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**Oral Presentations**

***SESSION II- VULCANOSPELEOLOGY OF THE WORLD***

## **THE EXPLORATION OF HIBASHI CAVE, SAUDI ARABIA**

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Ghar al Hibashi, located 300 kms SE of Jeddah in the Nawasif-Buqum lava field is the longest lava tube so far mapped in Saudi Arabia (565 m long). Lava levees, stalactites and stalagmites are found throughout the cave and it has a lava channel 13 m long. A bed of loess, up to 1.5 m thick covers the floor and its age is now being determined by OSL. Coprolites from hyenas, sheep, wolves and foxes are found in many parts of the cave and may be very old. Two areas are covered with burnt bat guano and samples taken from one of these areas were found to contain a number of rare cave minerals. A human skull found in the cave has been carbon dated at 450 years BP and shows possible evidence of foul play.

Researchers working with the Field and Space Robotics Lab at MIT to develop microrobots for cave exploration on Mars recently requested permission to use photos of Hibashi Cave to illustrate the possible interior conditions of lava tubes on Mars.

Hibashi Cave is occasionally visited by local people and is in need of protection from vandalism.

## **A DIGITAL LIST OF NON-KARSTIC CAVES IN HUNGARY**

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The Volcanospeleological Collective has carried out the study and cataloguing of non-karstic caves in Hungary since 1983. They have compiled descriptions, surveys and photographs from each recorded cave. The cave documentation fills more than twenty volumes, mainly as manuscript notes. However, access to this documentation is restricted. We decided to compile an easily accessible, standard list, of non-karstic caves in Hungary, where changes and updates can be easily made. We decided that a digital list would be the most suitable format.

We began to compile the register in 2002. We have listed each known non-karstic cave and located their positions on a map. Cave surveys and photographs, accompanied by short descriptions were also included in the list. Eighteen regions are represented where non-karstic caves occur. Index Maps were prepared for most of the regions. These are linked to the detailed maps with tabular summaries. The language of the list is Hungarian with an English translation, mainly to facilitate the use of the homepage.

The digital presentation of non-karstic caves was carried out using Arcview GIS as well as available digital map material. Detailed Maps and Index Maps with different scales were developed for specific regions as project files (apr). Layout Maps were then prepared. The layout maps were exported in jpg file format. This enables further utilization and handling. The dbf database was filled with cave data and other data to generate regional data sheets. The digital data from the non-karstic cave list facilitates its use by various presentation software programs and allows transfer of the cave registry to other formats.

The final summary of the non-karstic caves in Hungary is to be found on the Home Page of the cave list. All relevant data has been compiled in htm and html file format.

## THE HIBASHI LAVA TUBE: THE BEST SITE IN SAUDI ARABIA FOR CAVE MINERALS

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Systematic exploration of lava tube caves in Saudi Arabia started only recently, but several large examples have been now explored and mapped in various lava fields around that country.

One of the largest examples in Saudi Arabia is Hibashi Cave, located in Harrat Nawasif-Buqum lava field, 200 km east of Jeddah. It primarily consists of a huge rectilinear gallery (over 400 m long and 15 m wide) accessed down a breakdown slope in a wide collapse which gives entrance to a side corridor. The cave floor consists of uncemented, locally thick loess.

The cave was utilized long ago as shelter by wild animals including bats, hyena, wolf and fox. Many bones and coprolites are scattered throughout the floor. Large guano deposits also are present. Some of the guano has caught fire, partially burning overlying bones. The only true speleothems consist of a few small translucent yellow stalactites hanging from the ceiling.

Three different expeditions were conducted in 2003. A few samples of secondary mineral deposits were collected for analysis. Despite the paucity of the samples, 14 different minerals already have been detected (Table). Most are related to biogenic mineralization of bones and guano deposits.

Table – Identified cave minerals of the Hibashi lava tube (Saudi Arabia)

<b>1</b> - Anhydrite	CaSO <sub>4</sub>
<b>2</b> - Aphthitalite	(K, Na) <sub>3</sub> Na(SO <sub>4</sub> ) <sub>2</sub>
<b>3</b> - Arnhemite	(K,Na) <sub>4</sub> Mg <sub>2</sub> (P <sub>2</sub> O <sub>7</sub> ) · 5H <sub>2</sub> O
<b>4</b> - Arcanite	K <sub>2</sub> (SO <sub>4</sub> )
<b>5</b> - Archerite	(K, NH <sub>4</sub> )H <sub>2</sub> PO <sub>4</sub>
<b>6</b> - Biphosphammite	(NH <sub>4</sub> , K) H <sub>2</sub> (PO <sub>4</sub> )
<b>7</b> - Calcite	CaCO <sub>3</sub>
<b>8</b> - Carbonate- hydroxylapatite	Ca <sub>5</sub> (PO <sub>4</sub> ,CO <sub>3</sub> ) <sub>3</sub> (OH)
<b>9</b> - Chlorapatite	Ca <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> Cl
<b>10</b> - Halite	NaCl
<b>11</b> - Hydroxylapatite	Ca <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> (OH)
<b>12</b> - Niter	KNO <sub>3</sub>
<b>13</b> - Opal-C	SiO <sub>2</sub> ·nH <sub>2</sub> O
<b>14</b> - Palygorskite	(Mg,Al) <sub>2</sub> Si <sub>4</sub> O <sub>10</sub> (OH)·4H <sub>2</sub> O
<b>15</b> - Pyrocoprite	(K,Na) <sub>2</sub> Mg(P <sub>2</sub> O <sub>7</sub> )
<b>16</b> - Pyrophosphite	K <sub>2</sub> Ca(P <sub>2</sub> O <sub>7</sub> )
<b>17</b> - Quartz	SiO <sub>2</sub>
<b>18</b> - Urea	CO(NH <sub>2</sub> ) <sub>2</sub>
<b>19</b> - Whitlockite	Ca <sub>9</sub> (Mg,Fe)(PO <sub>4</sub> ) <sub>6</sub> [PO <sub>3</sub> (OH)]

Besides other rare but well understood cave minerals (like arcanite and archerite), pyrocoprite, pyrophosphate, and arhemite are extremely rare organic compounds strictly related to combustion of guano. Previously these had been observed only in a few caves in Africa. In this paper the SEM images of these minerals are reported for the first time.

As a result of these findings, the Hibashi Cave must be considered the most important volcanic cave in Saudi Arabia and, by far, the richest mineralogical shelter in this Country.

#### FINAL REMARK

This research was made within the MIUR 2002 Project “*Morphological and Mineralogical Study of Speleothems to Reconstruct Peculiar Karst Rnvironments*”, resp. Prof. Paolo Forti.

# INVESTIGATION OF THE DISCHARGE MECHANISM OF HACHIJO-FUKETSU LAVA TUBE CAVE, HACHIJO-JIMA ISLAND, JAPAN

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Hachijo-fuketsu lava tube cave is located on Hachijo-jima Island south of Tokyo in the Pacific Ocean. This cave is believed to have been formed by the eruption of Hachijo-nishiyama volcano 1100 years BP. Its lava flow is basaltic, with silica content of 50.5%. Hachijo-fuketsu is the second longest lava tube cave in Japan. Despite good accessibility, it is well preserved. Its upper and middle sections have moderate slopes. Its lower end is flat and horizontal.

In modelling the discharge mechanism of this type of lava tube we used an inclined circular tube model for the sloping sections of the cave. For the flat, horizontal section in which the lava flow is driven by hydrodynamic head, we modelled a flattened circular tube. The yield strengths obtained from these two models were similar and comparable to those of other lava flows.

Regarding the inclined circular pipe case, the discharge mechanism of lava tube caves already has been established, based on Bingham characteristics of intratubal lava flow (Honda 2000, 2001a). A simple model of steady state isothermal laminar flow in inclined circular pipes and in flatten circular pipes were used for analyses. Comparison studies were based on the configuration of Hachijo-fuketsu.

Flow characteristics were studied as a function of parameters such as tube radius, viscosity, yield strength of lava and slope inclination. A critical condition was determined for the discharge parameters in which the yield strength plays a dominant role. Existing observational data were introduced to the critical condition. This model was applied to lava tube cave of Mt. Fuji, Mt. Etna, Mount St. Helens, Suchiooc volcano, Kilauea volcano and others. Some deduced yield strengths of lava of the caves in these areas were found to be in good accordance with yield strength as estimated by other methods (Honda 2001b).

General flow equation of Bingham fluid can be shown as,

$$f(t)=(t-f_B)/\nu_B \quad (t > f_B, \text{ or } r > r_B)$$

$$f(t)=0 \quad (t < f_B, \text{ or } r < r_B)$$

Here,  $f_B$  is Bingham yield strength,  $\nu_B$  is Bingham viscosity, which takes specific value depending on the materials.  $t$  is shearing stress at  $r$ .

For laminar flow model in circular tube on the slope, the equation of the distribution of flow speed  $u$  of Bingham fluid are shown as follows:

For  $t_w = (d g \sin a)R/2 > f_B$ ,

$$u=(R-r_B)^2(d g \sin a)/4\nu_B \quad (r < r_B)$$

$$u=[R^2-r^2-2r_B(R-r)](d g \sin a)/4\nu_B \quad (r > r_B)$$

$$\text{For } t_w = (d g \sin a)R/2 < f_B, \quad u=0$$

Here,  $t_w$  is shearing stress at wall,  $a$  is angle of slope or inclination of tube,  $d$ : density of the fluid,  $g$ : gravity acceleration,  $R$ : radius of the tube,  $r_B$ : radius of the flowing position where Bingham yield stress takes  $f_B$ .

Here,  $(d g \sin a)R/2 = f_B$  is the critical condition to determine if the fluid in the tube can be drained out. For given and known relation between slope angle and diameter (height) of the tube, this critical condition can give the yield strength  $f_B$ . This critical condition means that when the yield strength  $f_B$  of Bingham fluid is higher than the shear stress at the wall, there is no flow of fluid, as a consequence, no discharge of fluid from the tube. From Table 1,  $f_B = 2.5 \times 10^4 \text{ dyne/cm}^2$  can be obtained for Hachijo-fuketsu.

The above model is, however, valid only for flow in inclined tubes. For perfectly flat lava tubes (0 degree), the effect of inertial as driving force due to the head of the flow must be considered, if the flow is continuous together with the inclined tube (Honda 2003). Very rough relation between drained tube length and mean head of the flow can be obtained as  $(d g R)H/2L = f_B$  by replacing  $(\sin a)$  by  $(H/L)$ . From Table 2,  $f_B = 2 \times 10^4 \text{ dyne/cm}^2$  was obtained for Hachijo-jima.

In summary, obtained basaltic yield stress from slope angle and height of some lava caves (Table 3) are reasonable values as compared with the yield stress obtained for Mt. Fuji.

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 Honda, T. 2003. *Formation mechanism of lava tube caves of Hachijo-fuketu in Hachijo-jima*. The 2003 Fall Meeting of the Volcanological Society of Japan, October; p. 160.

Table 1. Relation between slope angle and height of Hachijo-Fuketsu lava tube cave of sloped configuration

Location of lava cave	Slope angle(a)	Height(2R)
Upper reaches	4.5 degree	~5m
Intermediate reaches	14 degree	~2m
(Lower reaches)	(0 degree)	(~1m)

Table 2. Relation between head and length at horizontal location of Hachijo-Fuketsu lava tube cave of horizontally flat configuration for  $2R=1\text{m}$

Location of lava cave	Head(H)	Length(L)
Upper reaches	25m	33m
Intermediate reaches	85m	80m
Lower reaches	115m	150m

Table 3. Yield strength obtained from the critical condition

Name of volcano	SiO <sub>2</sub> fraction of lava	Obtained yield strength	References
Hachijo-nisiyama	50.4~50.5%*	2-2.5x10 <sup>4</sup> dyne/cm <sup>2</sup>	*M.Tsukui et al(2002)
Mt. Fuji	49.09~51.3%*	2.5~5x10 <sup>4</sup> dyne/cm <sup>2</sup>	*H.Tsuya(1971)

## LAVA CAVES OF JORDAN

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The central section of Jordan is covered by young alkalic olivine basaltic lava flows: the Harrat Al-Jabban volcanics. These are part of the large intracontinental Harrat Al Scham volcanic field. The origin of these lavas may be connected to the existence of a continental intraplate hot spot plume. Its eruptive site should appear to move southward as the Arabian Plate moves northward due to the opening of the Red Sea. The top most and therefore youngest flows, are ca. 400,000 years old (Tarawneh *et al.*, 2000).

In these lavas we explored, surveyed and studied four natural lava tunnels (Abu Al-Kursi, Beer Al-Hamam, Al-Howa Cave and Dabie Cave) and two other lava caves (Azzam Cave and Dahdal Cave) in September 2003 and March 2004 (Table). The two smaller caves are most probably pressure ridge caves formed by the buckling-up of the upper layers of pahoehoe flowing down from nearby Al-Qu'ays volcano, while they were still hot and plastic. Abu Al-Kursi (Figs. 1, 2, 3) and Beer Al-Hamam (Fig. 4, 5) are large lava tunnels, up to 15 m wide and 8 m high. Al Howa is the section of a medium-sized lava tunnel while Dabie Cave is the smallest of these conduits, less than 4 x 2 m in cross section. These tunnels served to transport lava subterraneously over long distances, i.e. in case of the large caves possibly over several tens of kilometres. Now they are accessible through ceiling collapses, which allow studying the structure of their roofs. These consist of uninterrupted sets of lava sheets which show that these natural tunnels did not form by over-crusting of lava channels, but by repeated under-flowing and inflating of initial lava deltas. In this way lava flows build forward only at the tip, while the rest of the flow is stationary apart from the lava flowing in the tunnel inside. These processes have been studied in Hawaii (e.g., Kempe, 2002) and now can be used to interpret findings elsewhere. The existence of these tunnels shows that the basaltic lava must have been very hot upon eruption, and that it was piped through the tunnels over long distances, thus allowing flow over terrain at slopes at or less than 2°, comparable to the distal slopes of Hawaiian volcanoes. In fact, there should be many subparallel tunnels in these youngest flows.

Table: Data of Jordan lava caves (locations WGS 84).

Name of Cave	Latitude	Longitude	Stations	Length	Stations	Depth	Direction	Type
Abu Al-Kursi W	32°15.401'	36°39.442'	2 to 18	77.1 m	2 to 18	8.1 m	N-S	Lava Tunnel
Abu Al-Kursi E	32°15.401'	36°39.442'	20 to 34	153.7 m	1 to 34	12.2 m	W-E	Lava Tunnel
Azzam Cave	32°17.104'	36°36.594'	13 to 25	44.1 m	1 to 25	4.2 m	NWN-SES	Pressure Ridge
Beer Al-Hamam	32°07.91'	36°49.42'	32 to 23	445.0 m	1 to 23	17.2 m	NW-SE	Lava Tunnel
Dahdal Cave	32°17.344'	36°35.718'	5 to 12	28.9 m	1 to 12	0.0 m	SW-NE	Pressure Ridge
Al-Howa	32°18.536'	36°37.240'	6-9,6-16	100 m	2-7	11.0 m	NW-SE	Lava Tunnel
Dabié Cave	n.d.	n.d.	0-14	197 m	-	1 m	N-S	Lava Tunnel

The age of these flows is much greater than those ages on the Island of Hawai'i. Thus it came as a surprise that such lengths of the tunnels still are accessible. Dahdal Cave, Abu Al-Kursi, Beer Al-Hamam and Dabié Cave contain thick sediment deposits. In the case of the three latter caves, this sediment causes their terminations. During torrential rains, the stream in a wadi washes surface sediment into Beer Al-Hamam. The lower part of the cave ponds during such rains, producing a large reservoir of water. Signs of rapidly flowing water are seen in the sediment surface in the upper part of the cave. The sediments were sampled at a profile. They are mostly silts with some fine sand. Quartz, calcite, plagioclase, illite and koalinite (in decreasing order of amount) compose most of the sediment. That indicates a wind-blown origin, possibly a glacial loess. In the upper centimetres the sediment also contain large concentrations of ammonium nitrate. This is derived from pigeon droppings. In both sections of Abu Al-Kursi, the floor is smooth and covered with a thin layer of fines, laid down by occasional floods that pond at the end of the cave. No sign of flowing water is seen.

All these caves were known locally. Until recently, Azzam Cave was used as a sheep pen. Its entrance was excavated recently, and a nearby sediment pile contains pot shards. Black drippings caused by the use of plastic irrigation pipes as makeshift torches reveal visits by adventurous explorers in Abu Al-Kursi. Visiting Beer Al-Hamam requires climbing down an overhanging pit 5 m deep, but it must have been visited in the past because we found stone cairns inside. Dahdal Cave contains a stone wall so it, too, was visited in the past. Some of these visits, however, may have been in prehistoric times: numerous flint tools (possibly neolithic) were found in the neighbourhood of Dahdal Cave and in two digs in the entrance of Abu Al-Kursi. Dahdal Cave, both sections of Abu-Al-Kursi and Dabié Cave contain camel bones and were used as dens by hyenas (Fig. 3). Shallow circular pits are seen throughout Abu Al-Kursi. They do not appear to be anthropogenic since no excavated material is present. Possibly they are hyena or wolf sleeping pits. The mandible of a wolf or jackal was collected in this cave. A mummified hyena was found in Dabié Cave. Considering the age of these caves, they could contain very valuable deposits of faunal fossils covering a large section of the Pleistocene.

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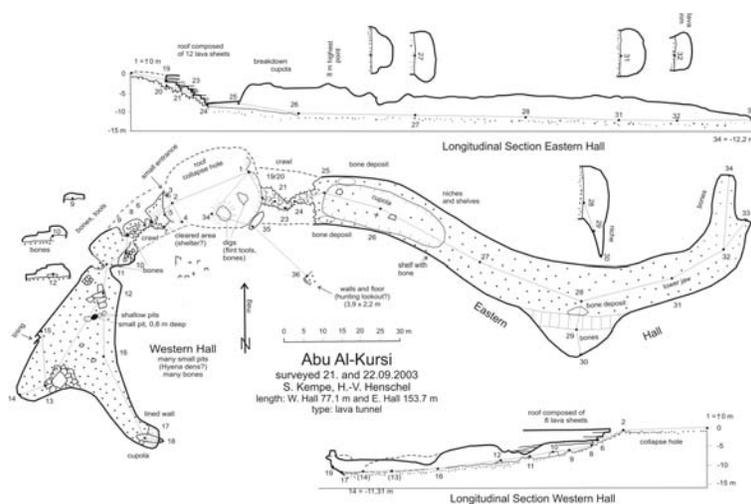
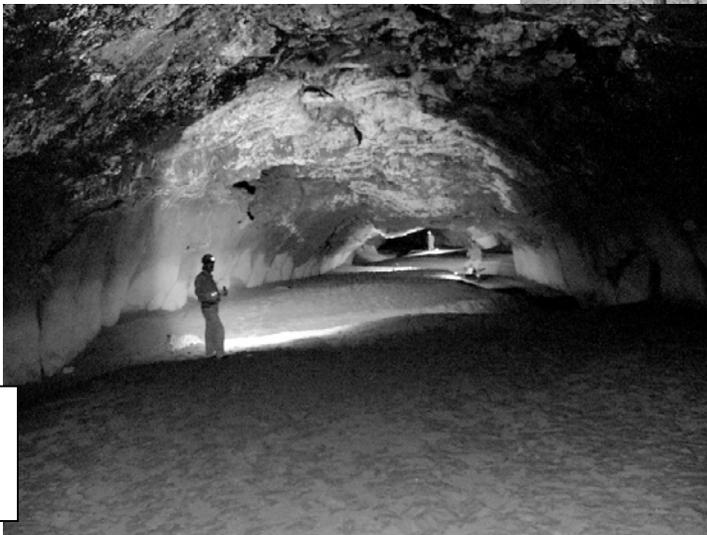


Fig. 1: Survey of the Abu Al-Kursi lava tube cave, in Jordan.



an upslope view of the  
of Beer Al Hamam.  
sediment floor with a

# CAVERNS IN VOLCANIC TERRAINS IN COSTA RICA, CENTRAL AMERICA

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Costa Rica is located in an evolved volcanic arc (< 30 ma), which is a product of the subduction of the Cocos plate under the Caribbean plate. This country contains many diverse volcanic landforms, developed during the last 200 Ma of its geologic history. This report presents the first classification of caverns and grottos in volcanic areas of Costa Rica, together with a preliminary inventory:

## **a) volcanic caverns**

The majority of its caverns of volcanic origin are small caves or grottos within lava flows (lava fields of Cervantes and Los Angeles). Also included are possible collapsed lava tubes of lava or “jameos”, and a grotto which forms part of a crater in Turrialba volcano. All these are less than 11,000 years BP.

## **b) caverns of marine origin (littoral caves)**

These are small caves mostly located in areas frequented by tourists. Thus they are comparatively well known. Most of them are located in cliffs and platforms of marine abrasion developed in oceanic basaltic complexes (ophiolites *s.l.*) These rocks are part of an accreted Cretaceous-Eocene complex located along the Pacific Coast. Comparatively well developed littoral caves also exist at Bajamar-Guacalillo beach in cliffs of Lower Pleistocene epiclastic rocks (debris flows and debris avalanches). These are comparatively large caverns, some of which are interconnected. They are adjacent to sandy beaches, and usually are visited by tourists at the low tide. In addition, submarine and subaerial littoral caverns exist on Cocos Island in the Pacific Ocean. This island is the only subaerial exposure of the submarine Cocos volcanic range.

## **c) caverns of fluvial erosion**

This type of cave is uncommon in Costa Rica and is less known than the others. An example is present in Late Pliocene lava on the left margin of Peñas Blancas River, and a small grotto known as Cave of Death is present on the left bank of the Toro River. It contains lethal concentrations of CO<sub>2</sub>. Probably the best known and most spectacular example is a natural bridge formed in Middle Pleistocene ignimbrite called Puente de Piedra (Bridge of Stone). It provides a vehicular crossing of a creek in a town named Tacaes of Greece.

## **d) anthropogenic grottos**

The most important of these are pre-Columbian shelters excavated in pyroclastic flows (2.0-0.6 Ma) in the northern part of the country. These include the Indian Cave in Cañas and a

cave in Salitral of Bagaces.) Other grottos are present on pumice fall deposits dated of 0.30 ma (the Tibás layer), in the Central Valley of Costa Rica. In general terms, all the caves and grottos are located on Upper Quaternary age formations and were inhabited by humans or were used for rituals.

Because of their small size, those investigated to date have low speleological potential. Some of them, however, have a local tourism potential as well as geoarchaeological value not yet investigated nor exploited. In particular, caves of the spectacular Bajamar-Guacalillo beach have obvious value in geological tourism.

Not yet investigated are a probable natural lava tunnel at Turrialba volcano and a reported erosional tunnel at Liberia River.



Fig. Grotto that form part of a volcanic crater in Turrialba volcano

## **THE LAVA TUBES OF SHUWAYMIS, SAUDI ARABIA**

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Kahf Al Shuwaymis, located 204 km N of Medina in the Ithnayn lava field, is the second longest lava tube (513 m) so far mapped in Saudi Arabia. The lava source is Hazim al Khadra volcano, which is characterized by a series of large collapses terminating with the entrance to Kahf Al Shuwaymis. Several fumaroles are active on the slopes of this volcano, one of which emanates from inside a shelter cave. A small pressure-ridge cave was also noted in the area.

Dahl Romahah is located 168 kms N of Medina in the Khaybar lava field. This lava tube is 202 m long and is well decorated with flowstone and speleothems composed of secondary minerals which have leaked through the ceiling and walls. The cave contains a large cache of bones as well as coprolites from wolves, hyenas and foxes. The radon level in Dahl Romahah is considerably higher than in other Saudi lava tubes. In bygone days, this cave was used as a water reservoir by local people, who built a long wall on the surface to channel water into the cave.

Aerial photographs, maps and other reports suggest that many other lava tubes will be found south of these two caves.

## **DISCOVERY AND SURVEY OF HULDUHELLIR, A CONCEALED (ENTRANCELESS) LAVA TUBE CAVE IN THE HALLMUNDARHRAUN, W.C. ICELAND**

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Research undertaken on the Hallmundarhraun in 2000 to ascertain the effectiveness of different geophysical methods in the detection and mapping of cavities in basaltic lava flows revealed the possibility of a concealed continuation of the cave Stefánshellir. The 2000 survey by magnetometer and ground penetrating radar (GPR) indicated that the roof of the main passage of Stefánshellir lifted on other side of the 20m long lava seal that closed the upflow end of the known cave. A further survey in 2001 confirmed this finding and revealed over 350m of cave passage. In 2003 the team were interested in confirming the relationship between the Hallmundarhraun's chain of 20 or more shatter rings (or collapsed tumuli) and the Surtshellir-Stefánshellir lava tube cave system and extended the survey to embrace the three nearest shatter rings.

The results were quite remarkable, showing that the concealed cave - now given the Icelandic name Hulduhellir (Hidden Cave) - passed directly beneath the shatter rings, over a distance of approx. 1.2km from the upflow end of Stefánshellir. The geophysical data infers that Hulduhellir is in places a large diameter passage, although the form that it takes beneath the shatter rings is not clear. In order to better understand the pattern of magnetic anomalies around the cave, a comparable geophysical survey was made over the accessible, large main passage of Surtshellir, while attempts are also being made to replicate anomaly patterns with specialist modelling software.