Jordanian lava caves, an overview*

by

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Abstract

The center of Jordan is occupied by a vast intercontinental lava plateau, called the Harrat Al-Shaam, composed of Cenozoic (Oligocene-Quaternary) alkali olivine basaltic lava flows, the Harrat Al-Jabban volcanics or Jordanian Harrat (Al-Malabeh, 2005). The top most and therefore youngest flows are ca. 400 000 years old (Tarawneh et al., 2000). So far, we explored, surveyed and studied a total of 23 lava caves since September 2003. 3164 m of passages were surveyed up to now (Table 1). These caves are, compared with most other lava caves quite old and many of them end in washed in loess. In addition to the Lava tunnels (pyroducts) that conveyed lava underground over large distances, Jordan has also a large fraction of pressure ridge caves (Kempe et al., 2010), all associated with Quis/Makais volcanoes. Two caves are of doubtful origin.

1. Introduction

The Arabian plate is covered by seven larger and several smaller Cenozoic (Oligocene-Quaternary) basalt fields, the "Harrats". They stretch over a N-S distance of about 3000 km from Jordan and Syria through Saudi Arabia to Yemen. The estimated volume of eruptive material equals to between 103 and 105 km3. These wide-spread, poorly studied basalt fields are considered to be among the largest of predominately alkali-olivine basalt plateaus in the world (e.g., Al-Malabeh, 1994).

Our group studies the lava caves contained in the Jordanian section of the Harrat Al-Shaam, the 700 km long, most northern of these plateaus that covers about 45,000 km2 (ca. 25% of the Arabian Harrats) (Fig. 1). This Harrat is in Jordan ca. 220 km wide in the N and 30-50 km in the south. Geomorphologically, it forms a gently undulating lava plateau dotted with prominent tephra cones, low shield volcanoes, numerous pressure ridges and crossed by a few, up to 80 km long eruptive fissures. The plateau generally dips to the S and SE, starting at an altitude of ca. 1100 m (a.s.l) along the Syrian border and dropping down to 700 m at Al-Mafraq and to 550 m in the Al-Azraq area. The overall slope is at most 4°. The structure of the basalt plateau is a succession of flow sheets which form stepped cliffs along wadi walls or faults. The youngest of these flows are over 400 ka old (Al-Fahda area) (Tarawneh et al., 2000). It - and the other younger lava fields - does not show wadi incision yet, while the older flow series are heavily incised. The Harrat is covered by a 1-2 m thick loess layer that has been washed into the depressions forming playas (locally known as Qa') giving the less incised areas a mottled appearance.

2. Lava Caves

In these lavas we explored, surveyed and studied a total of 23 lava caves since September 2003. 3164 m of passages were surveyed as of spring 2012 (Table 1). Of the total, 1,486 m, or 47%, was surveyed in September 2005, among them the 923.5 m long Al-Fahda Cave, currently the longest cave in Jordan. Nine of the lava caves are lava tunnels (pyroducts). One cave (Treasure Pit) is pit dug by treasure hunters that probably leads into a sediment-filled lava tunnel. Ten caves are pressure ridge cavities and two caves (Beer Al-Wisad and Uwaiyed) are of unusual origin and one cave in the list is artificial (Eshaim Cave).

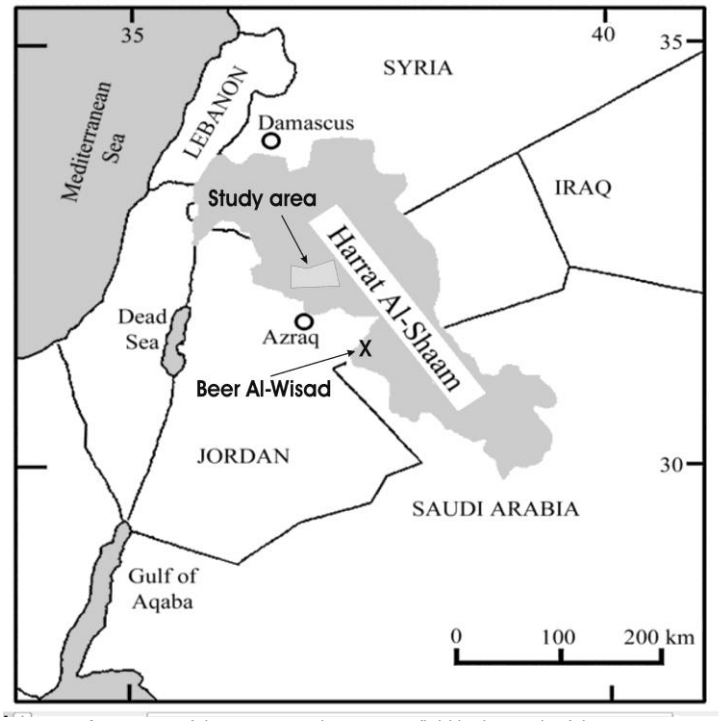

***Fig. 1**: Map of the Harat As Shaam Lava field in the north of the Arabian plate.*

Table 1: List of currently known and surveyed lava caves in Jordan, sorted by total passage length.

	Name of Cave	Latitude	Longitude	Stations	Length	Stations	Depth	Direction	Altitude	Type	Surveyed	Hyena Presence
1	Al-Fahda Cave	32°18.426	37°07.622	complex	**923.5**	2 to 54	6.7	SW-NE	792 m	Pyroduct	2005	xxx
2	Al-Badia Cave	32°07.91	36°49.42	32 to 23	445	1 to 23	17.2	NW-SE	783 m	Pyroduct	2003	no
3	Hashemite University Cave	32°13.362	36°33.579	21 to 35	231.1	1 to 23	10.0	NW-SE	787 m	Pyroduct	2005	xx
4	Al-Ameed Cave	32°13.214	36°33.179	complex	208	2 to 31	4.0	SW-NE	777 m	Pressure Ridge	2005	xxx
5	Dabie Cave	32°10.387	36°55.583	0 to 14	193.6	0 1to 13	1.8	NW-SE	881 m	Pyroduct	2004	xxx
6	Abu al Kursi East	32°15.401	36°39.442	20 to 34	153.7	1 to 34	12.2	W-E	883 m	Pyroduct	2003	xx
7	Kempe Cave	32°16.806	37°33.945	complex	139.4	complex	11.5	N-S	939 m	Pyroduct	2007	xxx
8	Hammam Cave N	32°13.219	36°34.340	complex	123.4	0 to 28	4.5	NW-SE	780 m	Pressure Ridge	2009	xxx
9	Al-Jolous Cave	32°13.925	36°34.206	0-15	112.6	-	n.d.	NE-SW	799 m	Pyroduct	2007	xx
14	Obada Cave	32°12.989	36°34.536	complex	107.6	0 to 6	3.4	NW-SE	766 m	Pressure Ridge	2008	xxx
10	Al-Howa	32°18.536	36°37.240	complex	97.1	2 to 6	10.8	SW-NE	939 m	Pyroduct	2004	no
11	Al-Haya Cave	32°17.743	36°34.745	1 to 11	81.3	1to 9	4.2	NW-SE	902 m	Pressure Ridge	2005	xxx
12	Abu al Kursi West	32°15.401	36°39.442	2 to 18	77.1	2 to 18	8.1	N-S	883 m	Pyroduct	2003	xx
13	Haleem Cave	32°13.441	36°33.675	1 to 12.	70.7	1 to 12.	4.7	NW-SE	791 m	Pressure Ridge	2009	xxx
15	Azzam Cave	32°17.104	36°36.594	13 to 25	44.1	1 to 25	4.2	NNW-SSE	902 m	Pressure Ridge	2003	no
16	Al Ra'ye Cave	32°17.618	36°34.791	1 to 6	42	1 to 34	3.5	NW-SE	900 m	Pressure Ridge	2005	no
17	Dahdal Cave	32°17.344	36°35.718	5 to 12	28.9	1 to 12	0.0	SW-NE	920 m	Pressure Ridge	2003	x
18	Henschel Cave	32°13.355	36°33.841	complex	21		2.50	W-E	788 m	Pressure Ridge	2009	no
19	Eshaim Cave	32°16.887	36°51.305	1 to 3.	20.6	1 to 3.	0.0	N-S	1029 m	Artificial	2009	no
20	Hammam Cave S	32°13.183	36°34.373	2 to 5.	12.4	2 to 4	2.4	NW-SE	780 m	Pressure Ridge	2009	x
21	Uwaiyed Cave	31°39.186	37°29.900	diameter	12		2.0	not def.	*681 m*	unknown	2008	xx
22	Beer al Wisad	31°44.527	37°27.991	chamber	11.4	Depth	11.5	not def.	627 m	unknown	2006	no
23	Treasure Pit	32°16.585	37°37.578		7.2	1-10,11	5.8	not def.	928 m	Pyroduct?	2006	no
				Sum	3164							

3. Lava Tunnels (Pyroducts)

Al-Fahda ("the lioness") Cave (Al-Malabeh et al., 2006) was named after the local name for one of the youngest lava fields (K–Ar age 0.46 ± 0.01 Ma sample HAS-7; Tarawneh et al., 2000) in the Harrat. It was first mentioned without any speleological details by Helms (1981, p.138) as El-Mughara in connection with the investigation of the famous Bronze Age desert city Jawa. Helms described a channel that leads to the entrance of the cave, apparently dug in an attempt to store water in times of plenty in the cave for times of need. This channel led to the rediscovery of the cave by the second author, who followed it from Wadi Rajil (830 m a.m.s.l) in the north downslope to the main entrance (730 m a.m.s.l) (Al-Malabeh et al., 2006) and surveyed by us in 2005 (Table 2; Fig. 2). The cave is also known under the name of Khsheifa Cave and was surveyed in parallel by Frumkin et al. (2008) yielding astonishingly similar results (their length 920 m).The cave has a very low slope, according to our survey of about 0.7°. Such a low slope is typical for tube-fed pahoehoe flows. Al-Fahda Cave is unusually wide but very low and has a very flat floor (at least were the rock floor is visible) (Fig. 3). It appears that this was caused by a later invasive flow filling the lower part of the tunnel. It shows a blocky surface and ends in two flow lobes shortly before the cave itself ends. It remains unclear if this fill is autochthonous, i.e, generated within the tunnel as a terminal slump of a higher viscosity, or allochthonous, i.e. caused by an invasion of a later flow of the Al-Fahda flow field through a ceiling hole (above the current accessible section of the cave). The main entrance to the cave today is through a late central ceiling collapse, exposing a cross section through the primary roof. It is composed of two relatively thick layers, in contrast to other caves that have up to 12 sheets in the primary ceiling (in case of Abu Al-Kursi) (for a more detailed study of the cave see Al-Malabeh et al., 2006).

Table 2: Survey results of Al-Fahda Cave (Al-Malabeh et al., 2006).

Stations	**Horizontal**	**m**	**Stations**		**m**
2-54a	Main survey downslope	488.60		End-to-end (as the crow flies)	**684.0**
8-11	Back of entrance	18.68		Sinuosity (771.03/684)	1.13
19-22	To second entrance	14.46	2-54a	Vertical (entrance to deepest point)	-6.74
50-51a	W-passage of terminal split	28.45	71-54a	Vertical extent of Main Passage	-8.41
4-5	Connection	6.05	71-54a	Horizontal length	755.12
5-71	Upslope passage	266.21	**Slope 1**	slope (°) (tan^{-1} (8.41/755.12)*	0.64°
67a-79	Mahmoud's Test Passage.	101.07	**Slope 2**	slope (°) (tan^{-1} (8.41/684)	0.70°
Total		**923.52**	**Width**	Maximal at St. 8	17.5
	Main Passage length			Minimal at St. 64	3.55
4-54a	Downslope passage	482.86		Mean of main passage (39 stations)	7.51
4-67a	Upslope passage	187.10	**Height**	Maximal St. 14	4.67
67a-79	Mahmoud's Test Passage	101.07		Mean of main passage (39 stations)	1.21
Total		**771.03**			

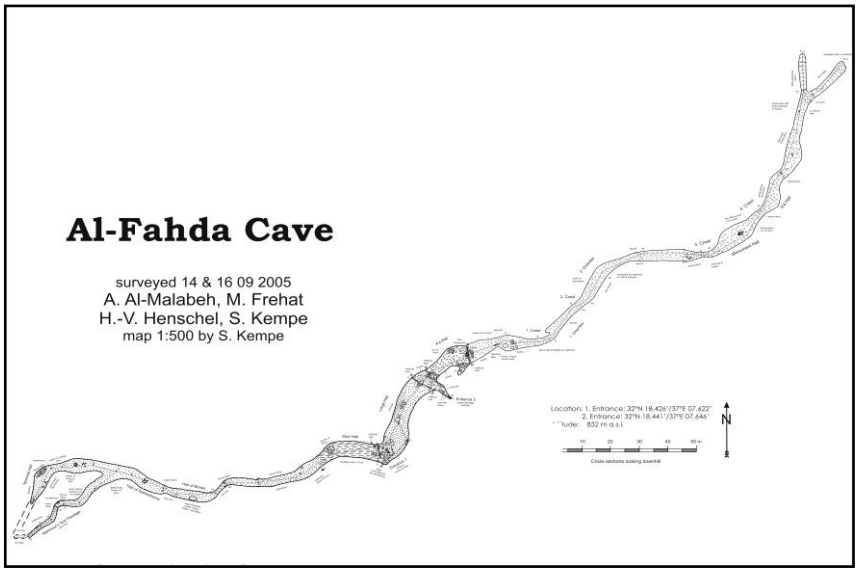

Fig. 2: *Map of Al-Fahda Lava Cave, longest lava cave in Jordan*

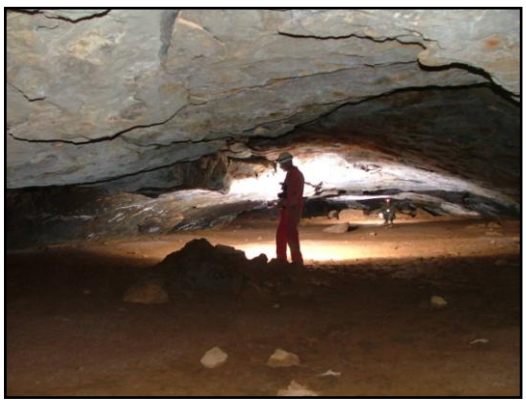

Fig.3: *View up-slope into Al-Fahda Cave from the entrance. Note flat, sediment covered floor and low and wide character of the tunnel (persons for scale).*

Hashemite University Cave is speleologically interesting also; it is reached through a collapse hole at the crest of a ridge. There the primary, 7 m thick roof is exposed consisting of only three pahoehoe layers. The uphill passage running NW is blocked by breakdown but from the north another low passage filled with sediment joins. The downhill tunnel is 180 m long before it opens up to a nearly circular room ca. 20 m in diameter. There, the cave ends in a lava sump. In a way, this is similar to the terminal lava sump of Thurston Lava Tube (Kempe & Henschel, 2009). It poses a structural riddle since one would expect that the back-up of the residual flow in the tunnel should close the cave at a narrow point but not at a wide passage. One possible solution could be assuming that the floor is a secondary ceiling (Kempe, 2002). A blowhole, situated near station 26, indicates that there could be an open passage underneath, giving some credibility to this hypothesis. In case of Kempe Cave, we can identify the source volcano for the first time in Jordan (Fig. 4) (Kempe et al., 2008). It is a low shield volcano in between larger stratovolcanoes. The crater is 120 m across and the rim is very even, suggesting that it once held an overflowing lava lake. The slope between crater (976 m a.s.l.) and cave (936 m) is only 1.2°. The cave itself (Fig. 5) is very low and curves around in half-circle; it is the most sinuous among the caves yet explored. Due to the fact that it is the cave furthest east and therefore the driest it also contains unusual speleothems, among them curvy gypsum flowers.

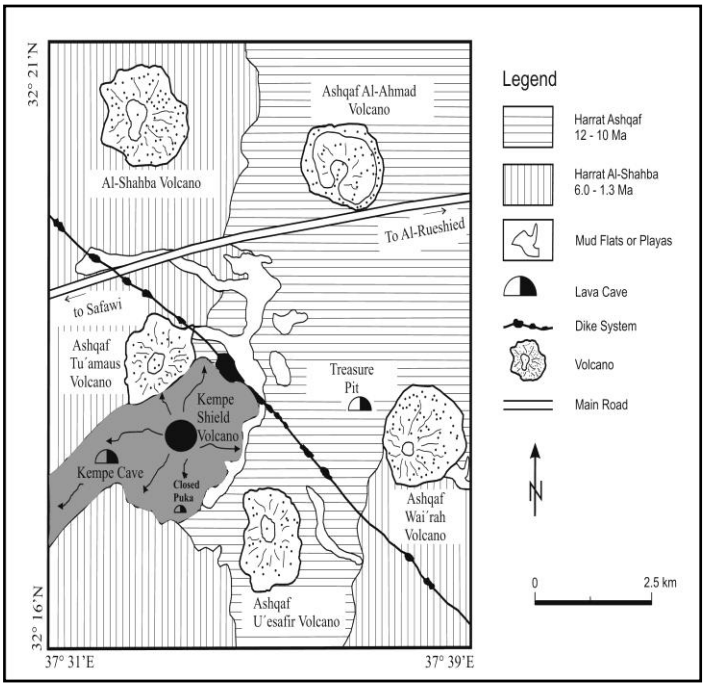

***Fig. 4**: Geological map of the Kempe Volcano (Map by Al-Malabeh and Kempe based on Field observations and Google Earth images).*

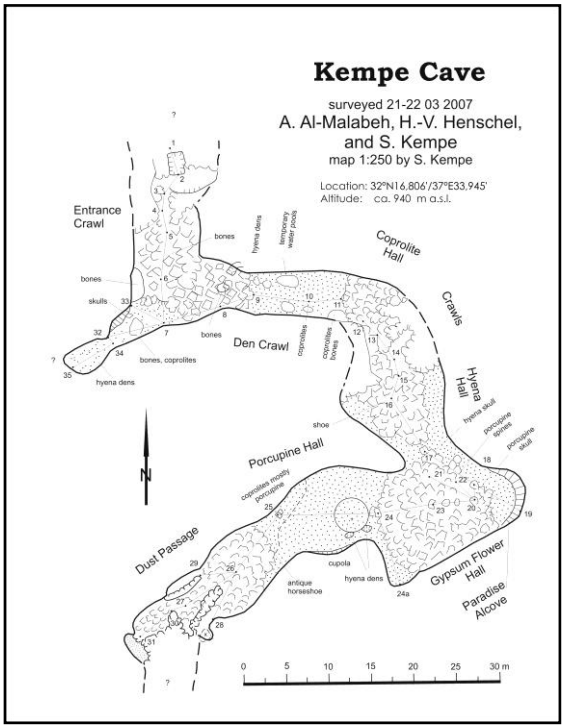

***Fig. 5:** Map of Kempe Cave*

4. Pressure Ridge Caves

A group of caves not showing any clear direction of slope nor any signs of horizontal flow, is grouped as "pressure ridge caves" (Kempe et al., 2010). They can be quite long (Fig. 6, map of Al-Ameed Cave), are very wide and low in general and can have several branches, petering out at their ends. Similar caves are known from Hawaii, but are not well documented.

Pressure ridge caves apparently form when half-solidified surface sheets possibly yield to the shoving of the hotter lava below by doming upward, often with axes perpendicular to the direction of pressure. The caves are however, not bound to pronounced tumuli put can occur under low, dome-like rises.

5. Other Lava Caves

Uwaiyed Cave is a circular 10 m wide chamber in highly weathered old basalt that may be caused by upward stooping of a hypogene, collapsed limestone cave at depth (Al-Malabeh &Kempe, 2012) (Fig. 7). Another (Beer Al-Wisad) one is an 11 m deep pit, also in very old lava, of unknown origin.

The discovery of so many lava tunnels in the Harrat is surprising considering their old age and the fact that the loess is easily washed into caves filling them eventually. Al-Fahda, Hashemite University, Dabie, Kempe and the two Abu Al-Kursi Caves are all closed by sediments. Only Al-Howa Cave is terminated on both ends by roof collapse due to the loading of a later a'a lava flow.

Al-Fahda, Al-Badia (Beer Al-Hamam), and the two Abu Al-Kursi Caves are rather wide, while Al-Howa, Hashemite University, Kempe and Dabie Caves are of smaller dimensions. All have very low gradients.

Lava falls and plunge pools, so often encountered in Hawai'i (Kempe, 1997), were not found in these caves. A secondary ceiling is possibly present only in Hashemite University Cave. Benches and shelves marking older flow levels occur in Dabie Cave, Al-Fahda and in one place in Hashemite University Cave. Branching is rare, apart from Al-Fahda Cave only Hashemite University and possibly Kempe Cave display branching.

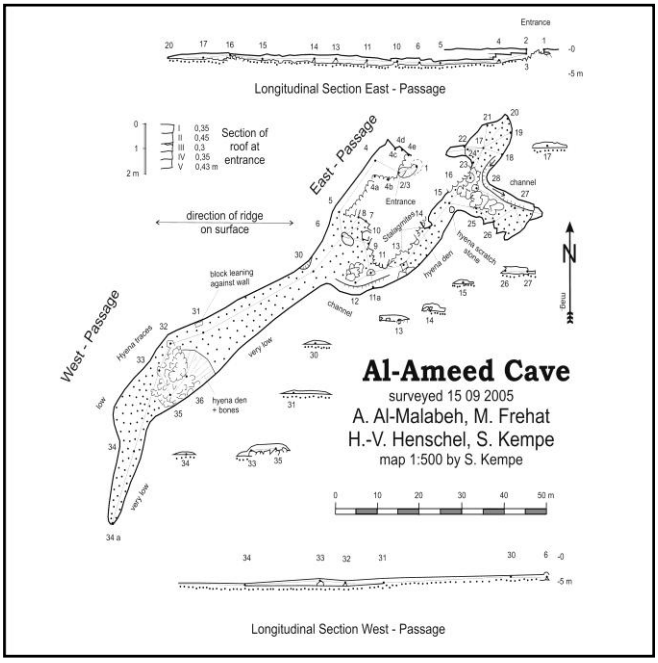

***Fig. 6**: Map of Al-Ameed Cave*

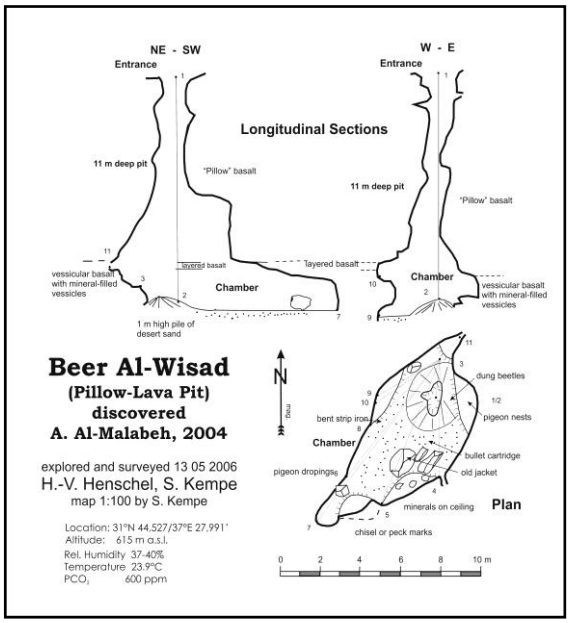

***Fig. 7**: Map of Beer Al-Wisad.*

The presence of the lava tunnels underscores the fact that the Harrat consists to a large part of tube-fed pahoehoe thus explaining its overall low slope.

Compared to Hawaiian tunnels (see data in Kempe, 2002; Kazumura, Keala and Huehue, some of the longest caves on Hawaii have sinuosities of 1.30, 1.25 and 1.2), most caves show a rather low sinuosity (Al-Fahda: 1.13), in spite of the fact that it has a lower slope than the mentioned Hawaiian caves (1.51°, 1.51°, 4.58° resp.). The hypothesis that there should be a reverse relation between slope and sinuosity can therefore not be substantiated. The winding of the cave should have provided for a "Thalweg", i.e. a path along which the lava flow was maximal with slip-off and undercut slopes to the sides depending on curvature.

The high proportion of "pressure ridge caves" and their length are another interesting finding. One of the reasons for this high proportion of caves not formed by underground linear flow of lava may be the low slope of the terrain being in places even below 1°.

Many of the caves (compare Table 1) have been used by hyenas, wolves, foxes and porcupines. Specifically hyenas left many bones of their prey, abundant coprolites, dens dug into sediment and scent marks (Kempe et al., 2006a). The caves therefore are also of high paleontological and taphonomic importance.

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