographic thickness of the flow lobe. One must therefore conclude that this canyonlike passage was also cut down into older strata. Along the walls horizontal shelves protrude, suggesting exposures of older lava layers. Figure 7A shows how the cross-section of the Keana Momoku Ahi could be interpreted geologically. The question remains, if the downcutting occurred only locally (where for example the preexisting surface gradient increased, compare the increase in gradient at about the position of the Calabash Cave in Figure 2), or if the tube developed a voluminous "trunk type" passage throughout. If this were the case, then the near-surface and narrow upslope branches of the Charcoal System (i.e., Ash Crawl Cave and Ledge Cave) cannot be identical with the Charcoal trunk. Rather another tube must be assumed not accessible or deeply buried by ash extending upslope of ash plugs 2 and 3.

The two cave systems have another interesting feature: their ash plugs. Principally two kinds exist (Figure 8), plugs caused by aeolian deposition and plugs caused by fluvial deposition.

The aeolian plug is probably quickly deposited. Wind blowing over a breakdown pit deposits its dust load easily into this "sediment trap" because turbulence would not be high enough to carry any

particle out of the pit again. The dust is driven over the lip of the pit, progressively building a steep cone until the other side of the pit is reached and further deposition stops. Such steep ash slopes can be seen in the Dining Hall of Ash Crawl Cave, in Sand Hall of the Keana Momoku Ahi and in the entrance sink of the Calabash Cave. Aeolian plugs can only occur if enough loose ash is available such as after the 1790 eruption producing the Keanakakoi ash. The ash plugs therefore serve as time markers. Only those breakdown holes which were open before 1790, could be closed by the Keanakakoi ash. Considering the amount of ash available after the eruption, one must conclude that all pits older than 1790 were probably filled while those breakdown holes open today must be younger than 200 years (i.e. the Keana Momoku Ahi entrance, the Ash Crawl Cave and Ledge Cave entrance and both the Earthquake Cave entrances). An exception is the entrance to Calabash Cave where fluvial erosion of the aeolian ash plug has reopened the entrance to this cave.

Fluvial ash plugs appear in Ash Crawl Cave, Ledge Cave, Calabash Cave, Keana Momoku Ahi and Lower Earthquake Cave. They need water as a transport medium. Fluvially transported ash tends to form horizontal deposits which in places may reach the ceiling of the cave sealing it. Since running water is scarce in the Hilina Pali area – available only once every several years during rainstorms – fluvial ash plugs need a longer time to develop. The fluvial plugs we see today therefore must be younger than 200 years. For archaeologists this possibility to date deposits opens up an interesting perspective: could the now closed trunk section of Charcoal Cave above plug 2 and 3 contain untouched prehistoric remains?

Acknowledgements

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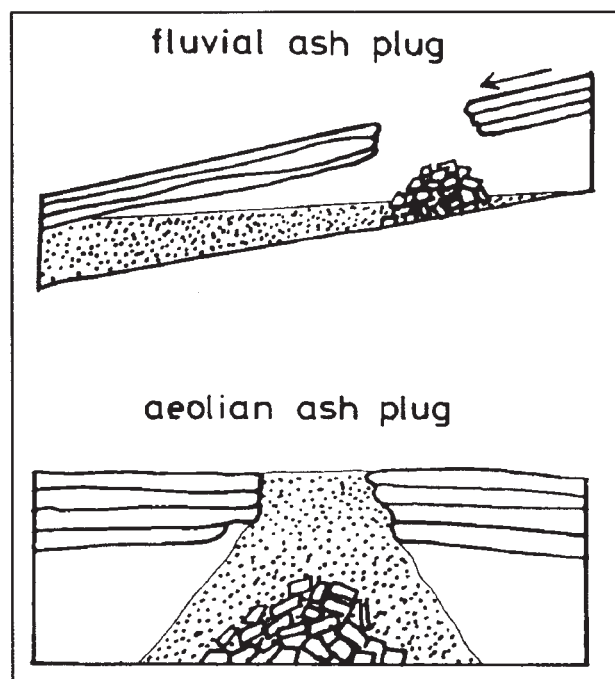


Figure 8—Scheme of the two different kinds of ash plugs encountered in the Charcoal System.

couragement and volcanological advice the present paper would not have been written.

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