Pressure Ridges Caves:
a Comparison between the Jordanian Caves of the Quis/Makais Volcanic Field and the Hawaiian Mauna Loa Eclipse Cave

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Abstract

Apart from pyroducts (lava tunnels, lava tubes) that actively conduct lava subterraneously, there are many other types of lava caves that can reach appreciable sizes. In the Cenozoic (Oligocene-Quaternary) alkali-basalt fields, the "Harrats", in Jordan we have surveyed 10 caves that lack any signs of laterally flowing lava. They all belong to the lava field of the combined Qais/Makais volcanoes. The field covers an area 28 km long and 6 to 10 km wide. It forms only a small fraction of entire Harrat. The field also contains two pyroducts, Al-Jolous Cave (113 m long) and Hashemite University Cave (231 m long), illustrating that the lavas are duct-transported pahoehoe flows. The age of the flow field is several hundred thousand years. Nevertheless it belongs to the younger flow fields in the Harrat since it has not developed an appreciable wadi network.

The caves form two groups, one to the north of the two volcanoes at an altitude at around 900 m and one to the south of the volcanoes at an altitude of around 780 m. Most of the caves are oriented perpendicularly to the flow direction and are associated with low ridges at the surface. All of the caves are very wide and low. The longest is Al-Ameed: a 120 m long cavity combining two very low and wide vaults connected by a wide and low passage. Due to the loess cover of the Harrat, these caves are all filled with an unknown depth of sediment, so that we cannot see the rock floor of them.

Caves that lack evidence of lateral lava flow are known also from Hawaii, but are so far poorly documented. Eclipse Cave occurs in a young lava flow of the Mauna Loa W-Rift. This cave turns out to be a combination of a pressure ridge cave and a small pyroduct. The pressure ridge hall is aligned perpendicular to the direction of flow. It is 70 m long and up to 2.5 m high, forming a rather regular vault. At the surface a low ridge exists above the hall. The surface pahoehoe slaps forming it, are tilted suggesting yield to a lateral pressure.

Our observations suggest that "pressure ridge caves" formed by the buckling up of one or a few inflationary lava sheets due to lateral pressure when half-solidified surface sheets yield to the shoving of the hotter lava below by doming upward, perpendicular to the direction of pressure. The caves are however, not bound to pronounced tumuli but can occur under low, lateral or dome-like rises. In case of the Jordanian caves it appears as if the lava of the Qais and Makais Volcanoes had properties sustaining the formation of the pressure ridge caves that are not matched by the properties of the other lava fields composing the Harrat.

Introduction

Apart from pyroducts (lava tunnels, lava tubes; for term "pyroduct" see Kempe, 2002, 2009 and Lockwood, 2010) that actively conduct lava subterraneously, there are many other types of lava caves that can reach appreciable sizes. In the Cenozoic (Oligocene-Quaternary) alkali-basalt fields, the "Harrats", in Jordan (Fig. 1) we have surveyed 10 caves (Table 1) that lack any signs of laterally flowing lava. They all belong to one lava field, i.e. that of the combined Quis/Makais volcanoes at 32° 17.105'N/36° 35.992'E (Fig. 2). The lava is an alkali basalt and the flow field covers an area of 200 km^2, 28 km long and 6 to 10 km wide with a slope of ca. 0.8° and a flow direction of 212° (Fig. 3). The field also contains two pyroducts, Al-Jolous Cave (113 m long) and Hashemite University Cave (231 m long), illustrating that the lavas are duct-transported pahoehoe flows. The lava field forms only a small fraction of Jordanian Harrat of about 11,400 km^2 but contains 12 of the 22 known caves (as of 2009; Kempe *et al.,* 2009). The age of the flow field is according to sample 47 of Tarawneh et al. (2000) about 500 ka. It therefore belongs to the younger flow fields in the Harrat, just as the Al-Fahda flow field further to the east, and it has not yet developed an appreciable wadi network. Instead the surface of the flow field appears to be "mottled". This pattern arises from the fact that the entire Harrat is covered by 1 to 2 m of loess that is washed into the depressions between the flow ridges,

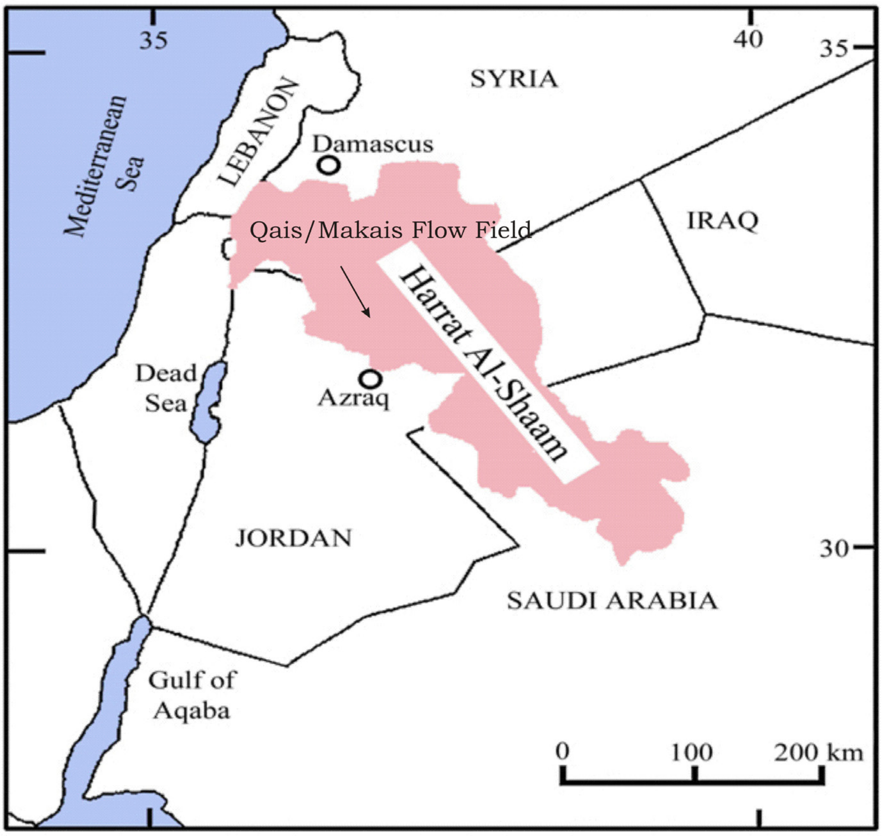

Fig. 1. Map showing extent of the Harrat in Syria, Jordan and Saudi Arabia.

thin. Other cavities are found below rather steep oval tumuli of debated origin. Overall these caves "were formed by drainage of sub-crustal injection and lava breakout" (Halliday, 2009). The first cave that, in our opinion, can be directly compared to the Jordanian caves is Eclipse Cave. It was incidentally discovered by one of us (SK) when parking the car along the highway to observe the total solar eclipse on 11th July, 1991. In March 2010 we (SK and IB) surveyed Eclipse Cave. It occurs in tholeiitic basalt lavas at 19°3.944'N/155°42.135'W that erupted from the Mauna Loa SW-Rift (Fig. 4). The flow is, compared to the Jordanian lavas, very young, but one of the older in this section of the Mauna Loa SW-Rift. ^{14}C sample W4232 collected at 19°05'41"/155°42'09", i.e. 3.2 km above our site, yielded an age of 780±70 aBP (Rubin *et al.*, 1987.)

Fig. 2. Panorama view of the tephra ring of the Quis Volcano to the north. Tephra is quarried from the western side the volcano.

thereby forming small irregular playas. Erosion has also removed the typical ropy surface features of pahoehoe. Similarly, the typical glazing of the lava cave walls has long been lost due to weathering and ceiling and walls show irregular pockets interpreted to be caused by weathering.

Caves that lack evidence of lateral lava flow are known also from Hawaii, but are so far only poorly documented. About 250 caves have been reported in the Kilauea caldera 1919 Postal Rift flow that are of varying genesis and that cannot be classified as pyroducts (Halliday, 2009). Many of them are low residual cavities along the perimeters of lava rises, wide and low bulges that collapsed after the lava that filled them drained. Lava drainage features are seen in some of them. The roofs of these caves are generally

Pressure Ridge Caves of the Quis/Makais Volcanoes

The pressure ridge caves of the Quis/Makais Volcanoes form two groups (Fig. 3), one to the north of the two volcanoes at an altitude at around 900 m (No. 4, 6, 7, 8; Table 1) and one to the south of the volcanoes (No. 1, 2, 3, 5, 9 and 10) at an altitude of around 780 m. However, this distribution may only represent our current knowledge, since we have not had the time to research the entire lava field for additional caves. Most of the caves are oriented perpendicularly to the flow direction (Table 1) and are associated with low ridges at the surface. All of the caves are very wide and low. They are elongated and can have several

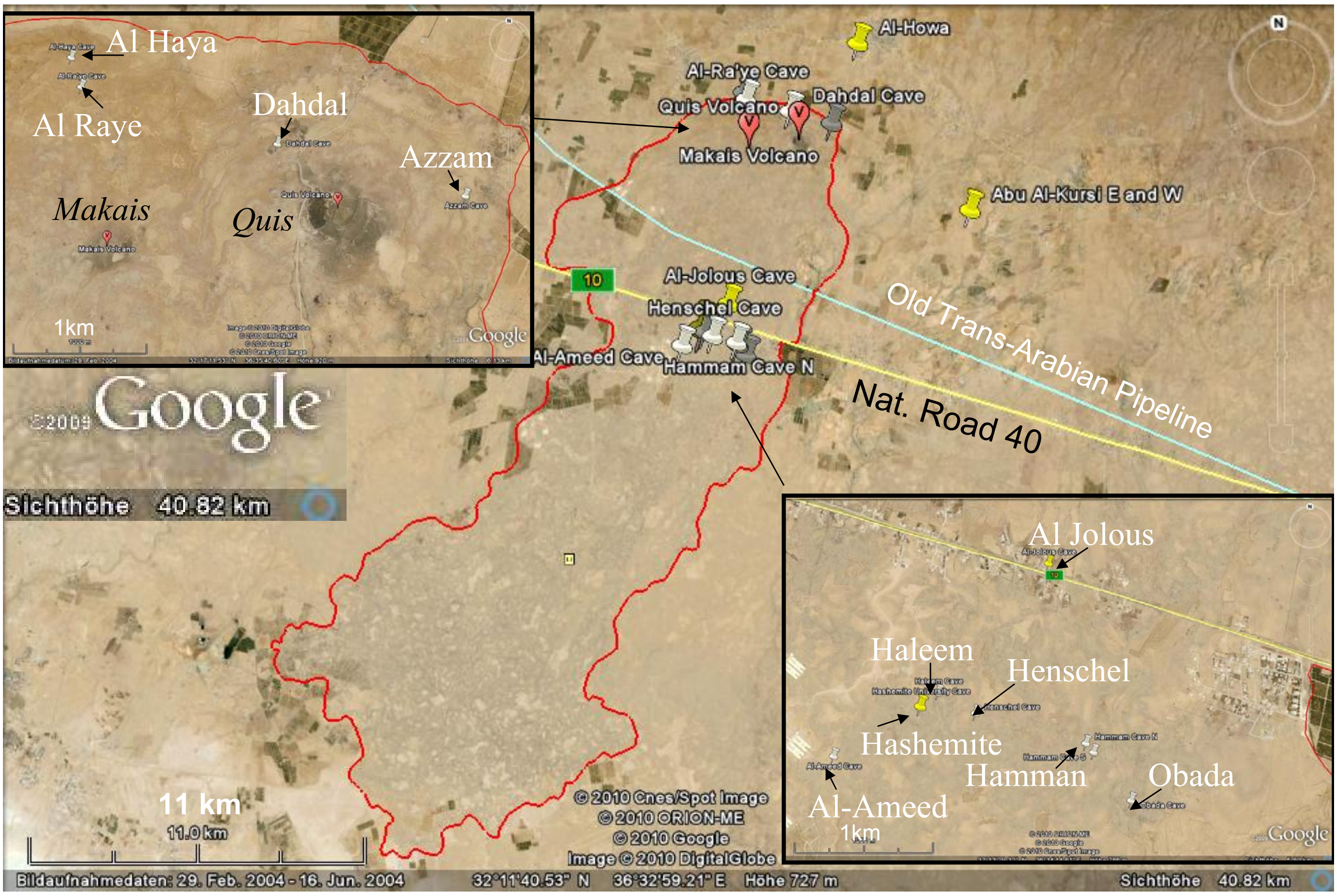

Fig. 3. Situation of the Quis/Makais Lavafield (Google Earth Picture). Insets show close-ups of northern area (upper left) and central area (lower right) with caves. Yellow pins mark pyroducts (including two systems to the NE in older lavas: Al-Howa and Abu Al-Kursi); white pins mark pressure ridge caves.

branches, petering out at their ends. Due to the loess cover of the Harrat, these caves are all filled with an unknown depth of sediment, so that we cannot see the rock floor in any of them. Most have been used by hyenas as dens and left plenty of bones and coprolites (Kempe *et al.,* 2006).

Table 1: basic data of "pressure ridge caves" investigated in this project.

Jordan	Name of Cave	Length	Depth	Direction	Altitude
1	Al-Ameed Cave	208	4.0	SW-NE	777 m
2	Hammam Cave N	123.4	4.5	NW-SE	780 m
3	Obada Cave	107.6	3.5	NW-SE	766 m
4	Al-Haya Cave	81.3	4.2	NW-SE	902 m
5	Haleem Cave	70.7	4.7	NW-SE	791 m
6	Azzam Cave	44.1	4.2	NNW-SSE	902 m
7	Al-Ra'ye Cave	42	3.5	NW-SE	900 m
8	Dahdal Cave	28.9	0.0	SW-NE	920 m
9	Henschel Cave	21	2.5	W-E	788 m
10	Hammam Cave S	12.4	2.4	NW-SE	780 m
	Total:	739.4			
Hawaii	Eclipse Cave total	140.6	3.8		
	Eclipse Cave pressure ridge section	70	3.8	NW-SE	636 m

The longest cave is Al-Ameed (Fig. 5). It consists of a 120 m long low cavity. Only two stations have ceiling height above 1 m. The cave is a combination of a 20 m wide vault in the north with a 15 m wide one in the south connected by a wide and low (0.6 m) passage. The northern vault collapsed centrally forming the current entrance. At the entrance the 2 m thick roof consists of five inflationary sheets between 30 and 45 cm thick. These layers are relatively thin, indicating that the lava was still very hot when the roof was emplaced at this location. This in turn is the consequence of the duct-fed pahoehoe that even 8 km below its source was still fluid enough to form thin sheets. It appears that in the northern vault, a sort of column existed since at St. 15, possibly an analogue to the column in Eclipse Cave (see below). The direction of Al-Ameed is more or less in direction of the flow (which is in contrast to most of the other caves in the flow field) and the surface ridge above the northern section is striking at an angle to the strike of the cave.

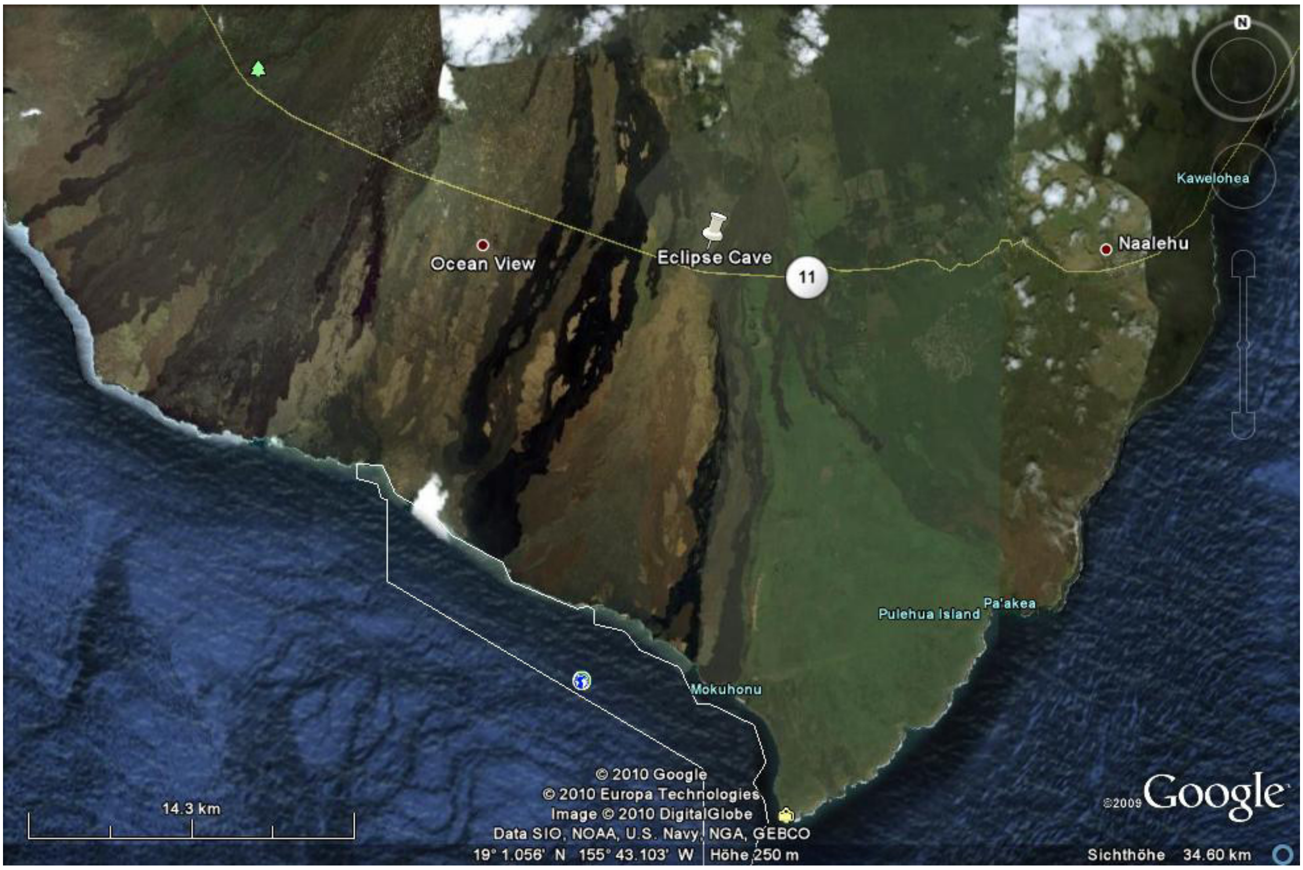

Fig. 4. Location of Eclipse Cave, Mauna Loa, Hawaii (Google Earth Picture).

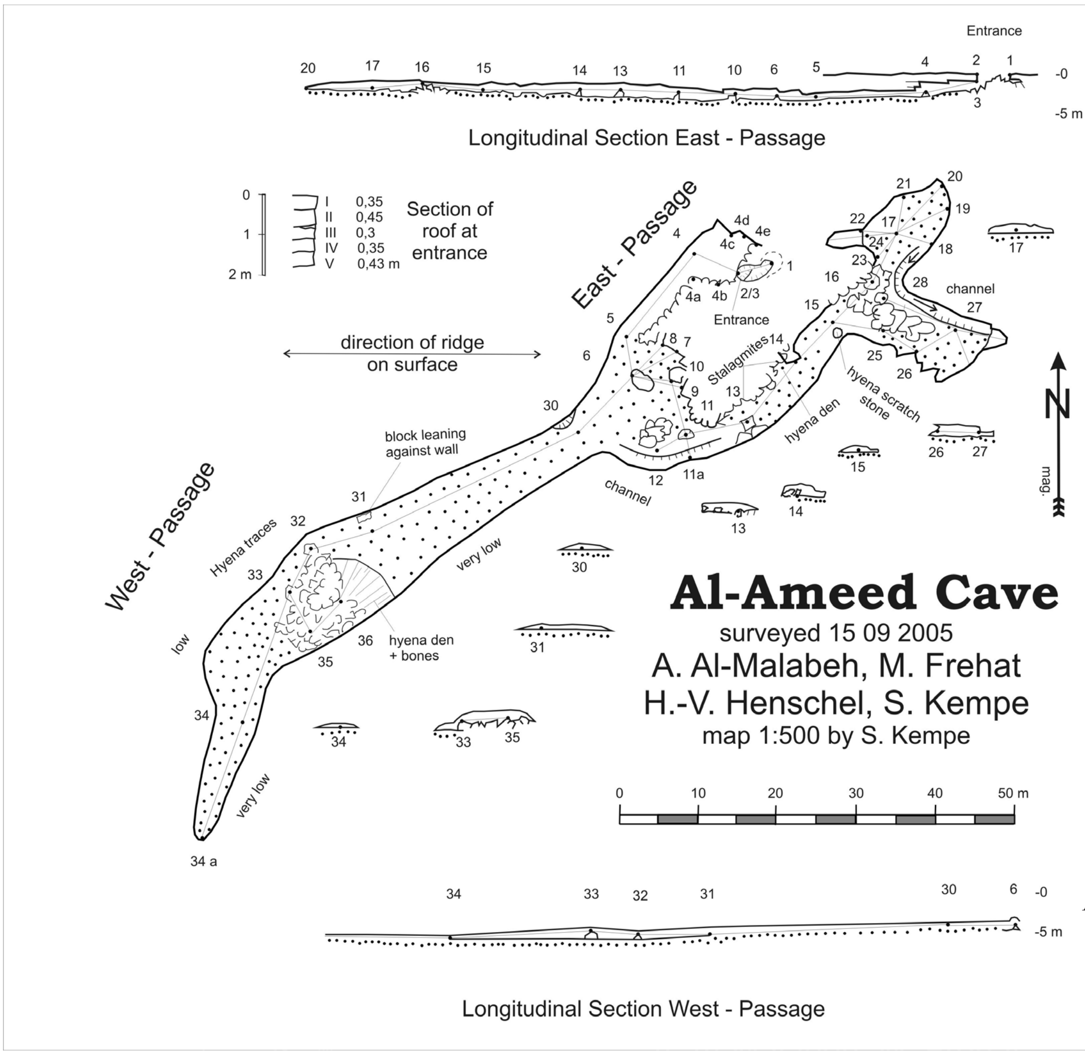

Fig. 5. Ground plan, cross-sections and longitudinal section of Al-Ameed Cave.

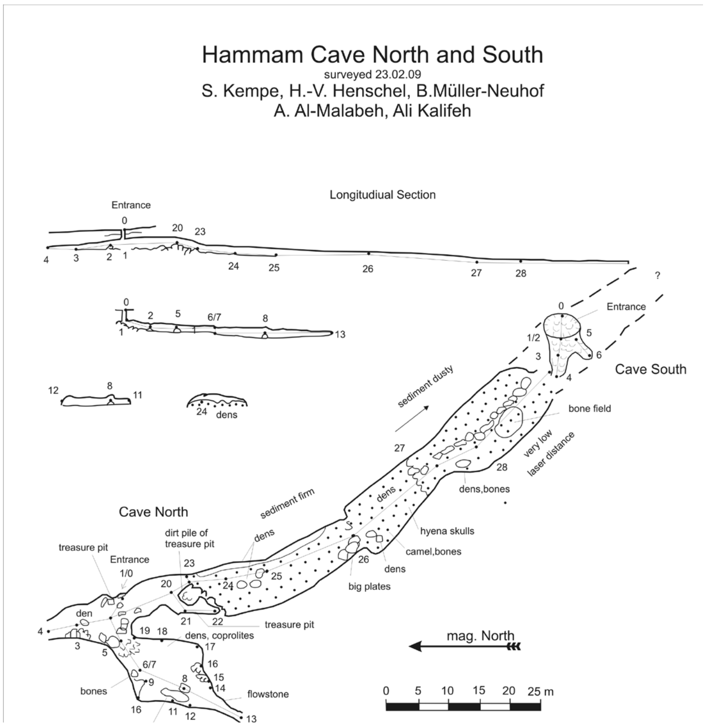

Fig. 6. Ground plan, cross-sections and longitudinal section of Hammam Cave.

The next longest cave is Hammam Cave North that, looking at the ground plan, might be mistaken for a pyroduct (Fig. 6). However, nowhere is there any sign of flowing lava and the branch to the SW, a room that has standing height in contrast to the rest of the cave that only allows crawling, with its circular is typical for the pressure ridge cave morphology. The main branch (Fig. 7), that leads southeast toward another entrance (Hammam Cave South) is low throughout. The roof height is again in the order of 2 m.

Fig. 7. View to south-east into main passage of Hammam Cave.

Obada Cave has three fingers, all ending very low (Fig. 8). The view into the main chamber (Fig. 9) reveals

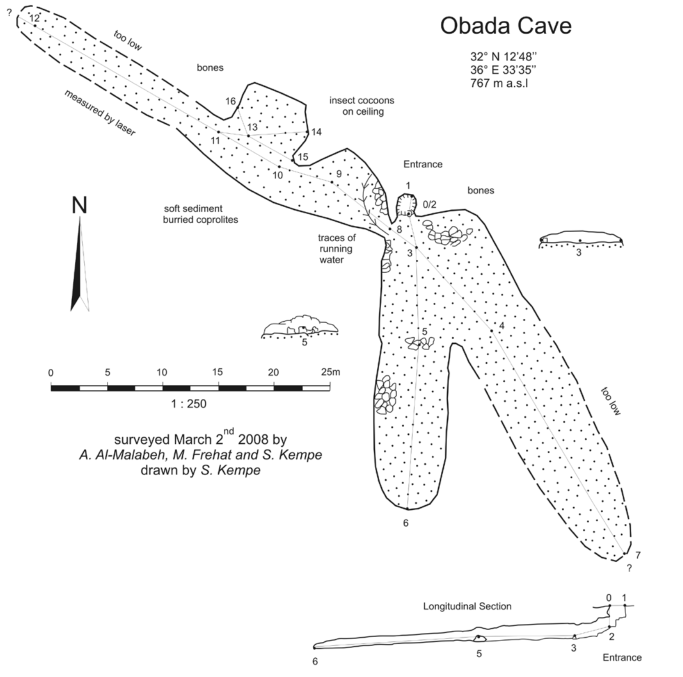

Fig. 8. Ground plan, cross-sections and longitudinal section of Obada Cave.

a very low, wide vault. The southern end of Haleem Cave is also a 20 m wide hall, nowhere high enough to stand (Figs. 10, 11). The cave has two openings, one that can be entered and a slot, not wide enough for adult humans to squeeze through. The cave follows a surface flow ridge (Fig. 12). Henschel Cave consists essentially of only one large low and circular room (Fig. 13). Its entrance is so small and has only recently been enlarged, that it has never been entered by hyenas; rather it contains a number of bird bones.

The largest cave in the northern group is Azzam Cave (Fig. 14), the one we explored first in Jordan. It is well known locally and its entrance has been artificially enlarged and stabilized because it is used as a sheep pen from time to time. The entrance is surrounded by a wall, also serving the modern herders. The sediment dug from the entrance pit was deposited nearby; it contains pot shards from various times. There is no distinct surface ridge above the cave (Fig. 15). This may indicate that the

Fig. 9. Panorama view into Obada Cave.

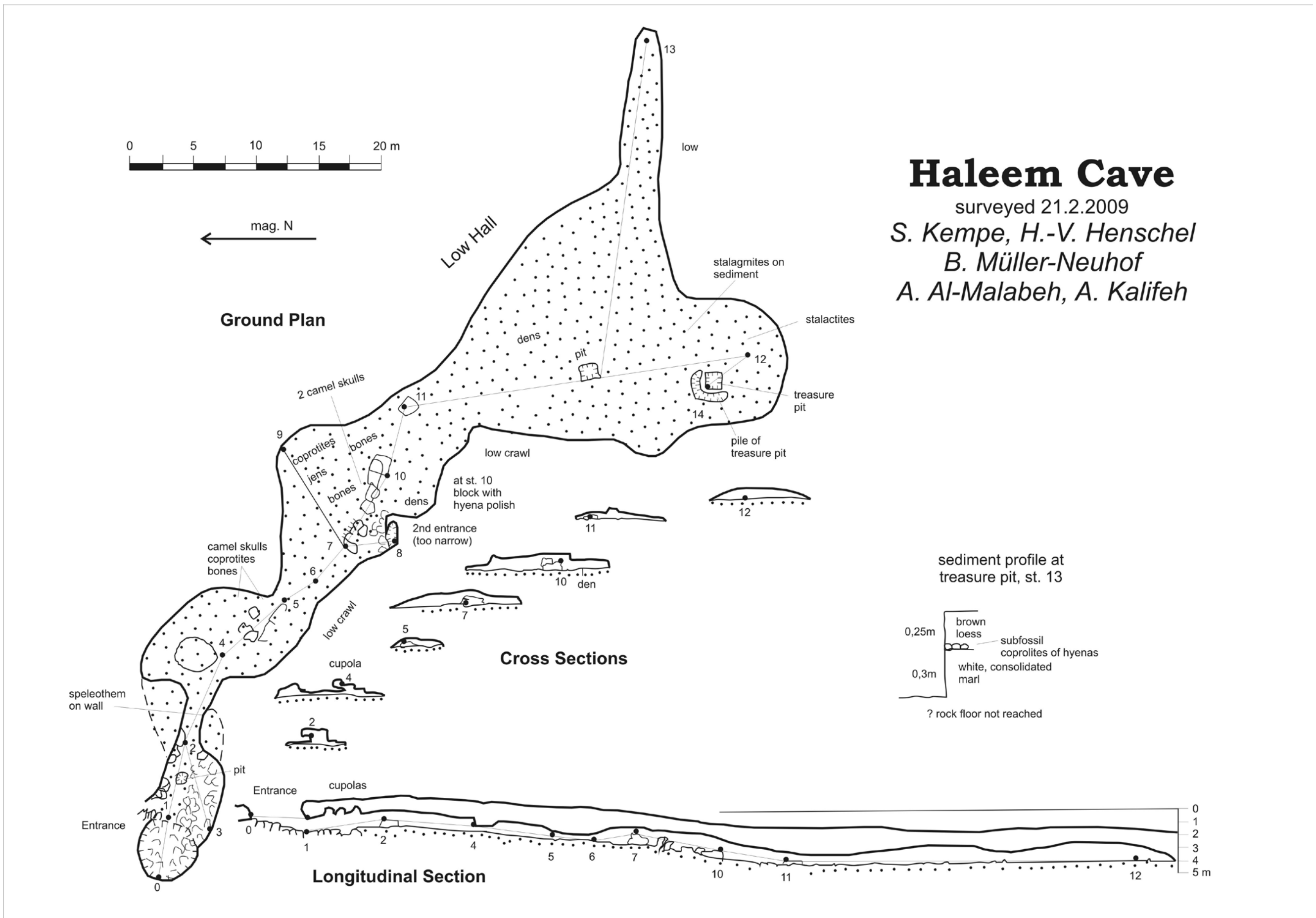

Fig. 10. Ground plan, cross-sections and longitudinal section of Haleem Cave.

Fig. 11. View east into the low and wide hall at the southern end of Haleem Cave.

original flow that contains the cave was later covered by other surface flows from the nearby volcano. Due to the weathering such features cannot be differentiated any more.

Eclipse Cave, Mauna Loa Hawaii

Eclipse Cave actually consists of a combination of a pressure ridge cave and a small pyroduct (Fig. 16). The pressure ridge hall is aligned perpendicular to the direction of flow. It is 70 m long and up to 2.5 m high, forming a rather regular vault up to 18 m wide (Fig. 17). The hall has a flat lava floor lacking any signs of lateral flow. Contraction cracks are as deep as 1.8 m, showing that the floor must have solidified from a very deep layer of fluid lava. To the west we discovered

Fig. 12. View south-east along the surface ridge above Haleem Cave.

that the cave also features a small pyroduct originated in a niche below the northern rim of the entrance puka (sinkhole) (Fig. 16). There lava upwelled from below, possibly an overflow from the actual mean pyroduct underneath. The lava then flowed downhill into a 2-3 m wide but very low tunnel (Fig. 18) that we could follow for about 20 m but did not survey. This conduit showed all the features associated with lateral flow of lava. The floor of the pressure ridge on the other hand is flat and does not show any flow lobes or any measureable slope. At the surface a low ridge exists above the hall (Fig. 19). The surface pahoehoe slaps forming it are tilted suggesting yield to a lateral pressure.

Conclusions

All these observations suggest that "pressure ridge caves" formed by the buckling up of one or a few inflationary lava sheets due to lateral pressure when half-solidified surface sheets yield to the shoving of the hotter lava below by doming upward, perpendicular to the direction of pressure. The caves are, however, not underneath pronounced tumuli but can occur under low, longitudinal or dome-like rises. Most interesting is the column in Eclipse Cave. It is not a lava stalagmite created by lava invading a crack from above. Around its foot it is surrounded by welded rough a'a-like apron. The only explanation for this unique feature we can suggest is that it was created during the process of upward doming of the roof. When the roof started to

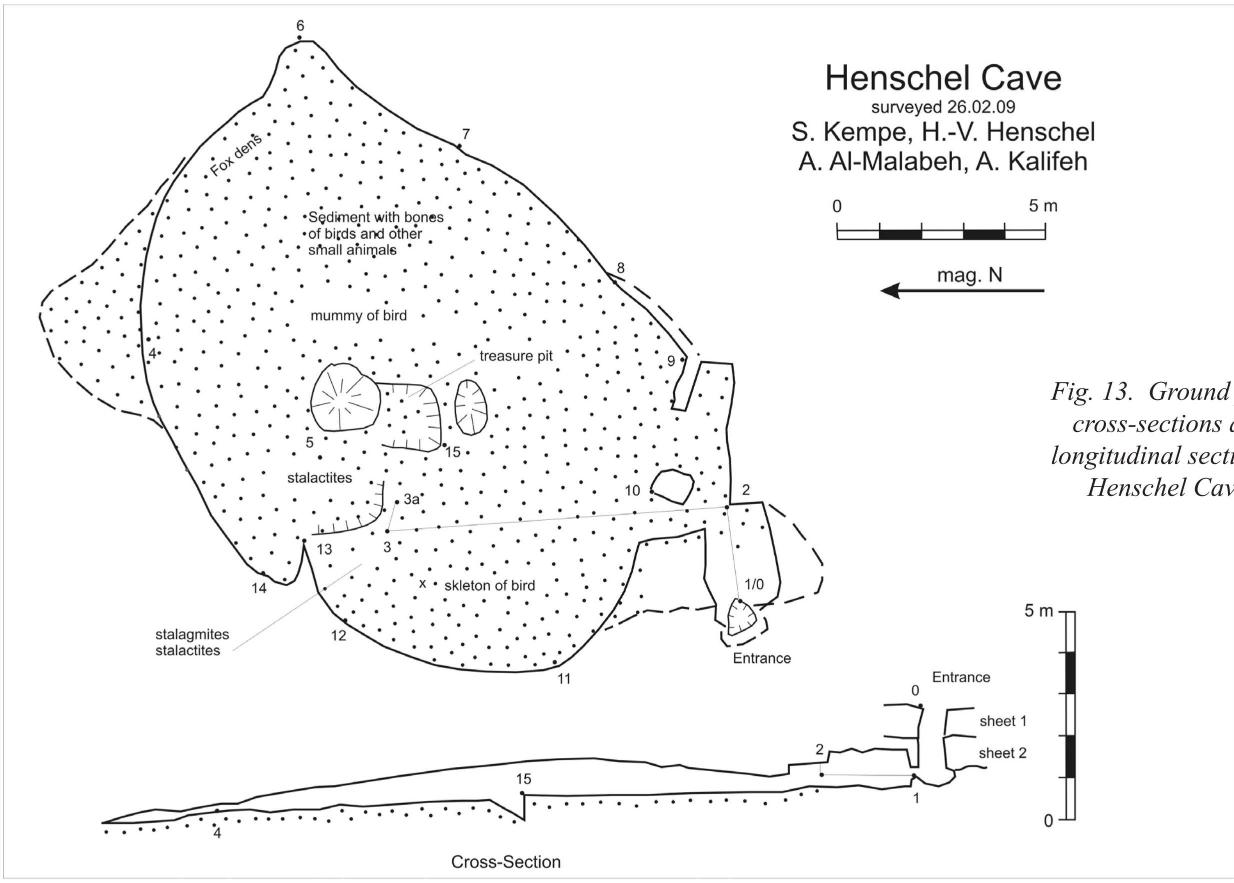

Fig. 13. Ground plan, cross-sections and longitudinal section of Henschel Cave.

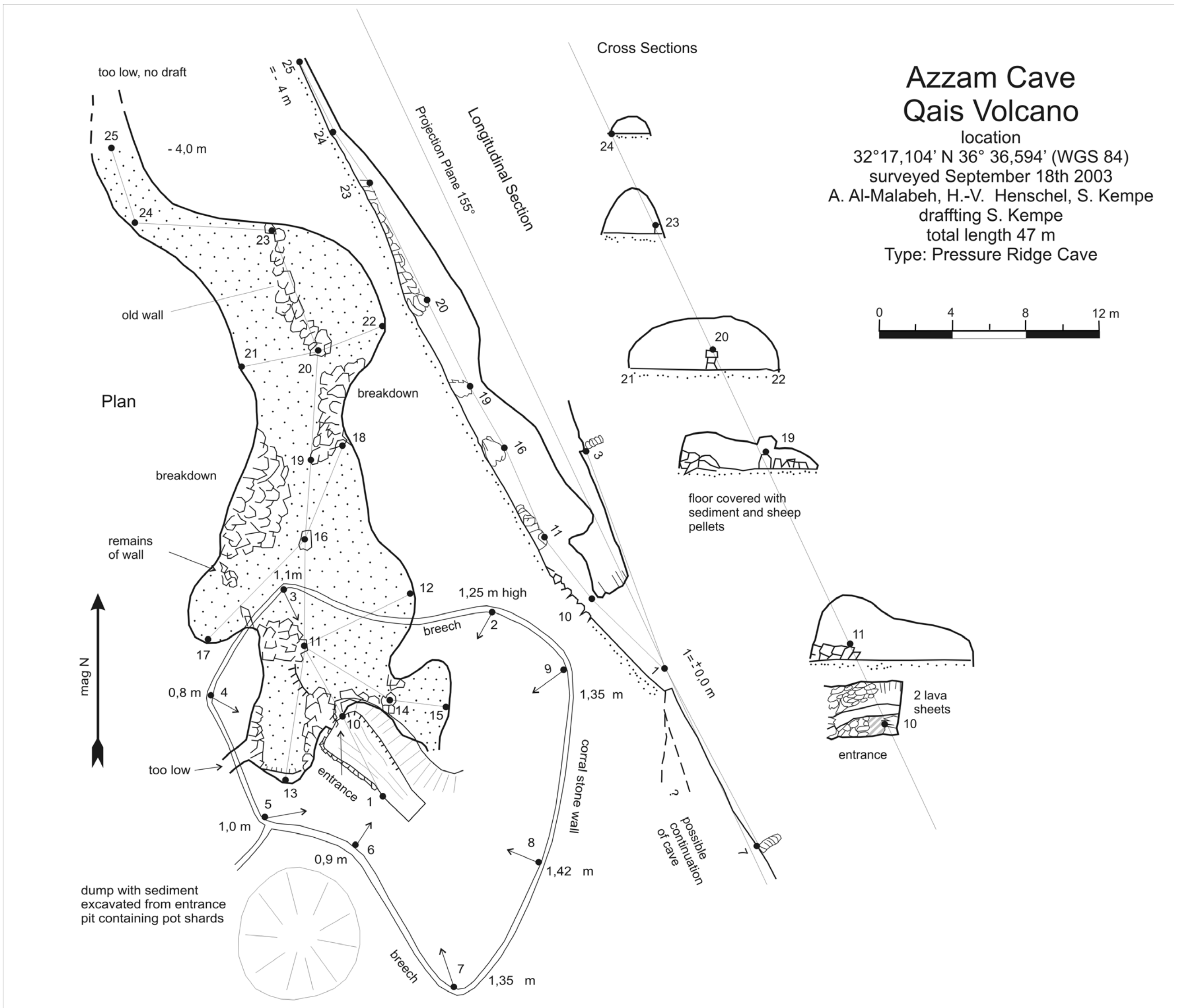

Fig. 14. Ground plan, cross-sections and longitudinal section of Azzam Cave.

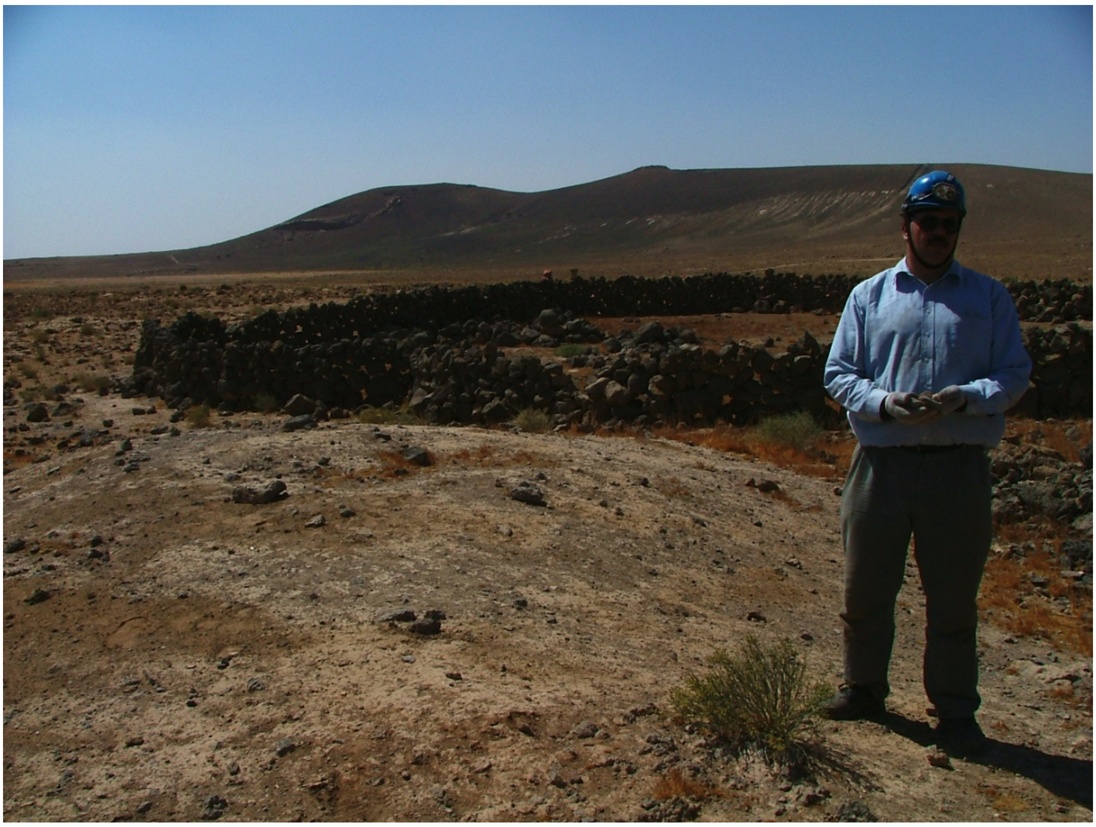

Fig. 15. View across the entrance of Azzam Cave towards the eastern flank of the Quis Volcano tephra ring.

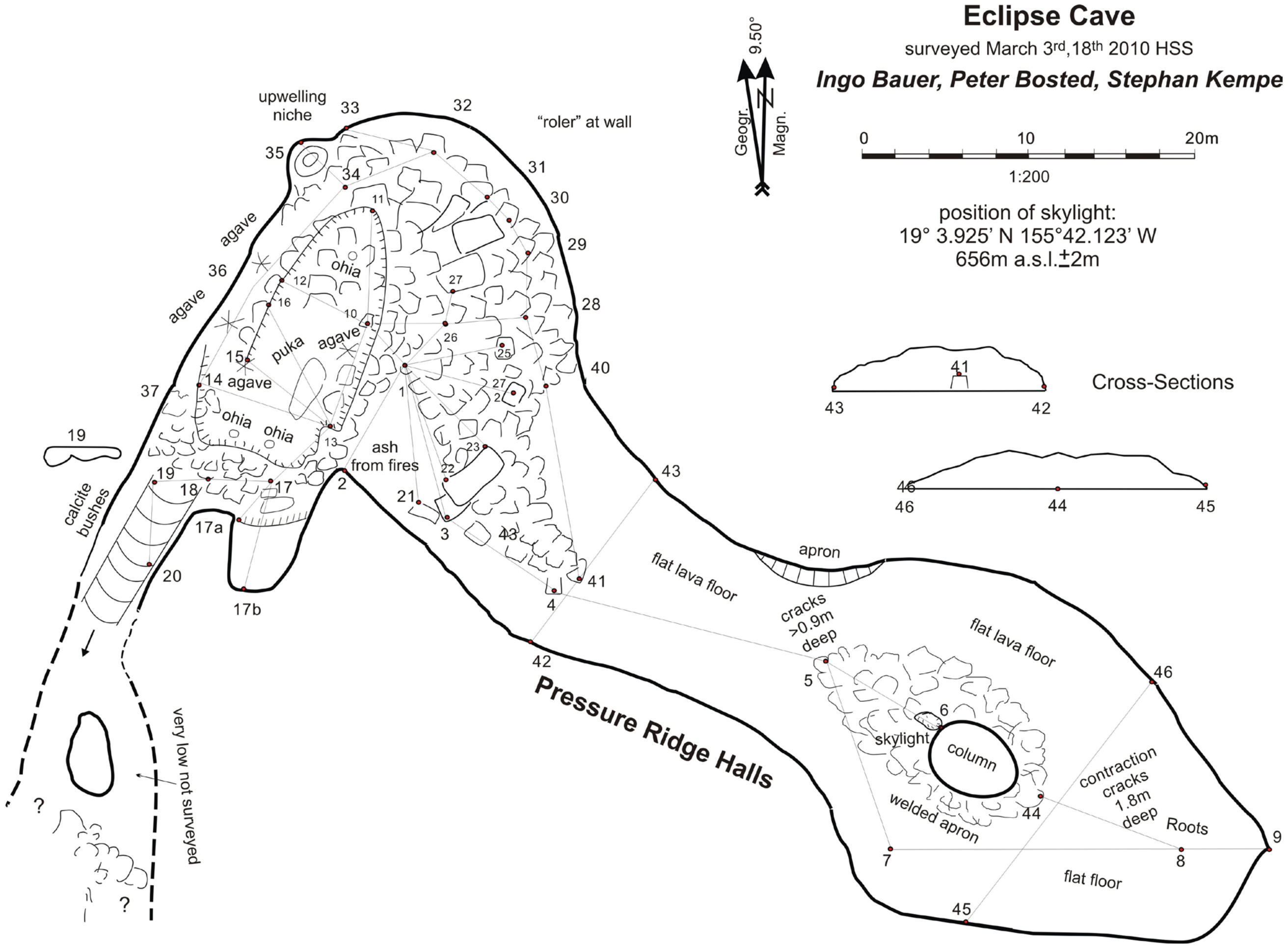

Fig. 16a,b Ground plan, cross-sections and longitudinal section of Eclipse Cave, Mauna Loa, Hawaii.

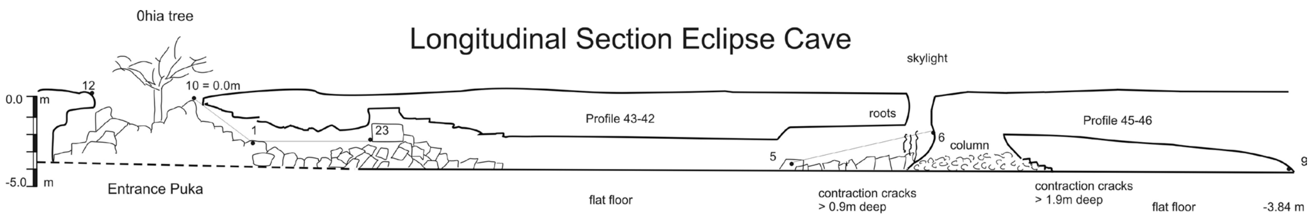

Fig. 17. Panorama view of the "column" to the west from the end of the pressure ridge section of Eclipse Cave. That the floor appears higher on the right side is an artefact of the construction of the panorama.

separate from the later floor, it could at first have stuck to the floor at this place. Then, as the roof moved up, the ceiling at this spot pulled lava up from the still molten floor chewing gum-like, peeling the original surface sideward to form the a'a-like apron.

In case of the Jordanian caves it appears as if the lava

Fig. 18. Panorama view into the downhill side of the small and low pyroduct to the western side of the Eclipse Cave.

Fig. 19. Panorama view of the ridge from the north below which the pressure hall section of Eclipse Cave is situated. The trees to the right mark the "puka", i.e. the entrance to the cave. The trees to the left have their roots in the cave, as seen on figure 17. The plates that form the roof of the cave have been tilted upward (center). Person (I.B.) for scale on the far left.

of the Quis and Makais Volcanoes had properties sustaining the formation of the pressure ridge caves that are not matched by the properties of the other lava fields composing the Harrat. What these properties are in detail and how they compare to that of the Elipse Cave Flow remains to be studied. It could be that during the cooling of lava a certain "viscosity window" exists that allows doming upward of a ca. 1-2 m thick surface layer separating it from the hotter layers below without breaking it.

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