GHAR AL HIBASHI, HARRAT NAWASIF/ AL BUQUM, KINGDOM OF SAUDI ARABIA

By

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With the collaboration of

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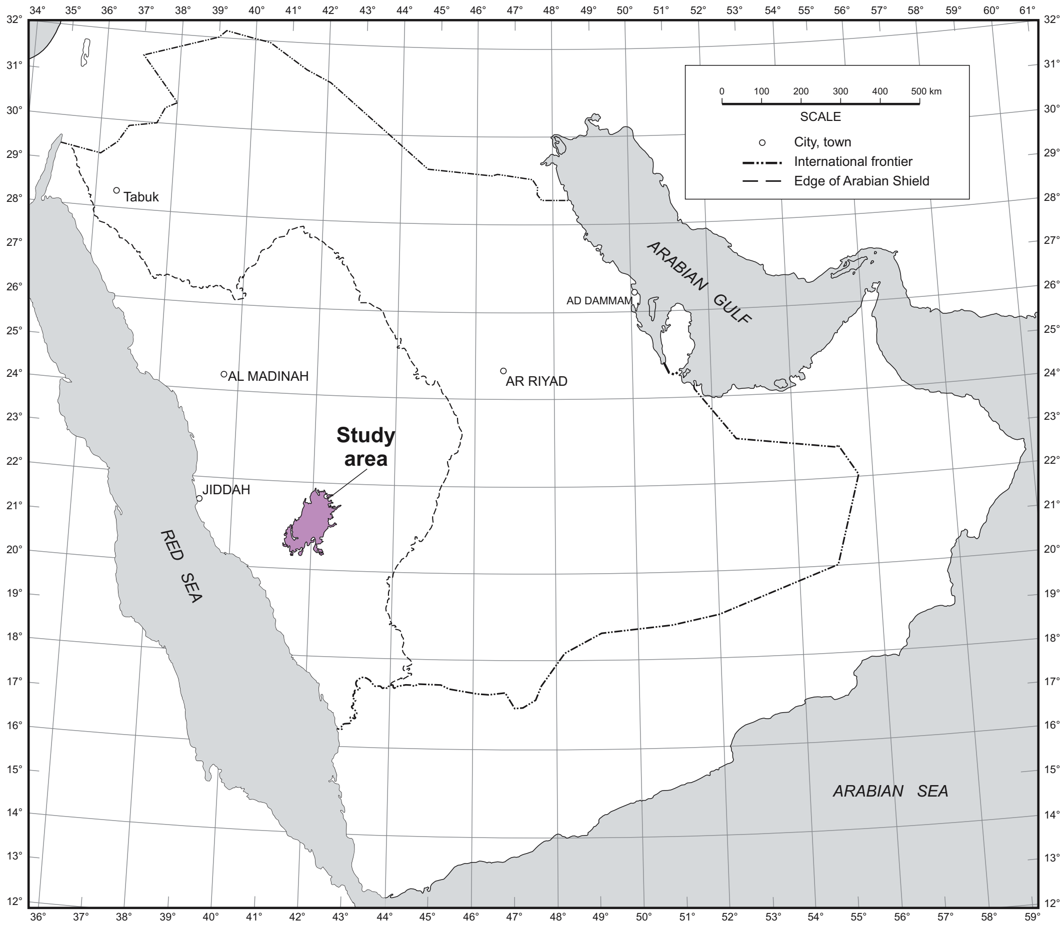

Index map of the Arabian Peninsula

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ABSTRACT

Ghar al Hibashi (sometimes spelled Hebashi) is a lava cave situated near the center of Harrat Nawasif/Al Buqum, a field of vesicular basaltic lava flows located east of Makkah in the Kingdom of Saudi Arabia. The cave lies approximately 6-7 m below the surface and contains 581 m of mainly rectilinear passages. Apart from lava stalactites, stalagmites and columns, Hibashi Cave contains many bones and the desiccated scat of hyenas, wolves, foxes, bats, birds and domestic animals, most of which has been well preserved due to the cave's temperature of 20-21°C and humidity of 48 percent. A human skull 425 years old and a man-made wall were found in the cave, but no archeological studies have been carried out. It is estimated that the cave may be 1.1 million years old.

Two large bat guano deposits in this cave caught fire at some point in the past, heating and partially burning animal bones and rocks lying on the guano surface and possibly affecting "bio-stalactites" thought to be formed of bat urine. These soft, yellowish, accretions, 4 cm or less in length and up to 1 cm in width, are found throughout the cave.

A few samples of secondary chemical deposits were collected mainly from the burnt guano areas for mineralogical analysis. Despite the scarcity of these samples, at least 19 different minerals were detected, most of which are related to the biogenic mineralization of bones and guano deposits. Three of them, pyrocoproite, pyrophosphite and arnhemite are extremely rare organic compounds strictly related to the guano combustion, which have been observed until now only in a few caves in Africa. Ghar al Hibashi may now be considered one of the richest known mineralogical shelters of the Arabian Peninsula, for which reason it has been included in the list of the ten minerologically most important lava caves in the world.

The original floor of Hibashi Cave is covered with a layer of fine (10 micron particle size) silt or loess, dominated by quartz, feldspar and kaolin, extending to almost every point in the cave. This silt is up to 1.5 m deep and was OSL-dated at 5.8±0.5 ka BP at its lowest level. Because similarly fine material is often blown about on the surface of Mars, researchers planning for the exploration of Martian lava tubes are using photographs and maps of Hibashi Cave to produce robotic motion simulations for testing the capabilities of microrobotic designs to navigate inside the caves of Mars.

The potential also exists to study phytoliths, found inside plant material preserved in animal scat abundantly available in Ghar al Hibashi, in order to learn more about past flora of the Arabian Peninsula as well as the process of desertification.

الخلاصة

غار الحباشي والذي يقع في الوسط ما بين حرة البقم ، وحرة نواصف ،. في جنوب شرق مكة المكرمة (المملكة العربية السعودية) ،هو عبارة عن أنفاق تحت سطحية تتكون طبيعيا في صخور هذه الحرات،وهي نتيجة انسياب الحمم البركانية من باطن الأرض إلى السطح على المنحدرات ، مكونة صخور بازلتية تتشكل بسبب قلة لزوجتها مع تضاريس سطح الأرض، وعمر صخور البازلت حوالي ١،١ مليون سنة .

الغار عبارة عن فتحه على سطح الأرض قطرها ١٦ مترا من السهولة النزول إلى باطنه والذي لا يتجاوز أقصى عمق فيه إلى ٨ أمتار. وتمد أطوال أنفاقه أفقيا تحت السطح إلى حوالي ٥٨١ مترا . يلاحظ في داخل الغار وجود الهوابط والصواعد البازلتية، التي تكونت قبل تصلب هذه الحمم نتيجة توقف اندفاعها وخروجها من باطن الأرض ، تسبب في تصلب أسطح الحمم على الأسطح الخارجية بسبب تعرضها للهواء ، واستمرارية انسيابها وانحدارها من الأسفل على المنحدرات بسبب أنها لا تزال ساخنة وقليلة اللزوجة لتكوين أنفاق تحت سطحي.

يلاحظ في داخل الغار وجود حفر متعددة بجانب الجدران وهي حفر للحيوانات المفترسة مثل الضباع والذئاب التي تسكنه منذ سنين، وأيضا وجود فضلاتها وبواقي فرائسها من عظام وجماجم الغزلان والجمال والحمير تتناثر في عدة مواقع في داخل الغار،حيث كانت ولا تزال تستخدمه الحيوانات كمأوى بسبب تكون أنفاقه الطبيعي والرمال الناعمة التي ترسبت على أرضيته، درجة حرارة الغار كما هي في باقي المغارات والكهوف في صحاري المملكة، والتي لا تتجاوز٢٦ درجة مئوية، ودرجة رطوبة %٤٨ ، بالإضافة إلى وجود أعداد كبيرة من الوطاويط والطيور مثل الحمام البري الذي يتخذ أسقف وجدران الكهوف مسكنا له احتماء من الطيور الجارحة والحيوانات المفترسة.

وقد تم اكتشاف جمجمة بشرية عمرها ٤٢٥ سنة ، وكذلك سورتم بنائه في القديم من الصخر ويعتقد أنه للحماية من مياه الأمطار التي كانت تندفع إلي داخل الغار.

يوجد بعض من الهوابط البكتيرية التي تحمل اللون الأصفر المائل إلى الاحمرار وطولها حوالي ٤ سنتيمتر، تتدلى في أجزاء معينة في الداخل على أسقف الغار حيث تتركز في الداخل ، وهذه الهوابط تكونت بفعل حريق كبير في الأجزاء الداخلية من الغار،والتي كانت قد اشتعلت في فضلات الوطاويط وعظام الحيوانات وارتفعت بسببها درجة الحرارة و تغطى سقف الغار باللون الأسود القاتم، وعند تحليل عينات تم التقاطها من هذه الهوابط وبواقي الفضلات المحروقة ، تم اكتشاف ١٩ معدن ، منها(بيروكوبريت، بيروفوسفيت وارنيميت) تعتبر نادرة الوجود وهي ناتجة من فضلات الوطاويط والتي تم اكتشافها فقط في بعض الكهوف في أفريقيا .

من هنا يعتبر غار الحباشي هو من أغنى المغارات في نوعية المعادن التي تم اكتشافها بداخله في شبه الجزيرة العربية، ولهذا السبب لوحظ اهتمام وكالة ناسا الفضائية لهذا الغار لتشابه بيئته وبيئة الكهوف في كوكب المريخ واعتبروه مثالا مطابقا لها، ويعتبره العلماء واحد من أهم عشرة كهوف غنية بالمعادن النادرة في العالم .

تغطي أرضية غار الحباشي طبقة رملية ناعمة دقيقة سماكتها ١،٥ متر جلبتها الرياح والمياه الجاريه. (حجم الحبيبات ١٠ ما يكرون) تسمى (لوس) والتي تعتبر من أفضل أنواع التربة الزراعية والتي تنتشر في الجزء الجنوبي الغربي من المملكة، ويتكون من المرو، فلسار وكاولين .

منطقة الغار لا زالت تحتاج للعديد من الدراسات المتخصصة والمختلفة (دراسات بيئية ، دراسات بيولوجية ، جيولوجية وعلماء آثار ليقفوا على الآثار الموجودة في تلك المنطقة .

INTRODUCTION

In the year 2001, the Saudi Geological Survey initiated subproject 4.1.3 "Mapping of underground cavities (caves) in Phanerozoic rocks." Studies of caves located in the Phanerozoic limestone belts of the country demonstrated that some contained artifacts, bones, etc. of historic, environmental and archeological value (Pint 2003), while others were judged aesthetically and structurally suitable for purposes of tourism (Forti and others, 2003, Cigna, 2004). In light of these studies, the investigation of cavities in Saudi Arabia was broadened to include lava tube caves in order to determine their possible value for scientific and touristic purposes.

Saudi Arabia has approximately 80,000 kms² of lava fields, known as harrats (fig.1). In late 2001 and early 2002, a preliminary survey for lava-tube caves was carried out in Harrat Kishb, a young basaltic lava field with an area of 5, 892 kms² centered about 270 km northeast of Jeddah. Six lava caves were located, three of which were mapped. These three caves were found to contain items of historical, geologic and archeological interest (Roobol and others, 2002).

From November 2002 to the present writing, other lava caves were located in Harrats Ithnayn, Nawasif/Al Buqum and northern, central and southern areas of Harrat Khaybar. Two of these caves, Dahl Romahah and Kahf al Shuwaymis, have been briefly described in Pint, 2004, but are still under study.

This report focuses on a single lava cave located in Harrat Nawasif/Al Buqum, namely Ghar al Hibashi, even though it is possible that there may be others in the area. This cave is referred to as Ghar in Arabic because this is the name given to the cave by people living a half kilometer away. In other areas, Kahf, Dahl, or Serdab are preferred by the local people. The English spelling Hibashi is used in this report, but elsewhere the name of this cave may be found with the spelling Hebashi or Habashi.

Hibashi Cave appears to be deserving of special attention due to the wealth of mineralogical data that has come to light from the analyses of speleothems found in it. It has, in fact, recently been included in the list of the ten mineralogically most important lava caves in the world (Forti, 2004). In addition, the floor of Ghar al Hibashi is covered with a layer of loess or fine silt, up to 1.5 m in depth, of considerable interest to sedimentologists as well as scientists studying the lava tubes of Mars, whose surface is covered with a similarly fine sediment, according to NASA, 2004. Hibashi Cave is also the site of two extensive guano fires, which have rarely been described in speleological publications (Martini, 1994b) and whose effect on secondary cave minerals is of interest to speleo-mineralogists.

The accidental discovery of a human skull and a man-made wall inside Hibashi Cave give hope that archeologists and historians could carry out fruitful studies in this cave. In addition, the considerable quantities of bones, guano and animal scat inside the cave may shed light on the past flora and fauna of the Arabian Peninsula. In particular, phytoliths found in plant fibers inside wolf and hyena scat from Hibashi Cave may be of value in studying the desertification of Saudi Arabia.

It is hoped that this publication will confirm the importance of Hibashi Cave and will be of use to government authorities in protecting the cave from vandalism and intrusions.

GEOLOGY OF HARRAT NAWASIF/AL BUQUM

Ghar al Hibashi is located in Harrat Nawasif/Al Buqum, a group of lava flows encompassing about 11,000 km² and roughly situated between the towns of Turubah and Ranyah, E of Makkah, Saudi Arabia. The location of the cave and its geological surroundings are shown in figure 2. The northern portion of this lava field is generally referred to as Harrat Nawasif whereas the southern portion is locally called Harrat al Buqum. Because Ghar al Hibashi is located approximately in the center of the field, we have used the combined name of the entire lava field to describe the cave's location.

The origin of the basalts in Harrat Nawasif/Al Buqum is attributable to the period of magmatic eruptions that began in the Miocene and continued until historic times. These basalts are classified as Upper Tertiary and Quaternary. They are primarily titaniferous olivine basalts, including alkali basalts, basanites and nepheline-basanites, occasionally interlayered with pyroclastics. Hötzl and others (1978) took two samples of Harrat Nawasif/Al Buqum basalts for potassium-argon age- dating, yielding ages of 3.5±0.3 million years for the older basalts and 1.1±0.3 million years for the younger. Because of the relatively unweathered condition of the basalt in which it is found, it can be assumed that Ghar al Hibashi lies within one of the younger flows, however, it should be noted that the younger sample dated by Hötzl and others (1978) was taken from the area of Sha'ib Hathag, some 63 kms NE of Ghar al Hibashi. Arno and others (1980) report ages of 22.8, 15.8, 7.3, 4.4 and 2.8 million years for samples taken from the flows of this harrat, leaving the exact age of the basalt in which Hibashi was formed, very much in question.

Ziab and Ramsay, 1986, state that the Buqum basalt is between 20 and 25 m thick in the Turubah area but much thinner farther north. The depth of Ghar al Hibashi (about 22 meters from the surface to the cave floor) suggests that the cave may lie within the basalt studied by Ziab and Ramsay, which they describe as gray to dark gray, vesicular, medium grained and prophyritic, containing phenocrysts of olivine, titanaugite, plagioclase and opaque minerals. They further state that it has an SiO_2 content ranging from 42 to 47 percent, high TiO_2 (1.42-2.79 percent), and high P_2O_5 (0.32-0.67 percent). Almost all the rocks they studied were undersaturated, with 0.3 to 7.8 percent nepheline, 8-21 percent olivine and no quartz in the norm. All the rocks were highly sodic and normative albite exceeded normative orthoclase, typically by a factor of approximately five.

Figure 3 is an aerial photograph at a scale of 1:50,000 showing the flat-lying undeformed, unmetamorphosed basaltic lava flows and cinder cones in the vicinity of Ghar al Hibashi. Lava flows from what appear to be at least four different events can be seen within one kilometer of the cave entrance. Whereas steep-walled scoria cones less than 200,000 years old lie less than two kilometers from the cave, the entrance to Ghar al Hibashi appears to be located in an older flow.

THE FORMATION OF LAVA CAVES

The process by which a lava cave or lava tube is formed is briefly described by Roobol and others (2002). A more detailed explanation is provided below by Prof. Stephan Kempe, who has spent twenty years studying some of the world's longest lava caves in Hawaii.

> *Fluid basaltic lavas of low viscosity form long tunnels resulting from deltaic, rapid breakouts at the tip of the flow. One delta forms a thin sheet of lava which cools rapidly. The next breakout lifts this surface sheet up by inflation and yet another delta is formed. This process can be repeated several times forming multi-layered primary roofs. Inside, prototubes channel the lava into a few lava conduits. One of them grows faster than the others draining them of lava. These tubes cause thermal insulation of the lava flowing inside, which then can propagate over long distances. Depending on the period of their activity, they can incise considerably into bedrock (thermal erosion). One of the erosive processes is associated with back-cutting lava falls. In the down-cutting process initial passage-braids and distributaries are deprived of their lava supply and a deep, meandering underground canyon is formed, in which the lava flows, river-like. The widening of the tunnel causes roof collapse and breakdown blocks are carried down tube. In this way, the primary roof is partially removed forming large irregular halls and domes. Where the primary ceiling collapses entirely, colder air enters and convects up-tube, causing consolidation of secondary ceilings, thereby re-installing the insulating properties of the tube and ensuring its further function as a long-distance and long-lived subsurface lava conduit. These processes can potentially excavate large, up to 20 m wide and deep tunnels and may be responsible for large sinuous lava channels on the moon and Mars.* (Kempe, S., 2004)

DESCRIPTION OF GHAR AL HIBASHI

The exact location of Hibashi Cave is given in Pint, 2001, where it is registered as Cave No. 180. The cave is located approximately in the center of Harrat Nawasif-Buqum inside a vesicular basaltic area, in a slightly raised portion of a major basaltic flow emanating from a large crater to the southeast. The cave lies approximately 22 m below the surface and contains 581 m of passages. The main passage is mostly flat and runs east-west, intersected by a side passage running NW-SE, downsloping from an entrance collapse to the floor of the main passage. Plan and profile maps of the cave are shown on the Plate.

Ghar al Hibashi was formed during lava flows. The entrance is a collapse 14 meters in diameter. At least three layers of lava flow are indicated by strata exposed between the surface and the cave ceiling along the SE wall of the entrance pit. (fig. 4).

Within the entrance pit, a floor of break-down and sediment, 0.5 to 7 m below the surface, permits easy access to the cave without need for ladders or ropes. The break-down material ranges in size from 2 meters to less than 5 cms in length. Some trash and body parts of sheep and goats lie scattered on the pit floor and graffiti can be found on the side walls (fig. 5).

A steep downslope (average 30 °) stretches from the dripline of the entrance pit to the vicinity of station 4. The upper portion of this slope is covered with broken rocks from the ceiling. The middle and lower portions of the slope consist of powdery gray sediment similar to the loess found on the floor of the east and west branches of the cave (fig. 6). Mounds of rock-dove guano less than 40 cm high are found between the dripline and station 4 and rock doves were occasionally seen in this area during field investigations.

The walls and ceiling of the cave are composed of vesicular basalt. Immediately SE of the dripline, the cave ceiling is covered by a tan, spongy, organic substance of unknown origin, perhaps produced by insects (fig. 7). This substance extends into the cave as much as 10 m from the dripline.

At station 4, a 7-m wide column supports the ceiling. This is partially enclosed by a man-made rock wall, approximately 32 m in length, located on the NW side of the column, possibly constructed as a corral or perhaps to protect animals and food from floods (fig. 8). The remains of the wall are approximately 50 cm high. The age and possible uses of similar walls found in Ghostly and Mut'eb Caves are discussed in Appendix 1 of Roobol and others, 2002. An animal pawprint was noted near station 4 but its origin has not been identified (fig. 9).

Between stations 5 and 6, the floor of the cave is flat and covered with sediment underlying a bed of sheep and goat droppings at least 7 cms thick (fig. 10) that extends from wall to wall.

Near station 5, mud up to 3 m in height, covers the walls. All walls commonly indicate that water flooded the cave in the past.

Beginning south of station 5, shallow depressions 30-40 cms deep and 1 to 1.5 m in diameter can be seen on the floor. These are found in all the flat areas of the cave where powdery sediment covers the original floor. These depressions probably were made by animals such as hyenas, wolves, and foxes, as resting places (fig. 11).

Daylight is no longer visible beyond stations 6 and 7, where there is an entrance to passages extending west and east.

WESTERN PASSAGE

The westward-trending passage is 5 m high and 8 m wide near station 7; it has a rounded ceiling and a flat floor covered with a thick layer of sediment. The thickness of this sediment was 1.5 m at a point halfway between stations 8W and 9W, equidistant from the walls of the passage (fig. 11a). A sample of the sediment was taken from a pit dug at this point and its age and characteristics are discussed in the section on Loess Floor Cover below. Desiccated hyena scat, small twigs and basalt fragments were found at the bottom of the sampling pit. Fine silt (loess) covers the original basalt floor in all low-lying areas of the cave. Walking, no matter how slowly and carefully, raises particles of this sediment into the air, making breathing very difficult. In confined areas of the cave, such as the extreme east and west ends, where air circulation is minimal, breathing the silt-filled air resulted in heavy coughing, discomfort and illness for researchers, sometimes lasting weeks after visiting these areas. Surgical masks were used to reduce inhalation of this dust, but the warm temperature of the cave (an average of 21°C) makes the use of masks or breathing apparatus rather impractical. The impact of these considerations on future research or tourism in Hibashi Cave is discussed under Recommendations below.

Lava levees and gutters are found on both the north and south walls of the west-trending passage, between stations 9W and 11W. These range in height from 0.5 m to 1.3 m (fig. 12). Lava stalactites, 7 cms or less in length are abundant along the north wall whereas a dozen stalagmites up to 25 cms tall are found along the south wall (figs. 13 and 14). Vertical ripples up to a meter long are found on the walls above these stalagmites (fig. 15). A heap of breakdown piled along the north wall across from station 10W is about 4 m high and permits close examination of the ceiling, which is 6.1 m high in the center but 5.4 m high near the side walls of the passage. Soda-straw lava stalactites less than 5 cm long (fig. 16) are found here and, on a 10 cm-deep natural ledge located about 20 cms below the ceiling, a fragment of tree branch was found (fig. 17). This may have been deposited during flooding of the passage.

Between stations 10W and 11W there is a crack in the ceiling, nearly perpendicular to the direction of the passage (at an angle of 70°). It is 4 cm wide, and a slight vertical displacement can be noted.

Stains, dark brown or nearly black in color, are frequently seen on the side walls of the west branch of the cave (fig. 18). These are assumed to be coatings of bat urine. Although no bats were captured for identification in this cave, it should be noted that stains similar in color were found on the walls of Serdab Tayib al Issim in the Habakah region of Saudi Arabia. A naturally preserved specimen from that cave was identified as Asellia tridens by Dr. Ian Nader of the King Khalid Wildlife Commission (Al-Shanti and others, 2003).

A second loess sample was taken from a pit dug southeast of station 11W, in the middle of the passage. The sediment was found to be 40 cm deep at this point.

Near station 11W, the passage turns northwest. Between stations 11W and 12W, the ceiling of the cave drops to a height of 1.2 m above the surface of the sediment and the passage is 3-5 m wide (fig. 19). West of station 11W, stalactite-shaped accretions, yellow to tan in color and 4 cm or less in length, are found on the ceiling of the cave (fig. 20). These formations are often less than 1 cm wide and are soft and sticky to the touch. Because they contain urea and arcanite, it is assumed that they were produced by bats repeatedly urinating in the same location on the ceiling. Laboratory analysis (Forti, 2004) of one such formation, which might be referred to as a bio-stalactite, revealed that, in addition to urea and arcanite, it also contained opal-C, biphosphammite, quartz, chlorapatite, niter and whitlockite. This sample, labled HI ZZ, was taken from near station 12W and is discussed under Secondary Minerals of Ghar al Hibashi, below.

From station 14W westward, desiccated animal scat, probably from hyenas and wolves, was observed on the surface of the sediment, normally in proximity to bones of various sizes and origins as well as animal parts such as gazelle horns and porcupine and hedgehog quills. The origins, prevalence, and importance of animal scat in Hibashi Cave are discussed in Appendix 1. Because plant material has been found in the desiccated animal scat collected from many Saudi caves, it may be possible to recover pollen, spores and phytoliths that may be of value for the study of flora, climatology, and desertification (Appendix 2).

Between stations 14W and 15W the passage height rises to 9.2 m. Near station 16W it is approximately 5 m. Groups of basalt rocks, fallen from the ceiling, can be seen on the floor. Vugs are found in the ceiling and walls, due to the rapid cooling of the lava.

West of station 16W the passage turns southwest and the amount of breakdown, bones and animal scat increases. At station 18W the ceiling height is 3.6 m and a 5-m-wide north-trending passage is found. This contains a great deal of breakdown and narrows to a dead end after 28 m. This passage has the highest concentration of bio-stalactites found in the cave.

Between stations 18W and 21W, the main passage turns southwest and narrows. Eight meters southwest of station 18W, a bed of gray ash at least 30 cm deep lies on the surface of the floor sediment and extends for 59 m to the extreme western end of the cave (fig. 21). Scat, rock fragments and bones lying on this bed appear to be burnt on their bottom sides. A thin, shiny black coating covers the side walls and ceiling of the area. The guano appears to have caught fire in this area, producing the greatest heat in the cul-de-sac W of station 21W, which was given the name Burnt-to-a-Crisp Closet. It should be noted that bats frequently roost in caves as far away from the entrance as possible and that the ceiling of this extreme western portion of the cave rises from 2.5 m at station 19W to 5.3 m at station 20W, dropping again to 1.6 m at station 21W, providing a dome-like area, ideal for maintaining the warm temperatures bats prefer for roosting.

EASTERN PASSAGE

The east-tending branch of Ghar al Hibashi begins near station 8 where the passage is 10 meters wide and 4.1 meters high with an arched ceiling and a smooth bed of loess covering the basalt floor. Signs of flooding can be seen on the side walls to a height of 2.5 m. Lava levees and gutters are found along both walls northeast of stations 9 and 10. The northwest levee is about 1.3 m high (fig. 22) while the southeast levee is less than 1 m high. In the middle of the passage, which is 4.1 m high, the depth of the loess bed was measured at 1.48 m using a thin iron rod. Hyena and wolf scat lie in front of the southeast levee along with bones and hedgehog parts (fig. 23).

Between stations 8 and 11 the remains of several small fires were found (fig. 24). It is speculated that these were not campfires, due to the inhospitality of the loess “carpeting” in this part of the cave. Instead, they may have served the purpose of providing firebrands for lighting, perhaps for the same people who built the stone wall near station 4 or who kept domestic animals in the sun-lit area of the cave.

A temperature of 20-22°C was noted at station 11, approximately 130 m from the entrance, using a maximum-minimum thermometer over a 24-hour period. During the same time period a constant humidity of 48 percent was registered at the same location (January 7-8, 2003). Radon tests were carried out in this part of the cave on November 3-4, 2003, yielding the following results: 25.6 Pci/L (on the floor) and 8.86 Pci/L (in the air).

East of station 11, an area of heaped breakdown begins, rising to a height of 6 m. Above it, the ceiling of the passage reaches its greatest height (at least 11m), forming a dome where bats were observed flying and roosting. Gouge marks are visible on some chunks of breakdown (fig. 25).

At station 14 there is a lava levee on the north wall, approximately 1.3 m high and 25 m long. Some 8 m southeast of this station (fig. 26), a bed of ashes lies on the floor, extending some 60 m east and 25 m south and covering approximately 950 square meters. Adjacent areas where the fire did not reach, for example inside the lava channel E of station 16, described below, demonstrate that what burned was bat guano. As in the ash bed at the extreme west end of the cave, scat, rocks, horns and bones lying on the surface are burnt on the bottom (figs. 27, 28, and 29).

It is possible that heat from the guano fire caused bat-urine bio-stalactites on the ceiling to drip onto objects lying on the floor, possibly aiding the production of secondary minerals rarely found in caves. Samples of wolf scat, ash, bones and basalt taken from this area yielded the following minerals: anhydrite, aphthitalite, arnhemite, arcanite, archerite, biphosphammite, calcite, carbonate-hydroxylapatite, opal, pyrocoproite, halite, pyrophosphate, quartz, urea, whitlockite and palygorskite (Forti and others, 2004). The production of these minerals is discussed below.

At station 15 there is an upper alcove to the east, covered with unburnt bat guano. This cul-de-sac measures roughly 8 m in diameter, is situated 2 m above the floor of the main passage and has bat-urine bio-stalactites on the ceiling. Traces of mud can be seen on the side walls. The temperature is higher than in the main passage and the air is stuffy and fetid.

Between stations 16 and 18 there is a 13-m-long, 1-m-wide lava channel oriented E-W, located on the N side of an incline of approximately 20° leading to an upper room. The channel is v-shaped in cross-section and contains mainly sediment/sand and guano, most of which is unburnt. It appears that a tongue of lava, forced up the slope, subsequently reversed direction, leaving the v-shaped channel behind (fig. 30). Above the eastern end of the lava channel there is a crack in the ceiling of the room, through which water, sediment, and sand appear to have entered the cave and filled the lava channel. On the ceiling of this semi-circular upper room (3.4 m above the main passage floor) there is a shiny black coating less than 1 mm in thickness, apparently produced by the guano fire (fig. 31) and covering every millimeter of the ceiling and the lava stalactites which adorn it. Laboratory analysis found aphthitalite, arcanite, and biphosphammite in a sample of this coating (HI 14). The soft, sticky bat-urine bio-stalactites described elsewhere in this report are also found on the ceiling of this upper room (fig. 32), obviously produced after the guano fire.

At the eastern end of this room, the original basalt floor of Hibashi Cave is exposed. Near station 19, there is a small passage 1.20 m high and 2.3 m wide which gives on to a 1.6-m-long downslope of 40° leading to a southward-trending passage 7 m wide filled with breakdown covered by a layer of unburnt guano 20-30 cm thick, which extends almost to station 21. Breathing is very difficult in this passage which is at the extreme eastern end of the cave. This area served as a bat roost, as did the extreme western end of Ghar al Hibashi. No bats, however, were found in this passage, in 2003-2004. It is possible that the two guano fires that smoldered in the eastern and western ends of this cave disrupted ancient roosting patterns. Breakdown continues northwest to station 24 where pieces larger than 3 m in diameter are found. The ceiling of the cave is 10 m high in this area.

On January 7, 2003, a human skull (fig. 33) was found by one of the authors, 8 m northeast of station 26, at the edge of a patch of sand 5 m in diameter. Radiocarbon dating indicates an age of 425±30 years for this skull, which is described and discussed in Appendix 2.

Station 27 is located on the south wall of the cave, only 12.5 m south of station 12, but neither station can be seen from the other, due to the mound of breakdown in the center of the passage. This breakdown, plus three columns measuring 20 to 34 meters in length, help to create the illusion that from station 12 to 27, the eastern portion of Hibashi Cave is a closed loop of variable width, whereas it is actually one large room. Past explorers' fear of becoming lost may explain why the human skull mentioned above was not previously removed from the cave. The ceiling height at station 27 is 9 m.

SECONDARY MINERALS OF THE CAVE

During three different expeditions carried out in 2003, a few samples of secondary chemical deposits were collected inside Ghar al Hibashi to be analzsed from the mineralogical point of view. This research was carried out as part of the MIUR (Italian Ministry for university and scientific research) 2002 Project "Morphological and Mineralogical Study of speleothems to reconstruct peculiar karst environments" under the direction of Prof. Paolo Forti and is described in detail in Forti and others, 2004.

EXPERIMENTAL METHOD UTILIZED

A total of 11 samples were taken from different locations inside the cave. A detailed analysis of all the samples by the stereoscopic microscope was performed to distinguish and to separate the different mineralogical phases eventually present in each sample. This analysis permitted the discarding of one sample (Hi 10A) consisting of a wholly biogenic structure (nests of some insect larvae, found on the ceiling of the cave near station 1). Then the single phases were analzsed by a powder diffractometer (Philips PW 1050/25), when the material was quantitatively sufficient and homogeneous, or by a Gandolfi camera (Ø : 114.6 mm, exposition: 24/48 hrs), when the material was scarce or inhomogeneous. The experimental conditions were always: 40Kv e 20 mA tube, CuKa Ni filtered radiation (l = 1.5418 Å). The same samples analyzed in the Gandolfi camera were later used to obtain images and chemical qualitative analyses through an electron scanning microscope (SEM Philips XL40) with an electronic microprobe (EDS - EDAX 9900) at the "Centro Interdipartimentale Grandi Strumenti" of the Modena and Reggio Emilia University. The petrographic identification of rock sample Hi8 was done on a thin section by using a polarizing microscope.

INVESTIGATED SAMPLES

A brief description of the morphology of each sample with a list of detected minerals follows. Sample locations are shown on the Plate.

Sample Hi2 - [Burnt wolf scat] - Partially burned excreta (35 mm di Ø) as a consequence of a guano fire. The following minerals have been detected: quartz, plagioclase, calcite, dolomite. Quartz and feldspar are residual, coming probably from the loess deposited inside the cave, which is rich in these minerals. Calcite and dolomite should be secondary in origin being absent in the lithology of the whole lava field.

Sample Hi6b - [Ash from burnt zone] - Heterogeneous sample consisting of a dusty brown sediment associated with numerous bone fragments partially covered by secondary crusts. These vitreous, semi-transparent globular scoriaceous crusts are clearly a melting product caused by the guano combustion. The following minerals were detected: aphthitalite, arcanite, carbonate-hydroxylapatite, chlorapatite, hydroxylapatite, opal-C, pyrocoproite, pyrophosphite, quartz, whitlockite,

Sample 7 – [Bone from burnt zone] - Fragment of a jaw with a few teeth (50x30x9 mm): inside the jaw is evident the progressive transition from the preserved partially porous bone material to the external vitreous semi-transparent globular saccaroid crusts, which gave rise also to small coralloids (fig. 34). The thickness and the colour of this layer change side by side, but the material is identical to that described for sample Hi6b. The teeth and some of the coralloid fragments are partially covered by euhedral prismatic vitreous transparent crystals, which are also arranged in concentric layers inside the teeth. The following minerals have been detected: anhydrite, aphthitalite, arcanite, calcite, carbonate-apatite, chlorapatite, halite, hydroxylapatite, opal-C, palygorskite, pyrophosphite, pyrocoproite, quartz, urea, whitlockite.

Hi8 - [From burnt zone floor] - Fragments of the reddish volcanic rock (fig. 35) associated with partially fired uncemented milky white to pale sky-blue grains: it consists of a vesicular dolerite rock rich in auhedral olivine and partially isoriented plagioclase crystals, with intergranular texture. The following minerals have been detected: anhydrite, archerite, arnhemite, opal-C, pyrocoproite, pyrophosphite, pyroxene, quartz, urea, whitlockite. Quartz and pyroxene are residual in this sample

Sample Hi9 – [Sediment sample from –70 cm below floor]: Silt from the cave floor: fine-grained heterogeneous dark brown sand. The following minerals have been detected: chlorite, feldspar, illite, quartz. Chlorite, feldspar and quartz are surely residual, coming from the desert sand and/or the lava tube wall, whereas illite may be also secondary in origin.

Sample Hi10A – Wholly organic material consisting of the remains of nests of insect larvae (fig. 7). No minerals were detected.

Sample Hi12 – [Content of lava channel]: An incoherent medium to fine-grained hazel-brown sample, which may be subdivided as follows: (a) thin, dark brown to mother-of-pearl luster, sometimes semi-transparent crusts (probably organic remains of bush or trees); (b) bended pale transparent crusts and small tubes; (c) lemon pale-yellow greasy grains; (d) orange to brown grains; (e) semi-transparent tubular fragments; (f) dark brown vitreous to wax spheroidal grains. The following minerals were detected: aphthitalite, arcanite, biphosphammite, quartz.

Sample Hi13 – [Lower extreme content of lava channel]: Dark incoherent material with graphite luster and variable grain size. The following minerals were detected: aphtitalite, arcanite, biphosphammite.

Sample Hi14 – [Burnt coating on ceiling]: Soft, sticky pitch-dark fragment. The following minerals were detected: aphthitalite, arcanite, biphosphammite.

Sample Hi15 – [Sticky stalactite between stations 18w-19w] - Small fragment of a stalactite (20x10 mm) consisting of sticky microcrystalline hazel-brown material partially covered by small vitreous semi-transparent prismatic crystals. The following minerals were detected: arcanite, biphosphammite, opal-C, urea.

Sample Hizz – [Sticky stalactites near station 12w]: Small stalactite fragments consisting of sticky, poorly cemented, hazel-brown to brown material. The following minerals were detected: arcanite, biphosphammite, chlorapatite, niter, opal-C, quartz, urea, whitlockite.

DESCRIPTION OF THE DETECTED MINERALS

A common characteristic of nearly all the samples is the strict interconnection of many of the mineralogical phases, which made it extremely difficult and sometimes impossible to separate them and to put in evidence the specific morphological peculiarities of each phase: this was particularly true for the samples coming from the burnt zone.

Anhydrite ($CaSO_4$ – orthorhombic) – Rare, found in the Hi7 and Hi8 samples. It occurs in small earthy sub-spherical aggregates of tabular milky-white ovoidal elements, with the external surface often drilled by many corrosion holes (fig. 36a)

Aphthitalite [$(K,Na)_3Na(SO_4)_2$ - trigonal] – It is one of the most common phases. It has been detected almost always associated with biphosphammite in honey-yellow to dark brown subspherical grains and/or vitreous fragments in the samples Hi6b, Hi7, Hi12, Hi13, Hi14. In Hi7 it was observed also as a thin film over apatite and as thin to thick ovoidal grains and as crusts in Hi8 (fig 36b).

Arcanite [$K_2(SO_4)$ - orthorhombic] – It was found several times as semi-transparent to lemon-yellow vitreous crusts, mixed with chlorapatite, opal-C, pyrocoproite and pyrophosphite in samples Hi6b, Hi7 or in plastic microcrystalline honey-yellow small aggregates mixed with aphtitalite and biphosphammite in samples Hi12, Hi13, Hi14, Hi15, Hizz. In sample Hi12 this mineral has a peculiar cauliflower appearance consisting of pale hazel-brown micro-grains (fig. 36c).

Archerite [$(K,NH_4)H_2PO_4$ -tetragonal] – This mineral is very rare in Hibashi cave: it was observed in sample Hi7 as small vitreous semi-transparent crusts over bone fragments and as pale-yellow vitreous coralloids in Hi8. In both these occurrences it is strictly associated with pyrocoproite and pyrophosphite.

Arnhemite [$(K,Na)_4Mg_2(P_2O_7) \cdot 5H_2O$ - hexagonal] – Extremely rare. This mineral was first described by Martini (1994a) and submitted to the Commission for New Minerals and Mineral Names (CNMMN) but not approved before its publication (Jambor and Roberts, 1999). In Arnhem cave (Namibia) arnhemite is one of the most common crystalline phases and occurs as aggregates of flakes, up to 50 mm (Martini 1994a). In Ghar al Hibashi it was found exclusively in sample Hi8, where it was detected only once; it is strictly associated with pyrophosphite and opal-C. Its occurrence has been confirmed by Rx analysis although it was impossible to define its crystal habit. In his paper, Martini supposed that arnhemite of Arnhem cave is not a direct product of guano combustion, but is the result of hydration processes of Na-K phosphate precursors developed at high temperature. If the Martini hypothesis is correct, the scarcity of arnhemite in the Hibashi lava tube may be the consequence of the much drier environment of this lava tube with respect to the cave in Namibia and/or to an insufficient time span after the guano-firing.

Biphosphammite [$(NH_4, K) H_2 (PO_4)$ - tetragonal] – It is the most common mineralogical phase in samples Hi12, Hi13, Hi14, Hi15 and Hizz, all coming from cave sectors not directly affected by guano combustion . It normally consists of yellow to orange to hazel-brown small, smooth spherical grains but sometimes gives rise to aggregates of vitreous, elongated prismatic crystals (samples Hi12, Hi14, Hi15 and Hizz) or to pitch-dark grains in the Hi13 sample. It is associated with aphtitalite, arcanite, opal-C and urea (fig. 36d).

Calcite ($CaCO_3$ – trigonal) – Very rare as a cave mineral, it has been found only in sample Hi7, where it is present as a flat aggregate of globular crystals overlaying a fibrous aggregate of chlorapatite or in very small fragments associated with aphtitalite (fig. 36e). It is more common as a detritic phase in the Hi2 sample where it gives rise to several-millimeter rounded grains

Carbonate-hydroxylapatite [$Ca_5(PO_4,CO_3)_3 (OH)$ - hexagonal] – It is present in Hi6b and Hi7 samples, being one of the phases of the thin transparent to semi-transparent glassy layer covering a milky-white bone fragment, which has been partially vitrified by combustion.

Chlorapatite [$Ca_5(PO_4)_3Cl$ - monoclinic] – It is present in Hi6b, Hi7 and Hizz; in this cave it is the most common mineral of the apatite group. It occurs as honey-yellow, thin, elongated iso-oriented fibers or in a fish-bone arrangement within small bone cavities (figs. 36e, 36f, 37a).

Halite ($NaCl$ – cubic) – Even if the Cl element is a fairly common element within all the analyzed samples, this mineral was detected only in sample Hi7. It gives rise to globular, sometimes flat crystals with rounded edges inside a pale, sky-blue semi-transparent coralloid where it is associated with chlorapatite (fig. 37a).

Hydroxylapatite [$Ca_5(PO_4)_3(OH)$ - hexagonal] – Identified in Hi6b and Hi7 samples within bone porosity to compact fragments partially transformed into whitlockite.

Niter (KNO_3 - orthorhombic) – Very rare, observed just once and only in the Hizz sample, strictly associated with biphosphammite.

Opal-C ($SiO_2 \times nH_2O$ – tetragonal) – Identified in semi-transparent to pale yellow viteous globular or coralloid crusts in Hi6b, Hi7, Hi8, Hi15, Hizz samples. It is strictly associated with K-phosphates and quartz, from which it is distinguishable due its flat, lenticular shape. It occurs as microblades identical to those which are mixed together (figs. 37b, 38b). Its genesis is evidently simultaneous with that of pyrocoproite and pyrophosphite and therefore strictly related to guano firing. Its detection was made by chemical analyses and it was confirmed by the shape of the ~ 22° 2J peak and of the other broad peaks which differentiate this mineral with respect to cristobalite and opal-CT (Jones & Segnit,1971; Smith, 1998). Unfortunately it was impossible to define the H2O content due to the dimension of the small blades and to its strict interconnection with the other mineralogical phases.

Palygorskite [$(Mg,Al)_2Si_4O_{10}(OH) \cdot 4H_2O$ - monoclinic/orthorhombic] – Very rare, identified only in the Hi7 sample. It consists of snow-white soft tufts of densely interlaced thin elongated vitreous fibres (fig. 37c).

Pyrocoproite [$(K,Na)_2Mg(P_2O_7)$ - monoclinic] – It is one of the more common minerals within the samples collected in the burnt zone (Hi6b, Hi7 ed Hi8). Pyrocoproite was firstly reported by Martini (1997) in Arnhem cave but it never was submitted to the CNMMN; among eight samples studied by Martini (1997), only one was not completely altered into arnhemite. The Hibashi pyrocoproite is present in transparent colorless smooth crusts as interlaced or iso-oriented pseudo-hexagonal and/or tabular crystals with indented edges (figs 37d,e,f; 38a). The relative abundance of this mineral in Hibashi cave with respect to Arnhem cave confirm the hypothesis that in this lava tube, the arnhemite forming process was hindered.

Pyrophosphite [$K_2Ca(P_2O_7)$ - monoclinic] – This is as common as pyrocoproite, with which it is always strictly associated so as to avoid their partition. It has been found in Hi6b, Hi7 and Hi8 samples. This mineral was described for the first time by Martini (1994a) in Arnhem cave where it occurs as anhedral, ovoidal grains up to 50 mm across, soft, and white with a vitreous luster. It has not been approved by CNMMN. No insulated grains of this mineral have been observed in the Hibashi samples; it is present only in the vitreous crusts over the bone and/or rock fragments (fig. 38b).

Quartz (SiO_2 - trigonal) – Fairly abundant, observed within Hi6b, Hi7, Hi8, Hi12 and Hizz samples where it occurs as thin crusts associated with opal-C, pyrocoproite and pyrophosphite or in insulated irregular grains, without the characteristic prismatic bipiramidal habit. It has also been observed as vitreous micro-spheres with their surface partially covered by chlorapatite.

Urea [$CO(NH_2)_2$ – tetragonal] – Detected in samples Hi7, Hi8, Hi15 and Hizz, it is surely the crystalline phase occurring with the best defined habit among all the minerals of Hibashi Cave. It always consists of small, colorless to pale yellow, transparent, tetragonal prismatic crystals isolated or in radial aggregates (fig. 38c,d).

Whitlockite {$Ca_9(Mg,Fe)(PO_4)_6[PO_3(OH)]$ - trigonal} – Abundant in samples Hi6b, Hi7 and Hi8 of the burnt zone and also in the Hizz sample which was taken from a zone not directly affected by guano-firing. In all but one, the occurrence the mineral was a Mg-rich variety of whitlockite. It has been observed within a milky-white, spongy material or small vitreous pinkish crystals over bone fragments and it consists of aggregates of subspherical grains of different dimensions (fig. 38e).

Rather interesting is a still undetermined material that normally occurs as tiny vitreous, transparent to colourless flakes or as small milky-white to silk-luster spheres (fig. 38f), uniformly characterized by interferences at ~11.8, 9.3, 5.8, 3.9, 2.9 and 1.82 Å. The shape and the chemical composition of this material are still under study. It is very similar to the arnhemite described by Martini (1994a, 1994b, 1997) in Arnhem cave (Namibia). It may be an intermediate phase between pyrocoproite and arnhemite with respect to the H2O content and the dimension of the elemental cell. Unfortunately, due to the small size of the sample and to the difficulty of separating it from the other mineralogical phases, it has so far proved impossible to obtain a sufficient amount of pure material to make a complete mineralogical definition.

The following, detrital and/or not cave-related, minerals were also detected: calcite (Hi2), dolomite (Hi2), feldspar (Hi2, Hi7, Hi8, Hi9, Hizz), illite (Hi9) and clinopyroxene (Hi8). These always consist of more or less rounded one-millimeter polished grains. No minerals were detected in Hi10

GENETIC MECHANISMS RELATED TO THE DETECTED MINERALS

Despite the scarcity of analyzed samples, at least 19 different cave minerals were detected, most of which are related to excreta of animals or to biogenic mineralization of bones and guano deposits (Table 1). Many of the detected minerals are well known in cavern environments but a few are uncommon. In reality, the total number of detected minerals is higher (23) but four of them (dolomite, feldspar, illite and pyroxene) have not been inserted in the list of Hibashi cave minerals (Table 1) due to a reasonable doubt that they have a cave-related origin. The residual and/or detrital origin of feldspar and pyroxene is more certain, being components of the host rock, whereas illite and dolomite may be also secondary in origin.

Illite is a well known cave mineral but it may also develop due to weathering of silicates on the surface or it may be residual. The location of the sample (Hi9) about 70 cm below the floor of the cave may suggest the evolution of this mineral directly within the lava tube. In fact it is difficult to justify such a deep location for a deposit which had to be brought into the cave by winds, when the upper part of these sandy deposits is composed of normal fragments of lava (which are surely airborne sediments).

The problem of the origin of dolomite is even more complex: in fact carbonate outcrops are absent in the whole volcanic region and the dry climate avoids weathering of the Ca++ and Mg++

Table 1. Identified cave minerals and their distribution within the cavity: Hi2: burnt wolf scat; Hi6b: ash from burnt zone; Hi7: bone from burnt zone; Hi8: volcanic rock from burnt zone; Hi9: sediment sample from –70 cm below floor; Hi10: nest of insect larvae; Hi12: content of lava channels; Hi13: lower extreme content of lava channel; Hi14: burnt coating on ceiling; Hi15: sticky stalactite between stations 18w-19w; HiZZ: sticky stalactites near station 12w.

Sample	Mineral	Formula	Characteristics
Hi7, Hi8	**1** - Anhydrite	$CaSO_4$	Orthorhombic - milky-white small earthy subspherical grains
Hi6b, Hi7, Hi12, Hi13, Hi14	**2** - Aphthitalite	$(K, Na)_3Na(SO_4)_2$	Trigonal – Honey yellow to dark brown subspherical grains and/or vitreous fragment mixed with **6** and/or **4**
Hi8	**3** - Arnhemite	$(K,Na)_4Mg_2(P_2O_7) \cdot 5H_2O$	Hexagonal – Soft uncemented white dull material mixed with **13** and **16**.
Hi6b, Hi7, Hi12, Hi13, Hi14, Hi15, HiZZ	**4** - Arcanite	$K_2(SO_4)$	Orthorhombic – Semi-transparent to lemon yellow vitreous crust, mixed with **9, 13, 15 e 16** or plastic microcrystalline honey yellow small aggregates mixed with **2** e **6**
Hi7, Hi8	**5** - Archerite	$(K, NH_4)H_2PO_4$	Tetragonal – pale gray glassy luster coralloids mixed with **15** and **16**.
Hi12, Hi13, Hi14, Hi15, HiZZ	**6** - Biphosphammite	$(NH_4, K) H_2 (PO_4)$	Tetragonal – Honey yellow to transparent subspherical grains and/or vitreous crusts or plastic microcrystalline honey yellow to dark brown and black masses with rare thin elongated prismatical crystals . Often mixed with **2**, **4**, **6** and **18.**
Hi7	**7** - Calcite	$CaCO_3$	Trigonal- Very rare as insulated crystals or aggregates of elongated crystals
Hi6b, Hi7	**8** - Carbonate-hydroxylapatite	$Ca_5(PO_4,CO_3)_3(OH)$	Hexagonal – honey yellow vitreous semi-transparent hard material
Hi6b, Hi7, HiZZ	**9** - Chlorapatite	$Ca_5(PO_4)_3Cl$	Monoclinic – Cream white microcristalline hard material with rare aggregates of small dumpy fibrous prismatic crystals
Hi7	**10** - Halite	$NaCl$	Cubic – Rare semi-transparent pale blue coralloid grains strictly associated with **9** and **14**.
Hi6b, Hi7	**11** - Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	Hexagonal – Porous to compact fragments within bone partially transformed into **19**.
HiZZ	**12** - Niter	KNO_3	Orthorhombic – Similar and always strictly mixed to **6**
Hi6b, Hi7, Hi8, Hi15, HiZZ	**13** - Opal-C	$SiO_2 \cdot nH_2O$	Tetragonal – Semi-transparent to pale yellow viteous globular or coralloid crusts mixed with **15**, **16** and **17**.
Hi7	**14** - Palygorskite	$(Mg,Al)_2Si_4O_{10}(OH) \cdot 4H_2O$	Monoclinic/Orthorhombic – Soft tuft of snow-white thin, bent, fibrous crystals
Hi6b, Hi7, Hi8	**15** - Pyrocoproite	$(K,Na)_2Mg(P_2O_7)$	Monoclinic – Semitransparent to pale grey vitreous globular saccaroidal crusts or pale green elongated pseudo-fibres. Often mixed with **16**.
Hi6b, Hi7, Hi8	**16** - Pyrophosphite	$K_2Ca(P_2O_7)$	Monoclinic – colourless to snow-white vitreous saccaroidal crusts. Nearly always mixed with **15**.
Hi6b, Hi7, Hi8, Hi12, HiZZ	**17** - Quartz	SiO_2	Trigonal – crust or insulated grains without the characteristic prismatic habit often associated with **13**, **15** and **16**.
Hi7, Hi8, Hi15, HiZZ	**18** - Urea	$CO(NH_2)_2$	Tetragonal – small colourless to pale yellow transparent prismatic tabular crystals or radial aggregates
Hi6b, Hi7, Hi8, HiZZ	**19** - Whitlockite	$Ca_9(Mg,Fe)(PO_4)_6[PO_3(OH)]$	Trigonal – Milky white spongy material or small vitreous pinkish crystals over bone fragments

The following, detrital and/or not cave-related, minerals have been also detected: calcite (Hi2), dolomite (Hi2), feldspar (Hi2, Hi7, Hi8, Hi9, HiZZ), illite (Hi9) and pyroxene (Hi8); no minerals at all have been detected in Hi10 ions from lava by seeping and/or condensation water within the cave. Therefore the single possible explanation for its presence is related to the frequenting of the cave by carnivores, which is clearly indicated by bones and other remains. Calcite grains found within coprolites are probably detrital. However, at least in one occurrence (Hi7) a calcite crystal was clearly of recent chemical deposition and therefore calcite was inserted in the list of cave minerals of Hibashi lava tube. Dolomite grains of Hi2 are in shape and size very similar to those of calcite but in no occurrence was it possible to clearly detect its genetic mechanism. In reality, its detrital origin is probable but not sure. In fact, bones cannot directly supply this mineral and dolomitic outcrops are very far away. At any rate, at the moment there is no evidence of its deposition during the mineralization of the scat inside the cave and therefore it may be that dolomite was a by-product of digestion processes. In fact, digestion processes may lead to the mobilization of calcium and magnesium from bones and/or meats which immediately or a short time later can be deposited as calcite and/or dolomite within the excrement. Therefore the genesis of dolomite would be absolutely uncontrolled by the cave environment.

This hypothesis seems to be confirmed by the fact that the single sample in which calcite and dolomite were found (together with feldspar) was Hi2, consisting of a partially burnt sample of wolf scat, in which no other minerals (amongst those normally related to biogenic mineralization of guano and coprolites like phosphates and/or sulfates) have been observed. The absence of the typical association of guano minerals is an indirect proof that the combustion took place when the wolf scat was not yet heavily transformed by the slow biogenic processes characteristic of the cavern environment and therefore all its organic content was transformed into volatile compounds by fire. For this reason dolomite, and perhaps also calcite, should not be considered true cave minerals.

Amongst the 19 cave minerals of Ghar al Hibashi, the highest number (nine) are phosphates, three are sulfates, three are silicates, and there is one example of carbonate, nitrate, chloride and organic compounds respectively, but the origin of most of them was controlled by the biogenic reactions related to the different steps in the mineralization of guano, bones, and scat.

Early cave mineralization processes (Hill and Forti, 1997) are those related to the development of the deposits of the lava channels (Hi12 and Hi13), where soluble sulfates and phosphates were found together with quartz and even more the bio-stalactites (samples Hi15, Hizz) in which highly soluble minerals like niter and urea have been found together with phosphates, sulfates opal and quartz. The deposition of opal and/or quartz is normal in such an environment because a high amount of silica is leached from the volcanic rock by seeping water and the acidification processes (direct consequence of the oxidation of the N-, S-, and P- organic compounds) lead to oversaturation with respect to these minerals.

The Hizz sample is by far more rich in mineralogical species (eight) than the Hi15 (four) and this may be explained by the fact that its location was farther away from the area in which the guano firing occurred: in fact the environmental conditions of the stalactites in the Hizz location were less disturbed by the fire and therefore some volatile compounds like niter had the chance to remain and other (quartz, chlorapatite and whitlockite) had the time to develop. On the contrary, it must be stressed that normally the main minerogenetic factor in Hibashi Cave has been guano firing: in fact all the other samples affected by such a phenomenon were those richest in mineralogical species (Hi7 with fifteen, Hi6B with ten, Hi8 with eight). The relatively lower number of minerals found in the Hi8 sample is explained by the fact that it consists of volcanic rock that was not covered directly by guano or other organic material and the cave minerals found over and inside it were surely deposited by smoke and aerosols and vapors as consequences of the guano combustion.

Three of the detected minerals within the burnt samples (pyrocoproite, pyrophosphite and arnhemite) are extremely rare organic compounds strictly related to guano combustion, which have been observed until now only in few caves of Africa (Martini, 1994a, b; Martini, 1997; Jambor and Roberts, 1999).

In Hibashi Cave, pyrocoproite and pyrophosphite are by far more common than arnhemite, which has been detected only in sample Hi8. According to the genetic mechanisms for these minerals, arnhemite (Martini 1994a) is not directly produced during the guano-firing event but is the consequence of the hydration of the minerals developed during the combustion. In its first location (Arnhem Cave, Namibia) arnhemite had the time to develop because the guano-firing occurred over 1500 years ago and also environmental conditions allowed for enough humidity inside the cave.

Actually no data are available to date the combustion processes inside Hibashi cave, which probably happened in even more recent times. But what is surely different in this lava tube with respect to Arnhem cave is the climate: in fact even if in this area rainfalls are quite abundant, the relative humidity within the cave appeared to remain always low.

As a consequence hydrated cave minerals (arnhemite, opal, and palygorskite) are very few and scarce, while other minerals, normally metastable may survive. This is the case of anhydrite in sample Hi7 and Hi8, which is normally rare in cavern environments because it easily transforms into gypsum, its more stable hydrated compound, which in turn has not been reliably detected in Hibashi samples, even if some elements seem to suggest its presence, although in very scarce quantity. It is highly probable that Hibashi anhydrite was not the mineral directly produced by the biogenic digestion of the guano and bones (the normal calcium sulphate originated by these mechanisms being gypsum) but it was the final product of the dehydration of gypsum due to the guano-burning events.

In conclusion, all the evidence from Hibashi cave demonstrates that the evolution of guano–burnt minerals to new hydrated compounds is strictly controlled by the amount of available water and therefore gypsum had no way to develop and arnhemite and palygorskite had just a scarce possibility to form.

MINERALOGICAL IMPORTANCE OF GHAR AL HIBASHI

A great variety of minerals developed within the cave environment as a result of the peculiar conditions which over time made it possible for different minerogenetic mechanisms to become active. Among these the one related to guano combustion is quite unusual and allows a better description of some very rare cave minerals, which were observed until now only in a few caves of Namibia.

Thanks to these findings, Hibashi lava tube has been referred to as the most important volcanic cave of Saudi Arabia and the richest mineralogical shelter of the country (Forti and others, 2004). For this reason, Hibashi cave has been inserted in the “top ten volcanic caves” for hosted minerals (Forti, 2004). This research is a further confirmation of the recently advanced opinion that among the different cavern environments, the volcanic one is the most favorable for the development of minerogenetic mechanisms and consequently of cave minerals.

LOESS FLOOR COVER

To date, six volcanic caves located in Saudi Arabia have been studied and mapped by speleologists. In each of these, sediment covers most, if not all of the original basalt floors. Mud and a phosphate-rich compound were found in lava caves on Harrat Kishb (Roobol and others, 2002) while sand, mud and dust cover the floor of Kahf al Shuwaymis in Harrat Ithnayn and wet and dry mud lies on the floor of Dahl Romahah in Harrat Khaybar (fig. 39) In addition, eight lava caves surveyed in Jordan show similar characteristics (Kempe, 2004). The sediment in Ghar al Hibashi, however, seems to consist mainly of a thick (up to 1.5 m deep) layer of powdery silt. In order to better understand the nature of the Hibashi sediment, researchers participating in the SGS Loessic Silt Project were invited to visit the cave.

COLLECTION OF SAMPLES

Two samples of silt were taken on August 31, 2003, in each case from the very lowest level possible, immediately above the original cave floor. The locations of loess sampling are shown on the Plate. Holes were dug by shovel in order to access the bottom of the sediment layer. A pressurized water sprayer was used to strengthen the side walls as the holes were dug and also to minimize the amount of dust in the air (fig. 40). Sample number one was taken from a point 4 m SE of station 11W, in the middle of the passage (fig. 41). The sediment was 40 cm deep at this point. The sample was forced into a heavy-duty PVC tube which was then sealed with tight-fitting end caps. Desiccated hyena scat, twigs and fragments of basalt were found lying on the original floor of the cave. The second sample was taken from the bottom of a hole dug halfway between stations 8W and 9W, equidistant from the walls of the passage. At this location, 60 meters closer to the cave entrance than the first sampling point, the sediment was found to be 1.5 m deep (fig. 42).

ANALYSES OF LOESS CONTENT

The results of analyses carried out on these samples will be reported in Vincent and Kattan, 2005 (in prep.). Below we briefly summarize comments on the Hibashi sediment communicated to the first author.

A laser granulometer indicates that this sediment is loess with a mean particle size of about 10 microns. It is a fine silt dominated by quartz, feldspar and kaolin, as determined by XRD analysis. The kaolin indicates that it was derived from deep weathering because it is an end-product clay mineral that now only forms in humid tropical conditions. The quartz is almost certainly derived from the deeply weathering laterites which are filled with eroded quartz grains. There is abundant evidence that deep weathering of the Shield took place in Miocene times after the uplift, releasing the quartz silt. Because the silt could not have come from the basalt in the area (which is a basic rock and quartz poor), it is not a local fluvial deposit, but must be related to the weathering underneath the local basalt or must come from further afield. It was almost certainly carried into the cave by air.

AGE DATING OF HIBASHI LOESS

Optically Stimulated Luminescence (OSL) was used to date the two samples from Ghar al Hibashi. The procedures were carried out during a six-month period in 2003 at Oxford University, U.K., using a Danish instrument from Riso. The age of sample 1 (depth: 40 cm, circa 150 m from the cave entrance) was found to be 4.5±0.2 ka while the age of sample 2 (depth: 150 cm, circa 90 m from the entrance) is 5.8±0.5 ka. Both of these dates are post-Holocene wet-phase (7 ka BP) and presumably relate to the onset of aridity and more frequent windstorms (P. Vincent, written commun., Nov. 2004).

ROLE OF HIBASHI LOESS FOR DESIGN OF MICROROBOTS FOR MARS

A joint project by the Field and Space Robotics Laboratory of MIT (Massachusetts Institute of Technology) and the Cave and Karst Studies Program at New Mexico Tech. (NM Institute of Mining and Technology) is using Hibashi Cave as a model for lava tubes on Mars. This project, funded by the NASA Institute for Advanced Concepts (NIAC) is looking at microrobotic technology for accessing such systems in extraterrestrial locations (Dubowsky and others, 2003).

Interest in lava tubes on other bodies including Mars and the Moon for future space missions has been suggested by a number of investigators (Boston, 1995, 2000, 2003; Boston and others., 2001, 2003, 2004a,b; Frederick, 1999; Horz, 1985; Kokh, 1996; Walden and others., 1988). A detailed NIAC study over four years has produced a set of enabling technologies that will allow robotic and ultimately human use of Martian lava-tube caves (Boston and others, 2001, 2003, 2004a,b). One of those identified technologies, i.e. the need for highly capable miniature robotics for ground-based detection, reconnaissance, and mapping of lava-tube structures, has led to the most recent project.

Mars has many lava tubes of great size (fig. 43) that are quite conspicuous on orbital imaging data from various Mars mission instruments. The NMT team has identified numerous instances of these. Because of the large amount of very fine surface material that is globally distributed on Mars by planet-scale dust storms occurring at fairly regular intervals, the NMT workers have hypothesized (P.J. Boston, written commun., Nov. 2004) that such materials would sift into lava tubes and create a flat floor of such unconsolidated deposits. The Hibashi system is filled with such material and presents a perfect analog for such a situation. According to P.J. Boston (written commun., Nov. 2004), the detailed map of the system, shown in the Plate, has been invaluable in producing robotic motion simulations created by the MIT team to test the capabilities of the candidate microrobotic designs to navigate into and around such a challenging environment. The project is continuing with a Phase II proposal to be submitted to NASA in mid 2005.

CONCLUSIONS AND RECOMMENDATIONS

A number of rare and unusual secondary cave minerals were found in Ghar al Hibashi in a small number of samples taken mainly from one area of the cave. It is recommended that similar studies be carried out on samples from the extreme western end of the cave. In like manner, a thorough study could be made of the cave silt and of the phytoliths contained in fibers found in the animal scat.

To date, no attempts have been made to dig for artifacts nor to study the bones, horns and other primate remains scattered throughout the cave. The subsurface may yield further finds of possible interest to historians, archeologists and perhaps paleontologists.

Studies such as those mentioned above could be carried out more easily in Hibashi Cave than in most other Saudi lava caves because:

- It can be reached via good roads from Jeddah, Makkah, or Riyadh.
- Off-road driving is limited to only twenty minutes, from a graded road to the cave entrance, over a vehicle-friendly track.
- There is easy access to the cave's interior via a gentle slope (no ropes or ladders required).

Due to the potential of Hibashi Cave for future studies, it would seem useful to date the lava flow in which the cave is located and to initiate a search for other lava caves in the Harrat Nawasif-Buqum area.

Although Hibashi Cave is considered of world-class importance, it is, at present, not protected by a gate or a fence and is occasionally visited by the general public, as indicated by several layers of graffiti (fig. 5) on its walls, both near the entrance and deep inside. If the cave cannot be preserved exclusively for scientific studies, it would be useful to control the spontaneous tourism now going on there. Visitors might be restricted to certain areas of the cave and a walkway might be built (perhaps of native basalt cobbles) to reduce the dispersion of loess into the air. Such a walkway might benefit both tourists and scientists.

Ghar al Hibashi represents an unusual and important part of Saudi Arabia's heritage and it is hoped that this publication will encourage further studies of the cave and at the same time, assist conservationists in protecting it.

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DATABASE ARCHIVE

For archival purposes, a digital version of this report is stored in the Saudi Geological Survey Geosciences Database. The work is retreiveable by author, title, report number, and by the following keywords: *Lava cave, Saudi Arabia, Harrat Nawasif, Harrat al Buqum, loess, basalt.*

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FIGURES

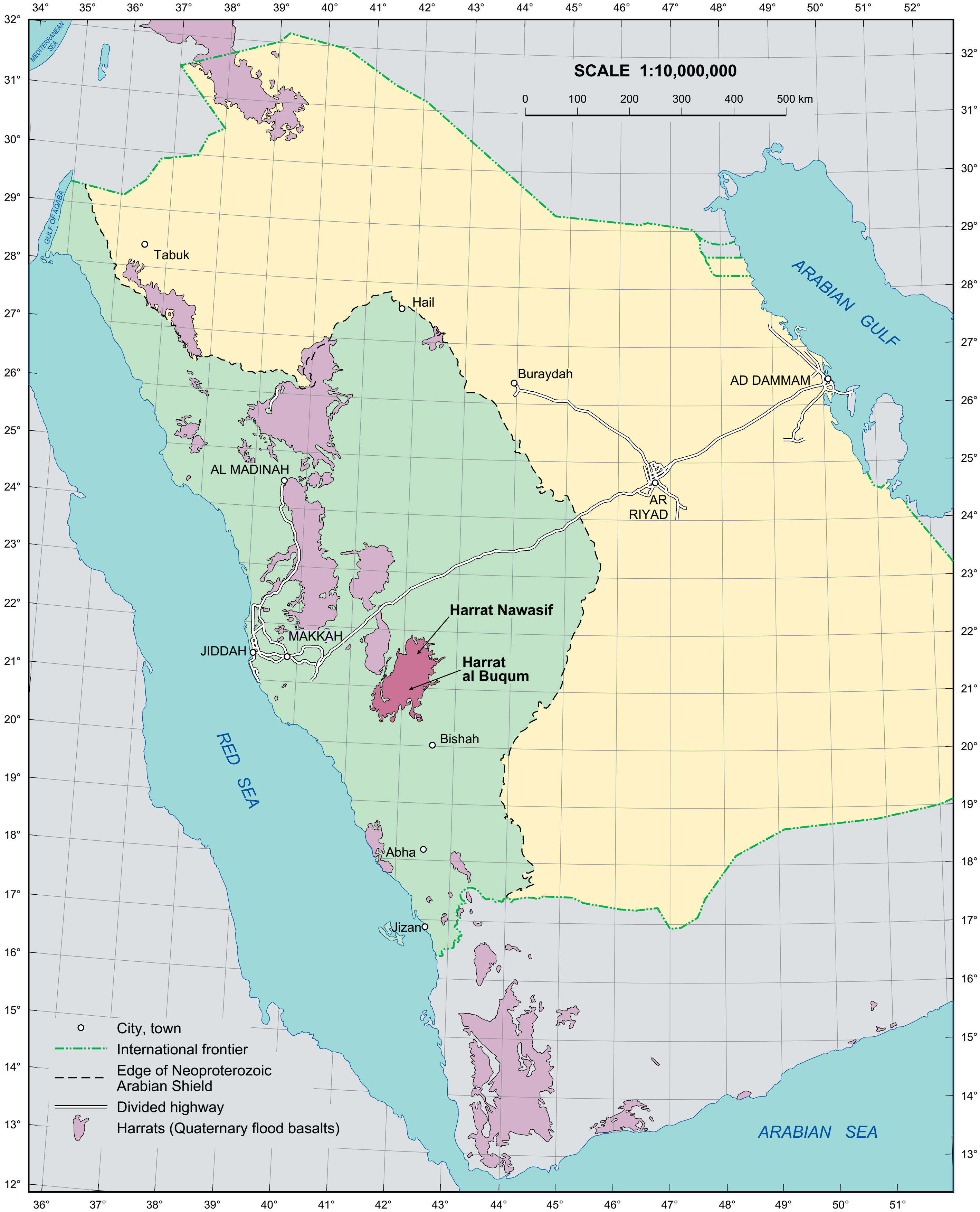


Figure 1. Map showing the Cenozoic lava fields of Saudi Arabia with Harrat Nawasif/Al Buqum indicated.

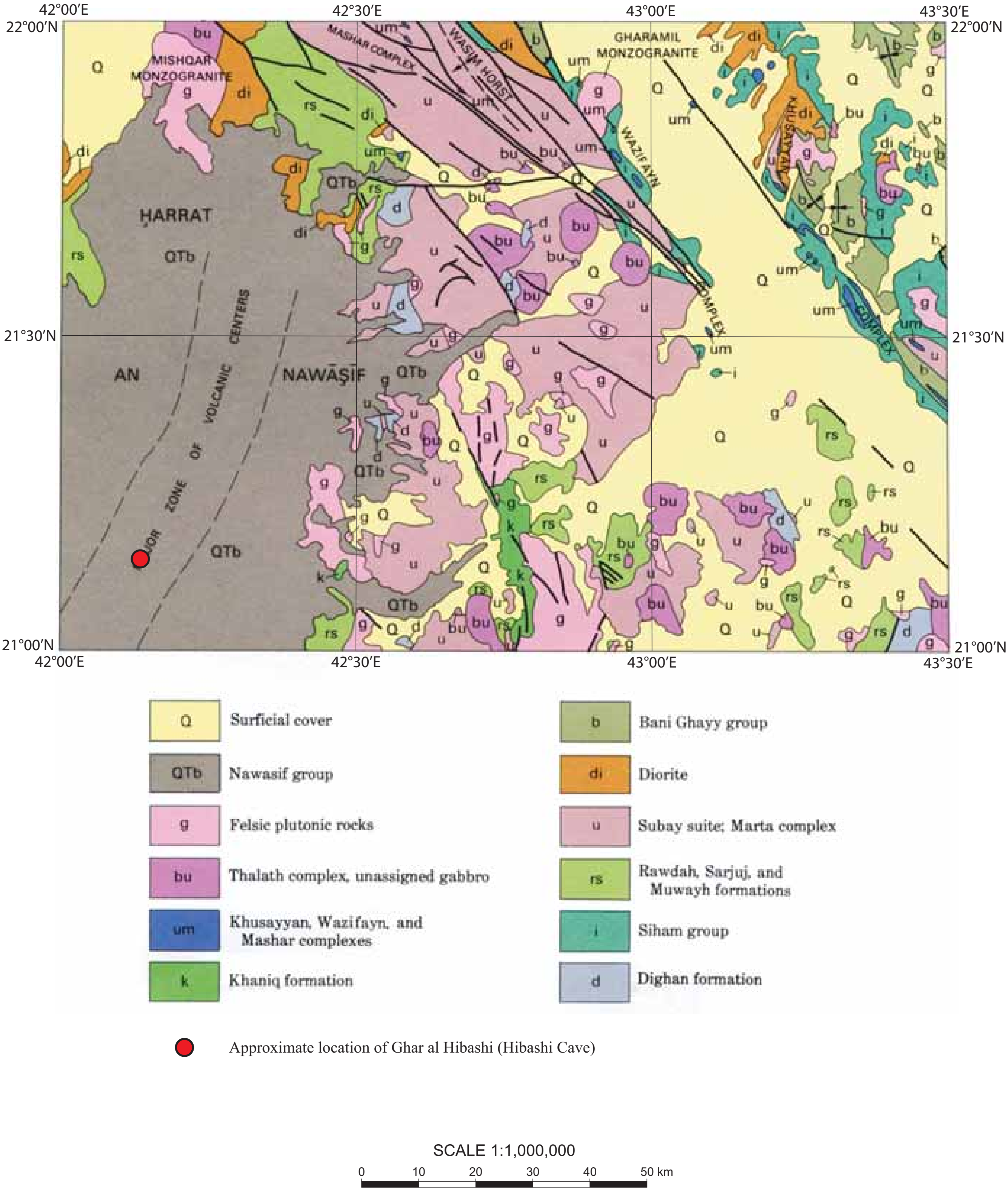


Figure 2. Geologic map of Harrat Nawasif/Al Buqum area showing location of Ghar al Hibashi.

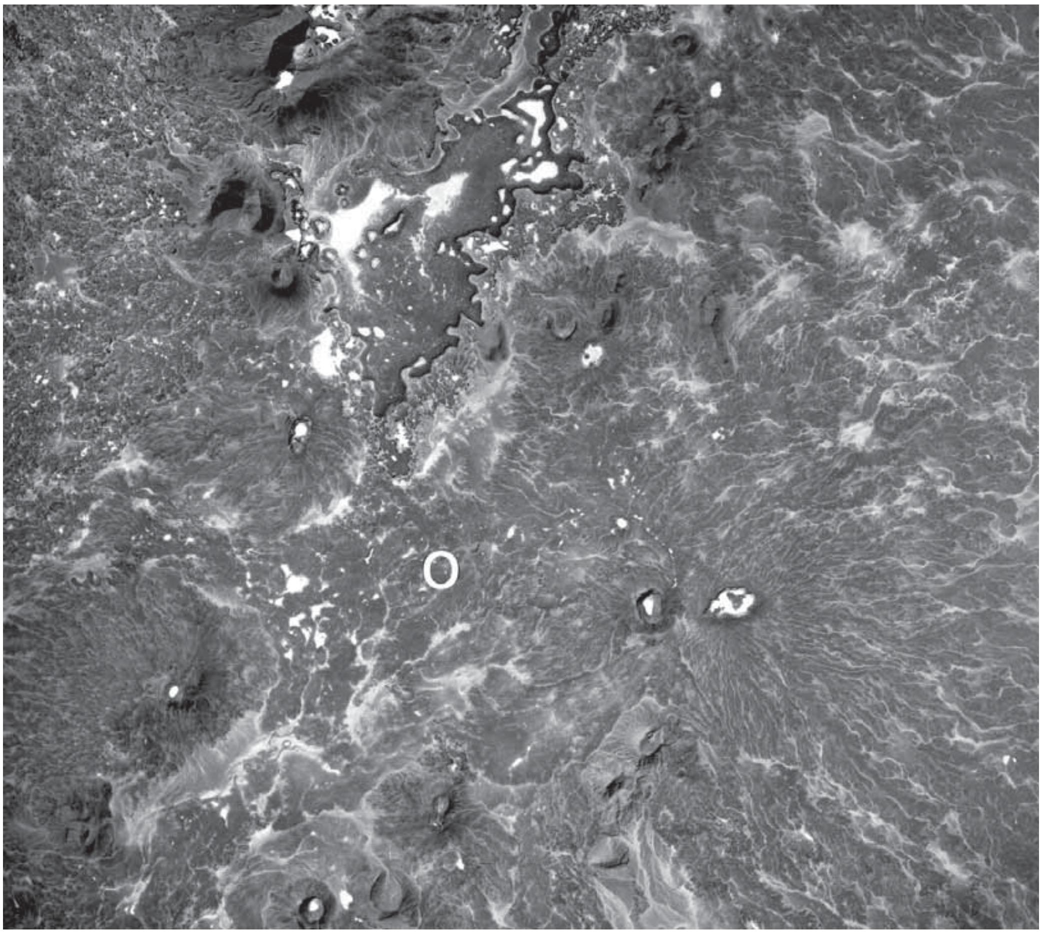


Figure 3. Aerial Photo at a scale of 1:50,000 showing area around Ghar al Hibashi (small dot inside white circle).

Figure 4. Entrance to Ghar al Hibashi, showing layers of lava flow.

Figure 5. Graffiti is found at the entrance pit and also deep inside the cave.

Figure 6. Steep, dusty slope leading from entrance pit into the cave.

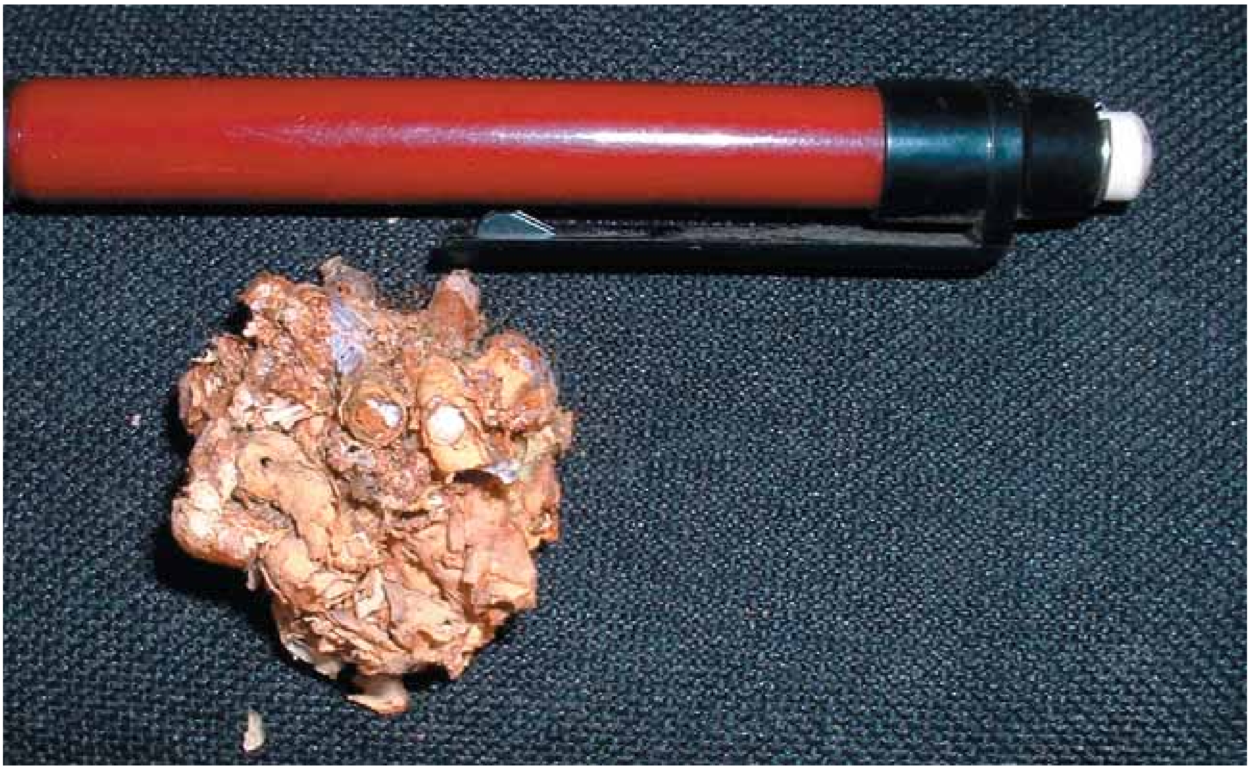


Figure 7. Organic material found on cave roof near the entrance pit.

Figure 8. Remains of a rock wall at the foot of the entrance slope.

Figure 9. Paw print of unknown animal, found near rock wall.

Figure 10. A bed of sheep and goat droppings within view of the entrance.

Figure 11. Depressions in the thick bed of loess, perhaps made by animals.

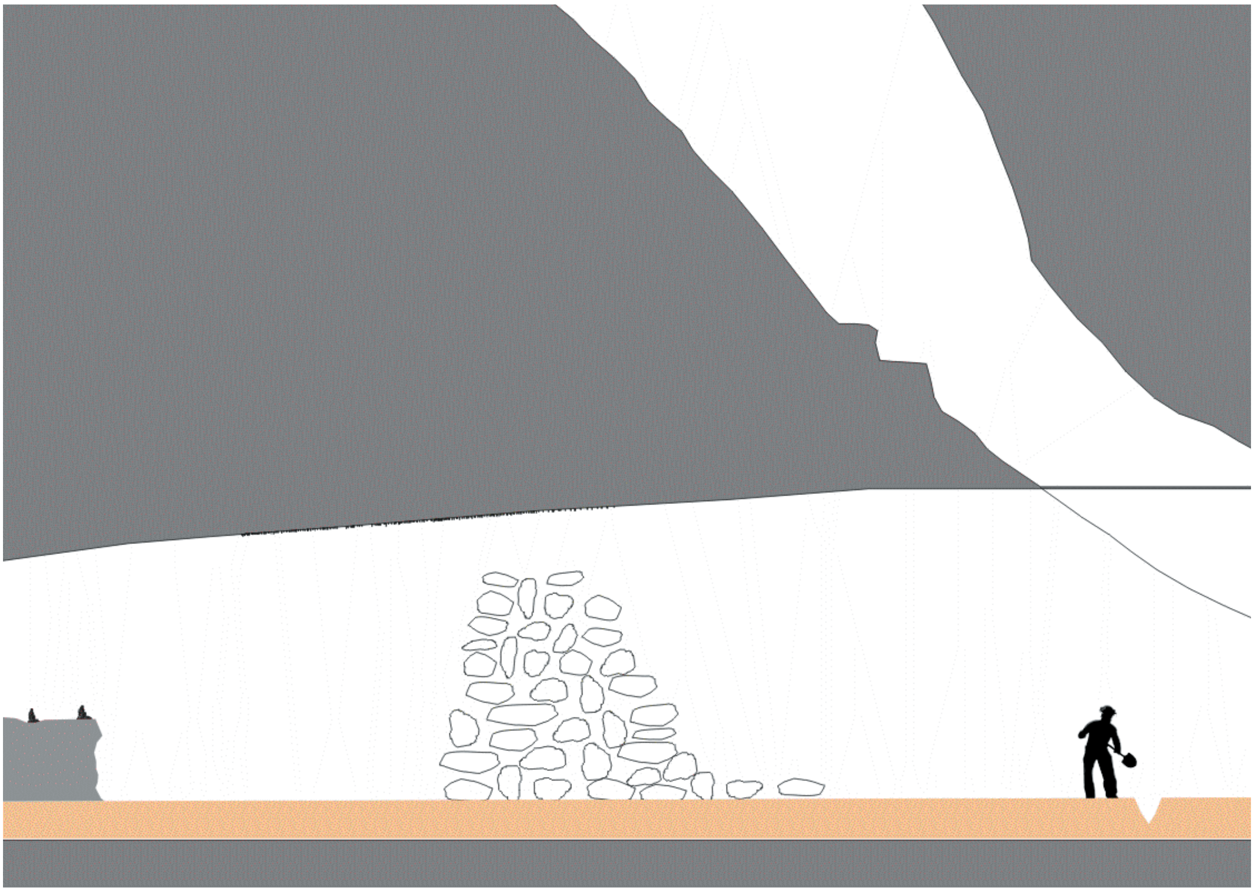


Figure 11a. Detail of profile map showing thickness of loess bed.

Figure 12. Lava stalagmites atop lava levee.

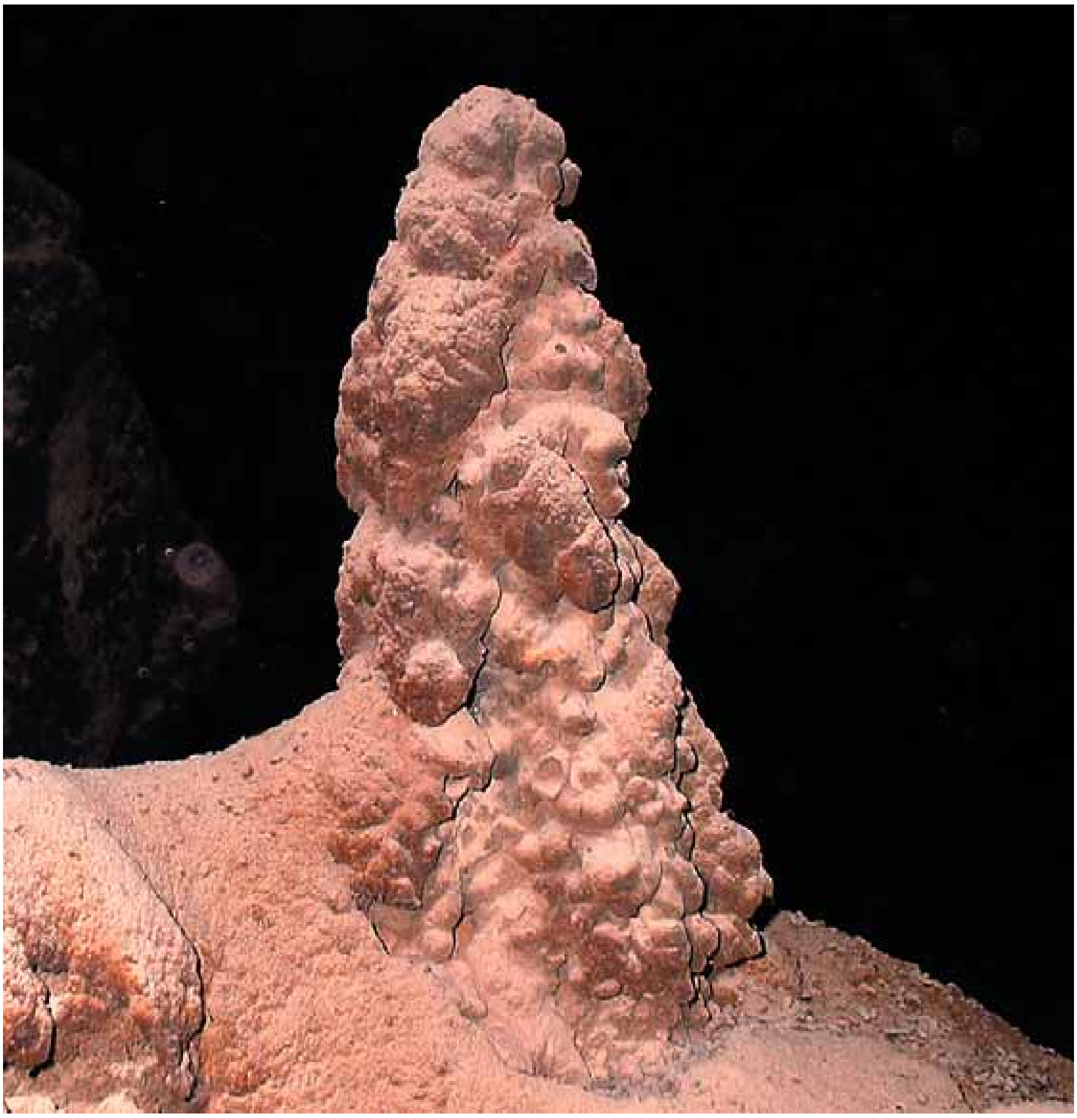


Figure 13. Lava stalagmite, coated with dust.

Figure 14. Lava stalagmite with dust coating removed by washing.

Figure 15. Ripples where lava has run down the passage walls.

Figure 16. Stalactites on the ceiling of the west-tending passage.

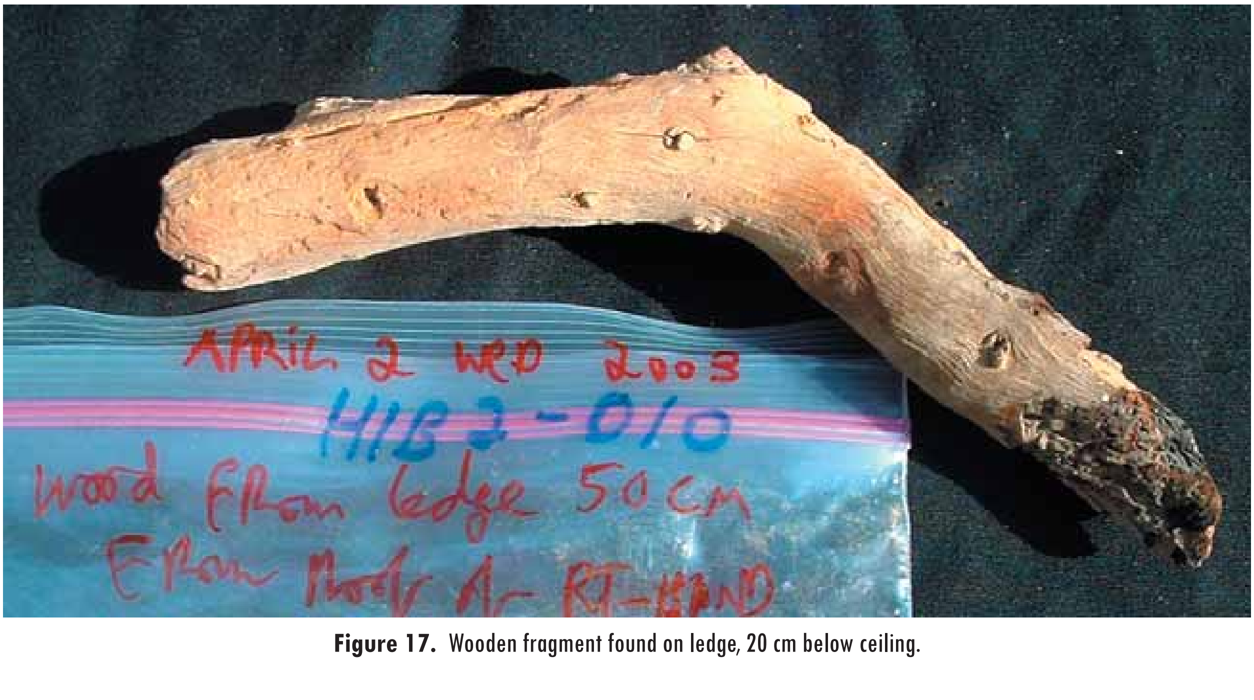


Figure 17. Wooden fragment found on ledge, 20 cm below ceiling.

Figure 18. Dark stains like this one are found on many of the walls.

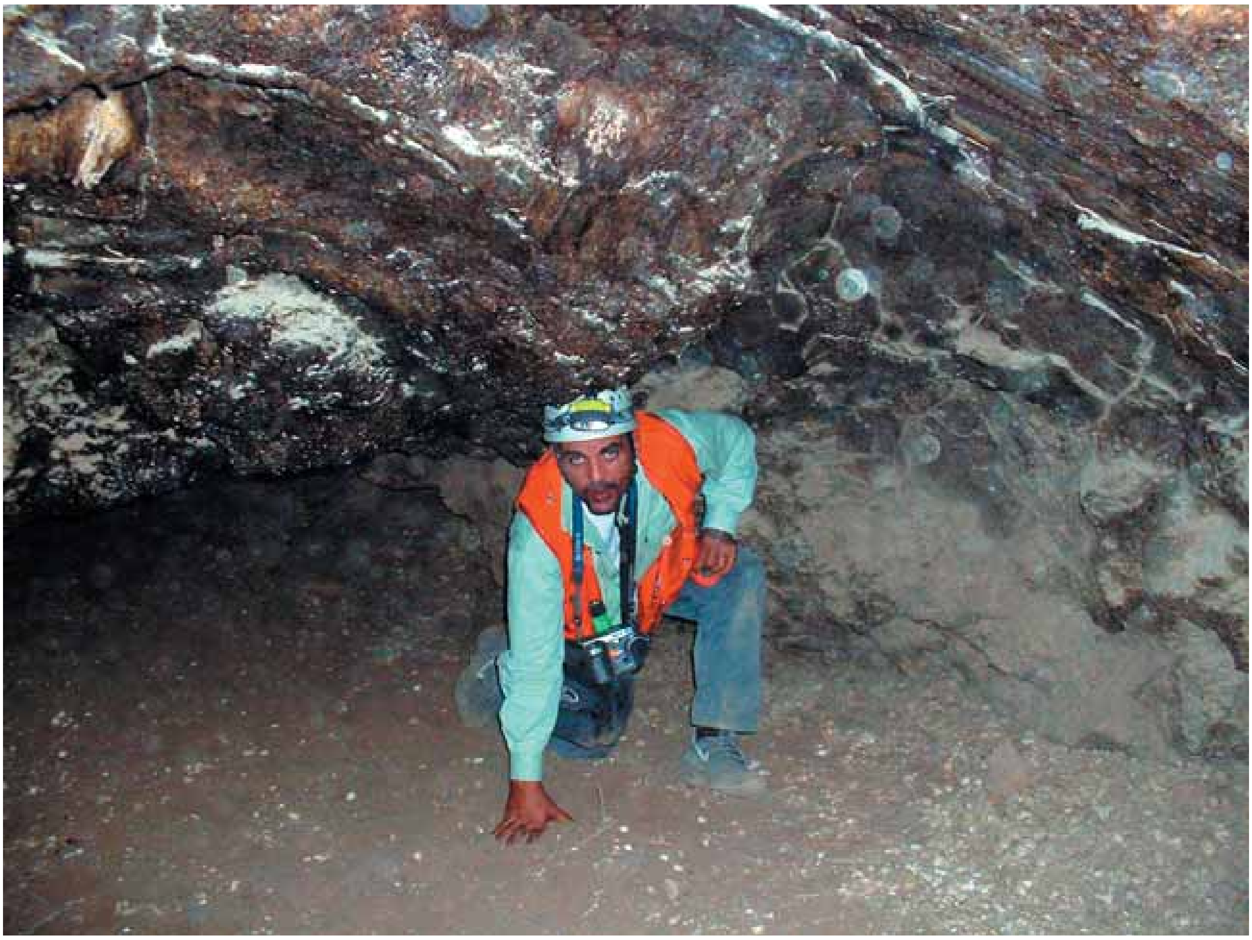


Figure 19. Low ceiling in west-tending passage.

Figure 20. Soft, bio-stalactites probably produced by bats urinating.

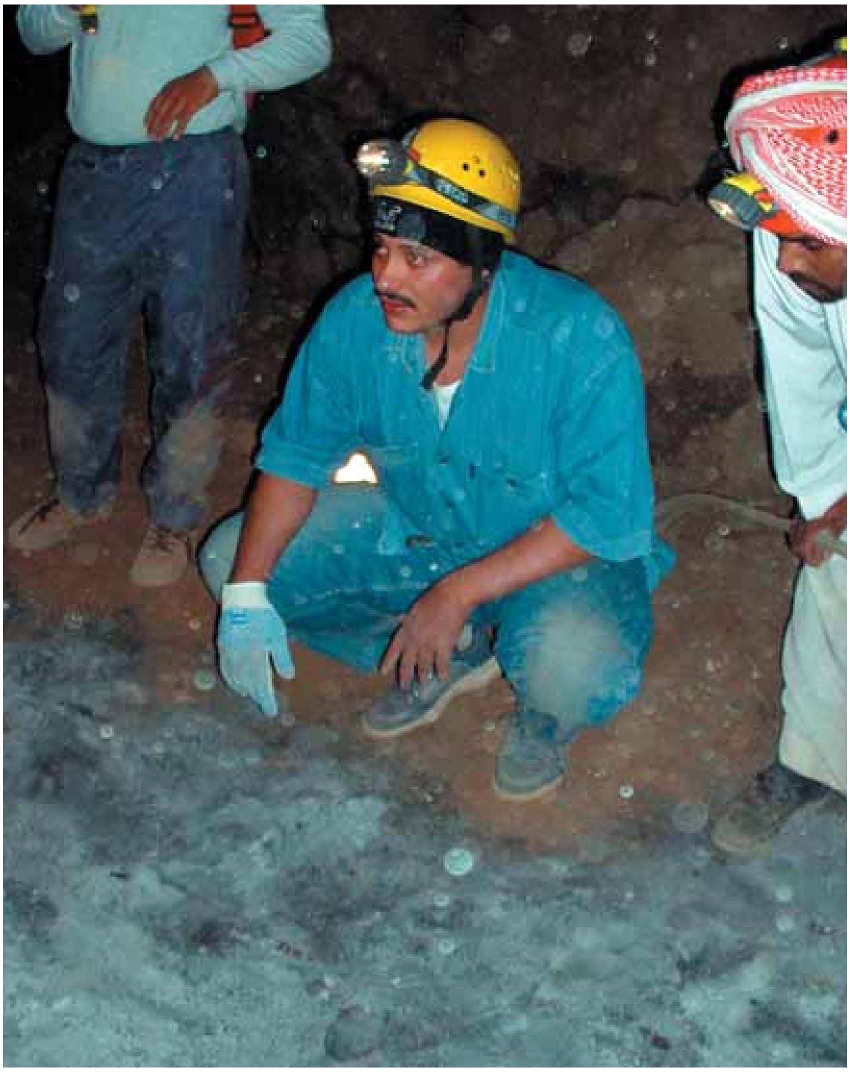


Figure 21. Bed of ash near far western end of the cave.

Figure 22. Lava levee on NW wall of eastward-tending passage.


Figure 23. Bones and hedgehog parts in eastward-tending passage.


Figure 24. Small fires made deep inside the cave may have caused the guano combustion.

Figure 25. Gouge marks on a rock near station 11.

Figure 26. NW edge of burnt guano bed in east-tending passage.

Figure 27. Bones lying on the burnt guano bed are charred on the bottom.

Figure 28. Charred gazelle horns found on surface of eastern burnt-guano bed.

Figure 29. Ashes and basalt fragments removed from burnt zone for analysis.

Figure 31. Black coating on ceiling above burnt guano.

Figure 30. Lava channel filled with sediment and unburnt guano, seen from bottom of slope.

Figure 32. Soft, sticky, bio-stalactites on coated ceiling.

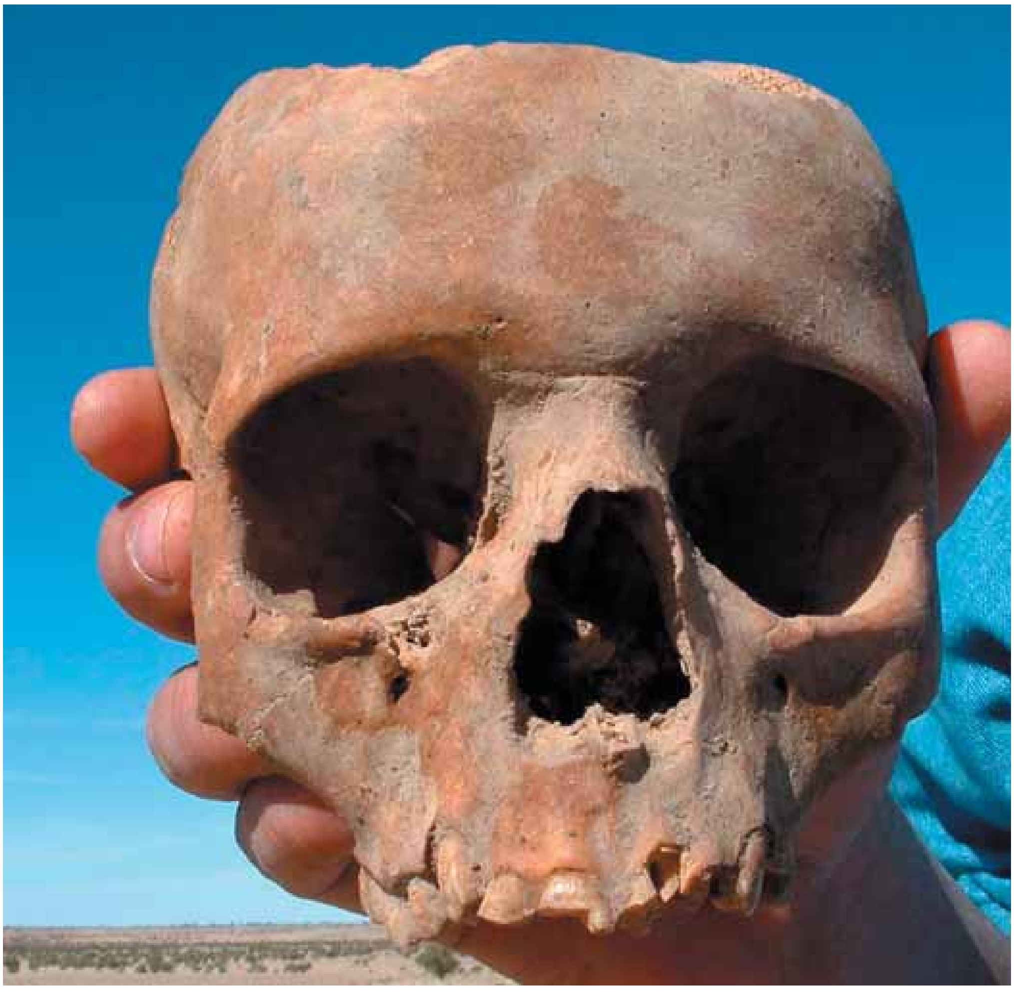
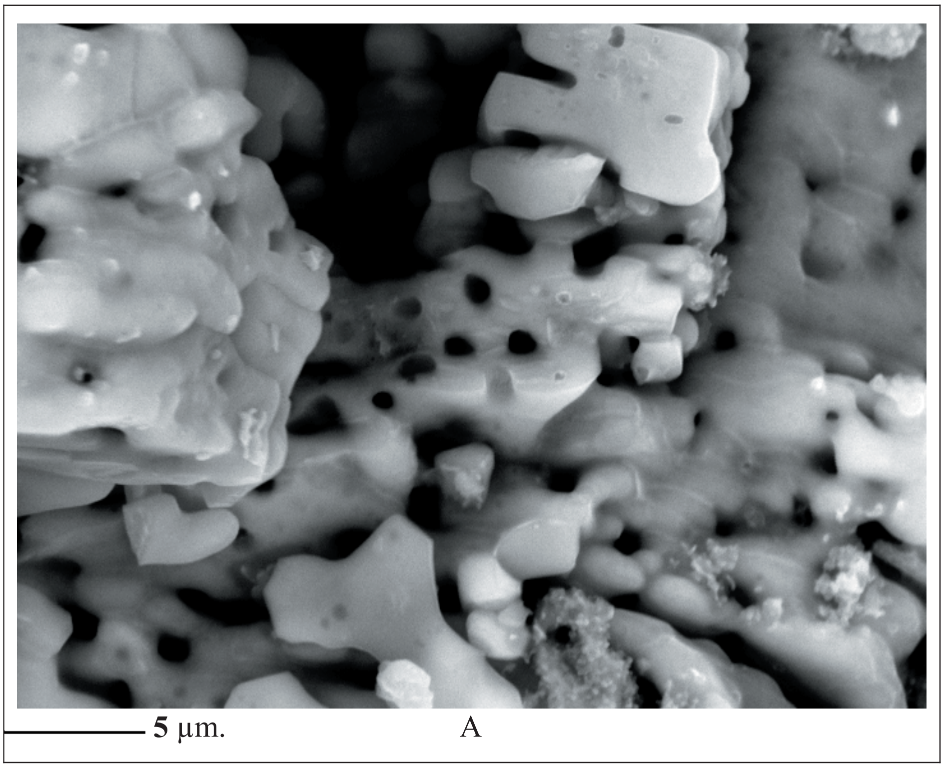


Figure 33. Human skull, 425±30 years old, found near eastern end of cave.

Figure 34. Fragments of a jaw with a few teeth partially covered by a scoriaceous crust.

Figure 35. Fragment of volcanic rock partially covered by a scoriaceous crust.



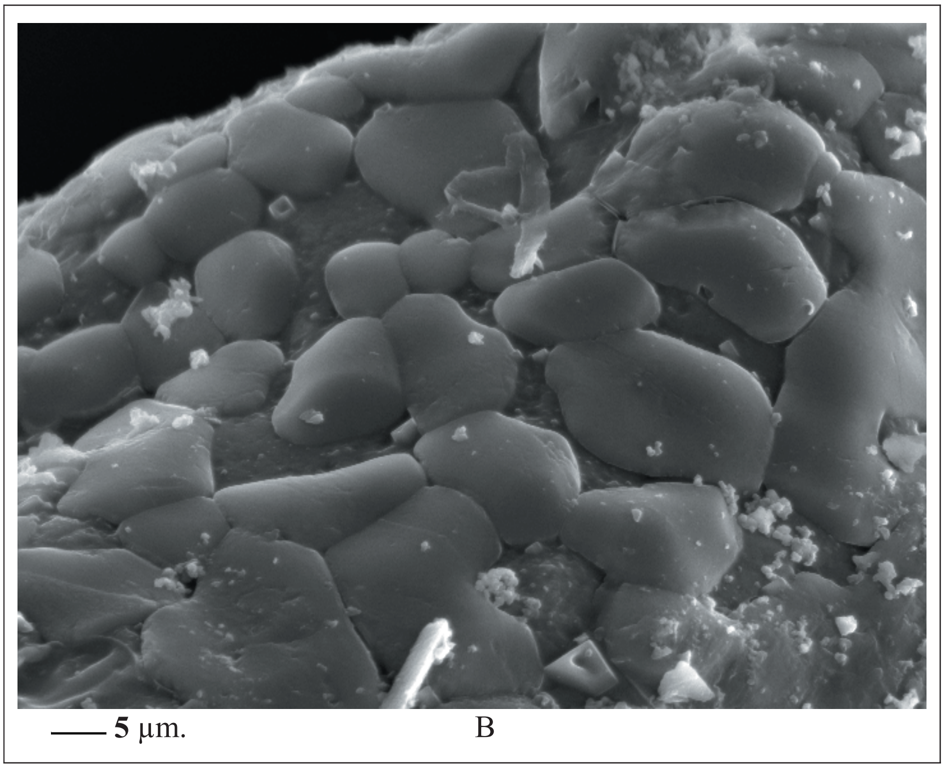


Figure 36. SEM images of Hibashi cave minerals: **A-** anhydrite with evident corrosion/redissolution holes (Hi8); **B-** aphtitalite crystals with small calcite grains (Hi7).

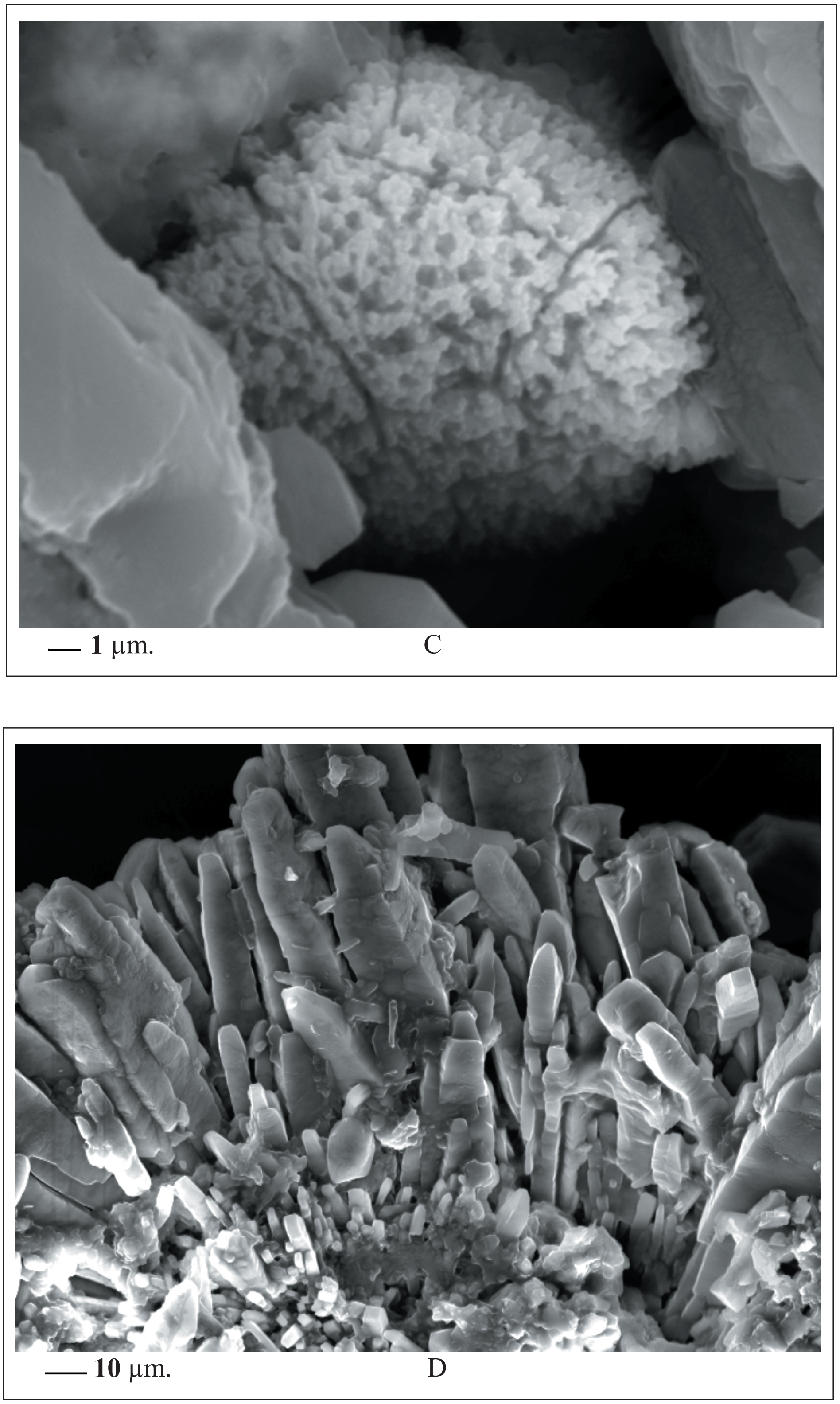
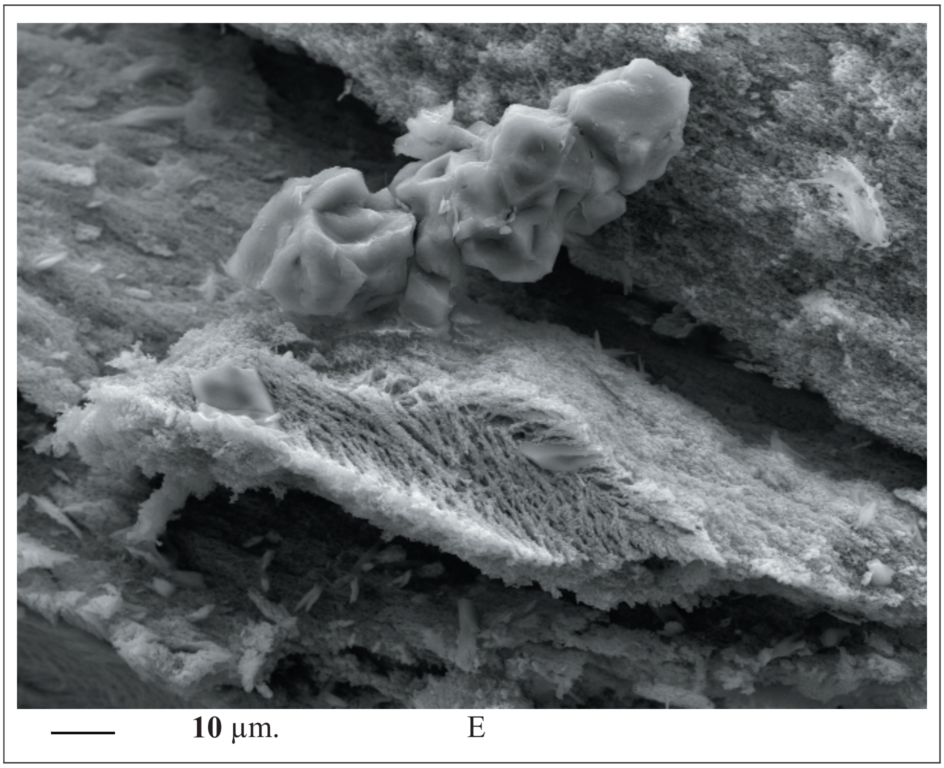


Figure 36. SEM images of Hibashi cave minerals: C- arcanite sub-spherical aggregate (Hi12); D- diadem aggregate of prismatic tetragonal crystals of biphosphammite (Hizz).



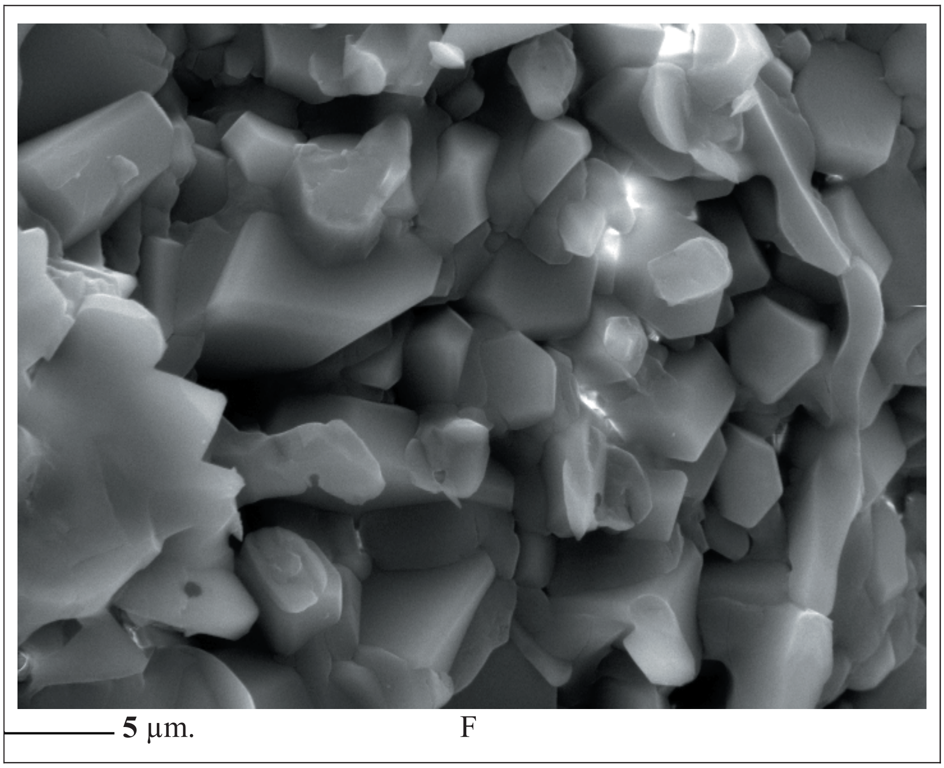


Figure 36. SEM images of Hibashi cave minerals: **E-** fibrous fish-bone shaped crystals of chlorapatite and elongated aggregate of calcite crystals (Hi7); **F-** pseudo-hexagonal crystals of chlorapatite.

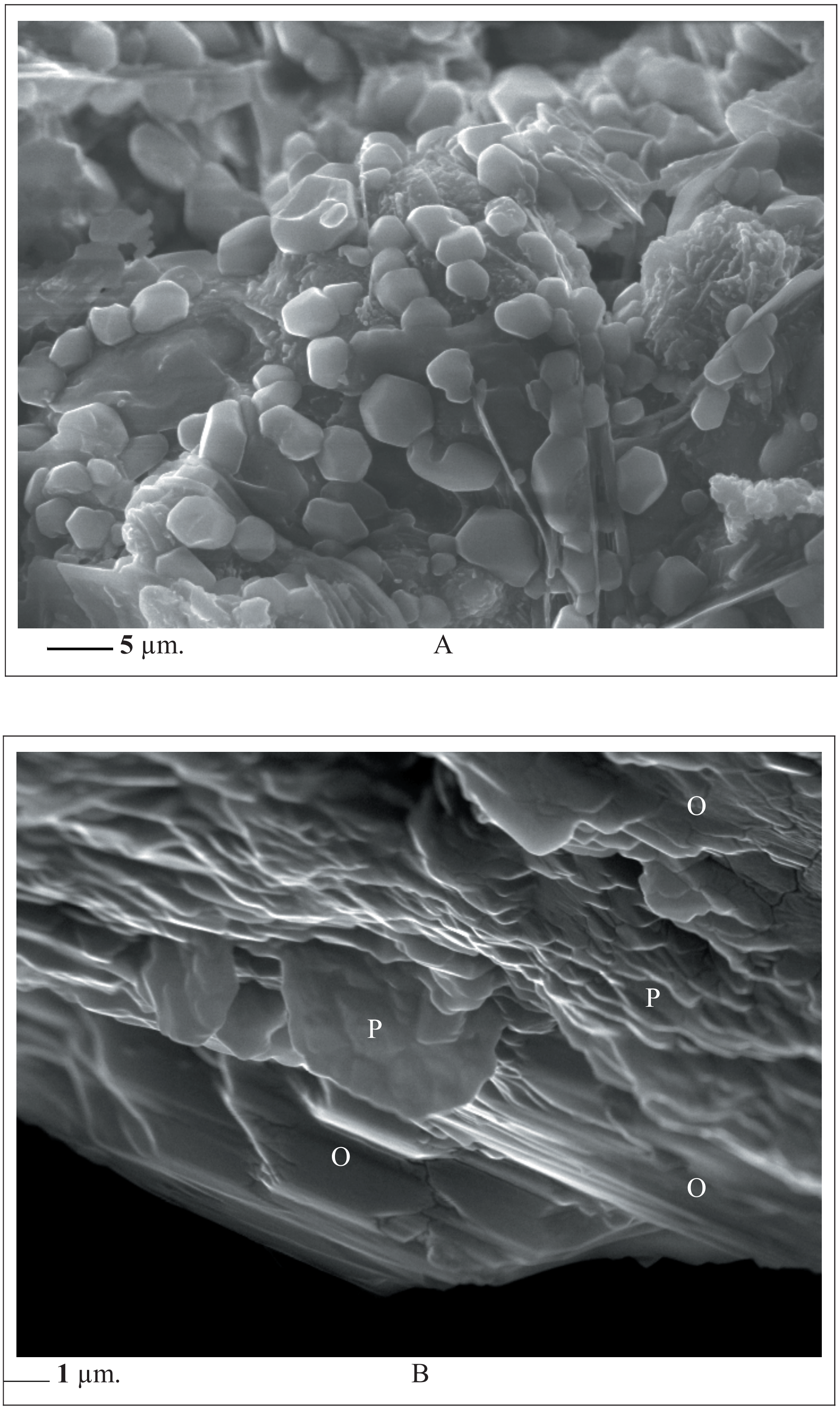


Figure 37. SEM images of Hibashi cave minerals: **A-** globular crystals of halite on chlorapatite (Hi7); **B-** Admixture of platy indented crystals of pyrocoproite (p) and tabular opal-C.

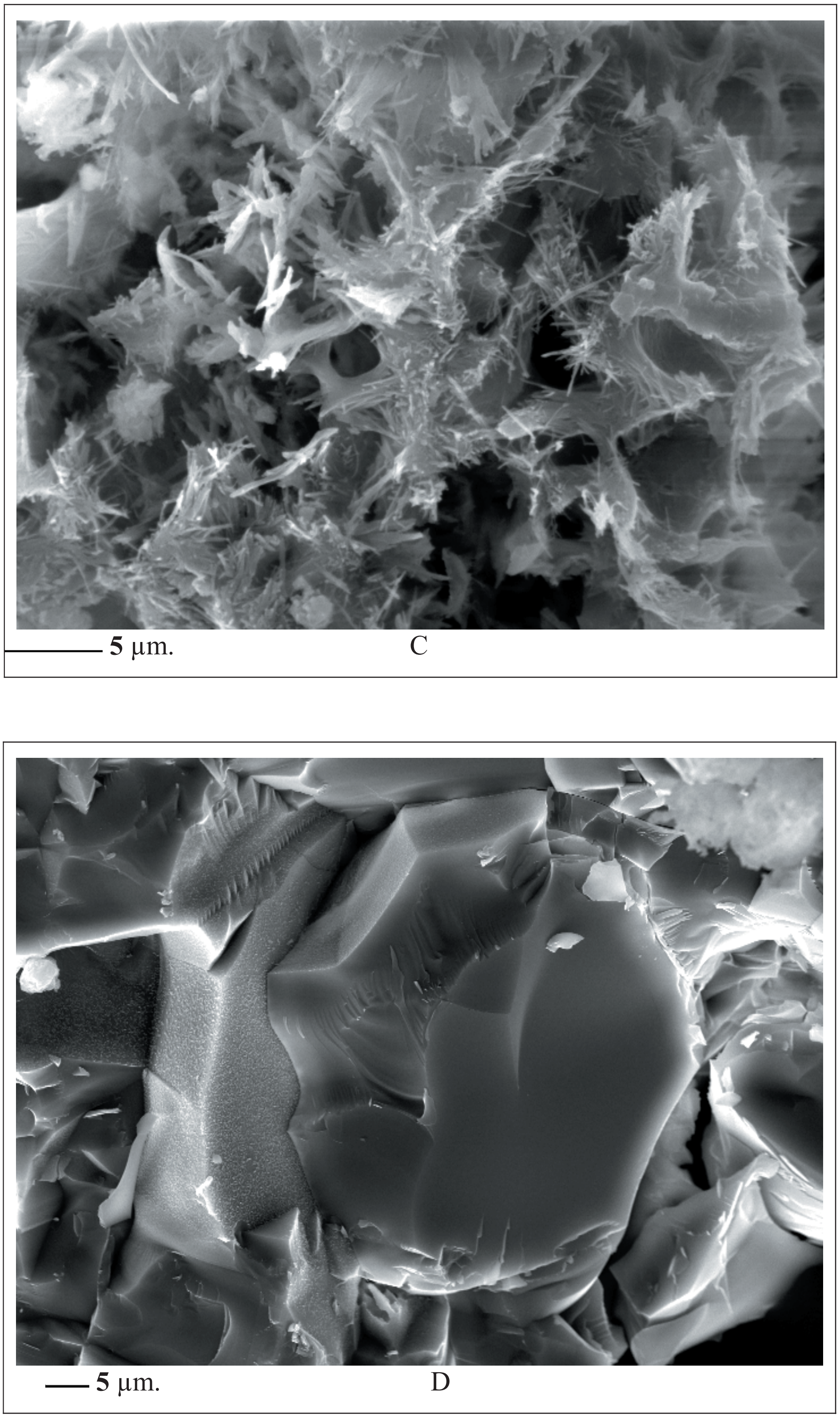
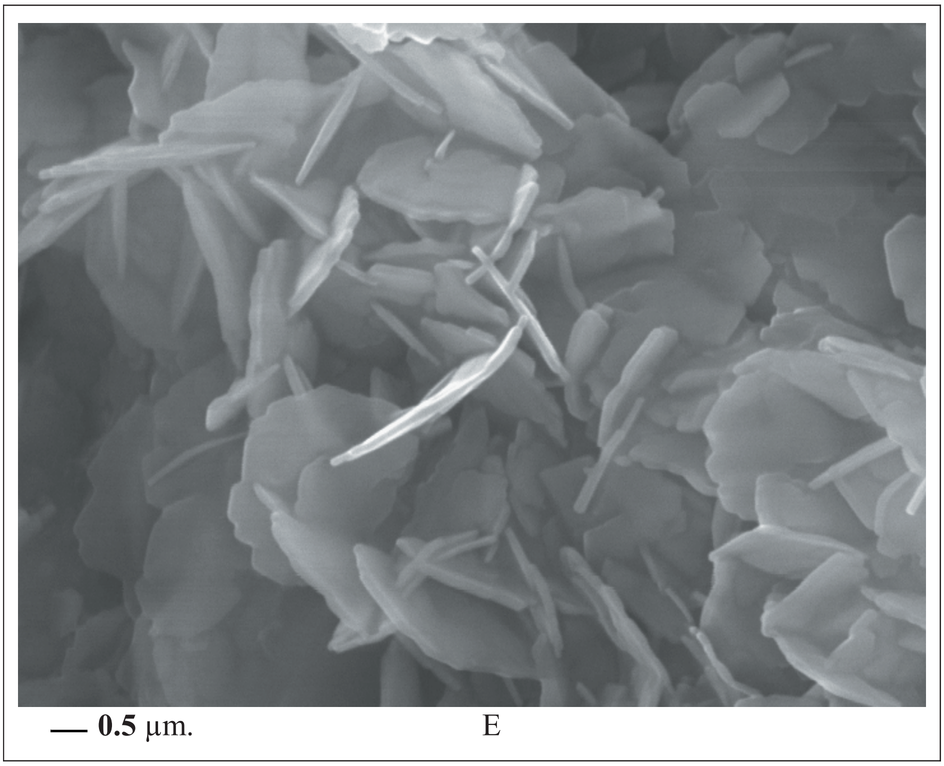


Figure 37. SEM images of Hibashi cave minerals: C- snow-white soft tufts of acicular crystals of palygorskite (Hi7); D – pyrocoproite crystals with concoidal fracture (Hi8).



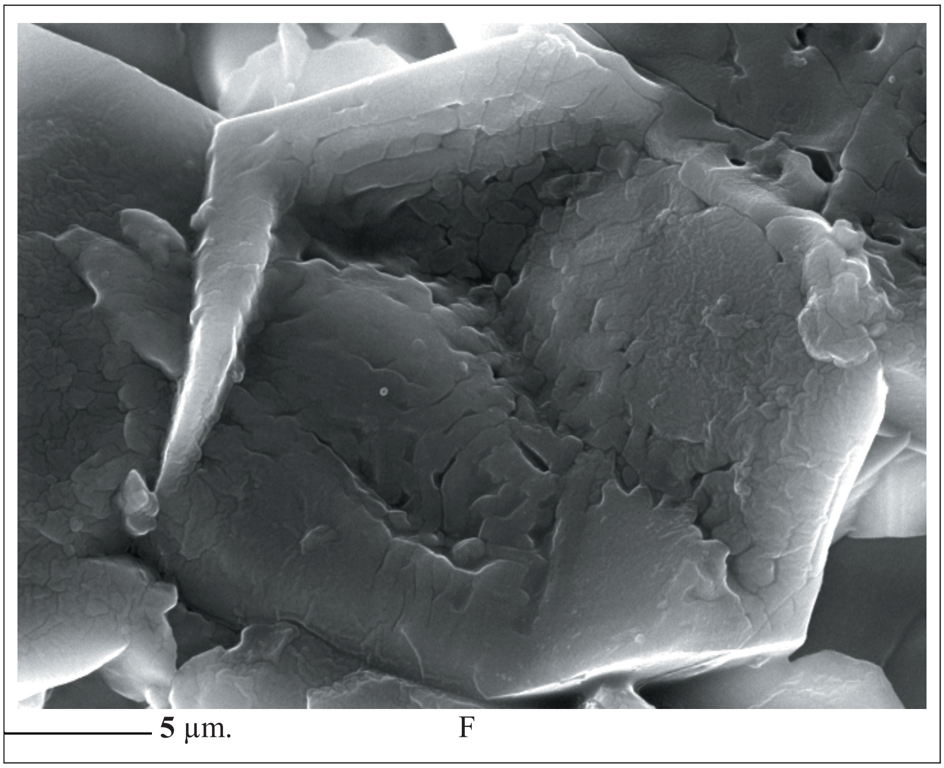


Figure 37. SEM images of Hibashi cave minerals: **E-** interpenetrating group of platy indented pyrocoproite crystals; **F-** close view a pyrocoproite pseudo-hexagonal aggregate of platy indented laminar crystals with helicoidal structure (Hi8).

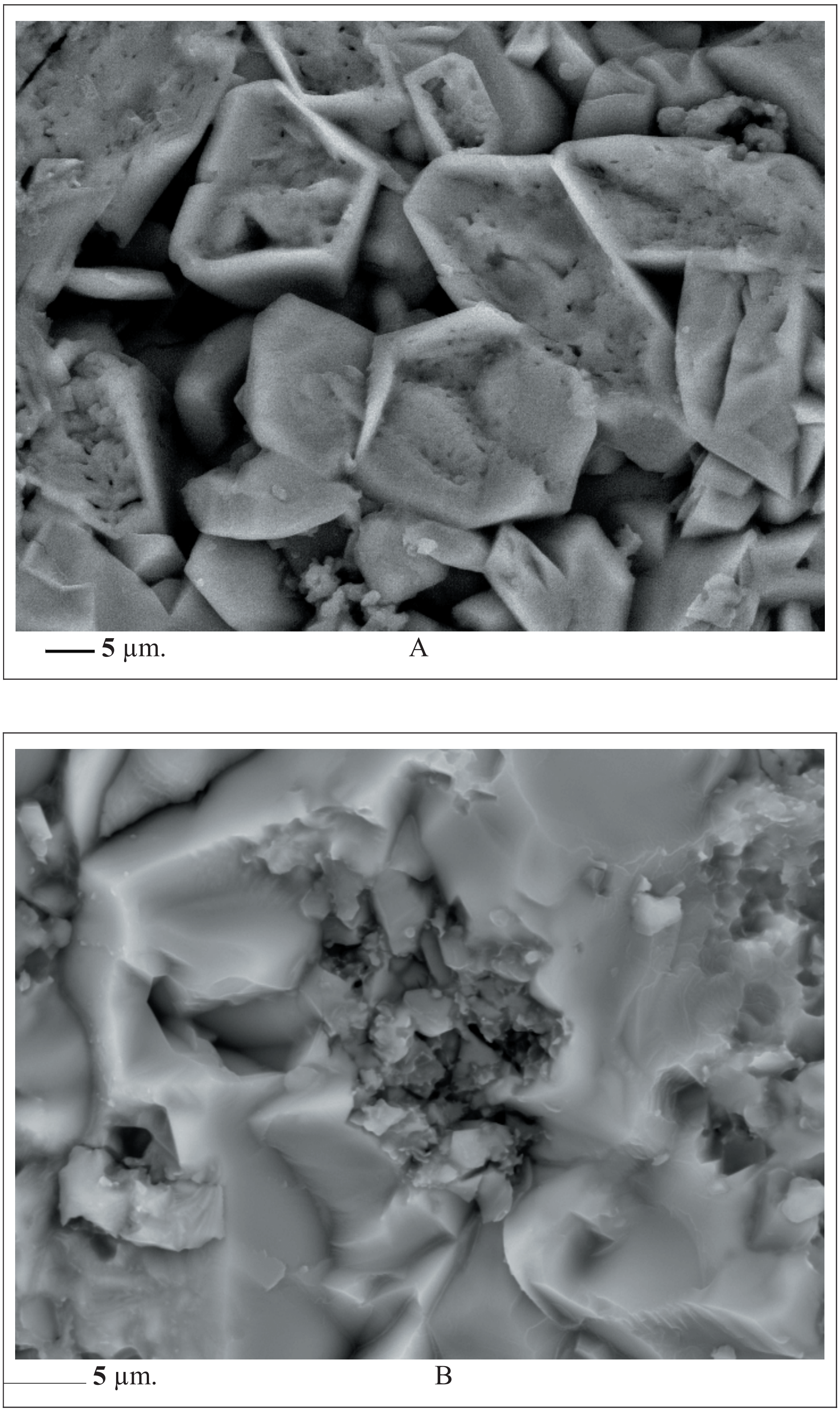


Figure 38. SEM images of Hibashi cave minerals: **A-** pyrocoproite pseudo-hexagonal aggregates of platy indented crystals (Hi8); **B-** compact pyrophosphite with small opal-C spheres inside the hole (Hi8).

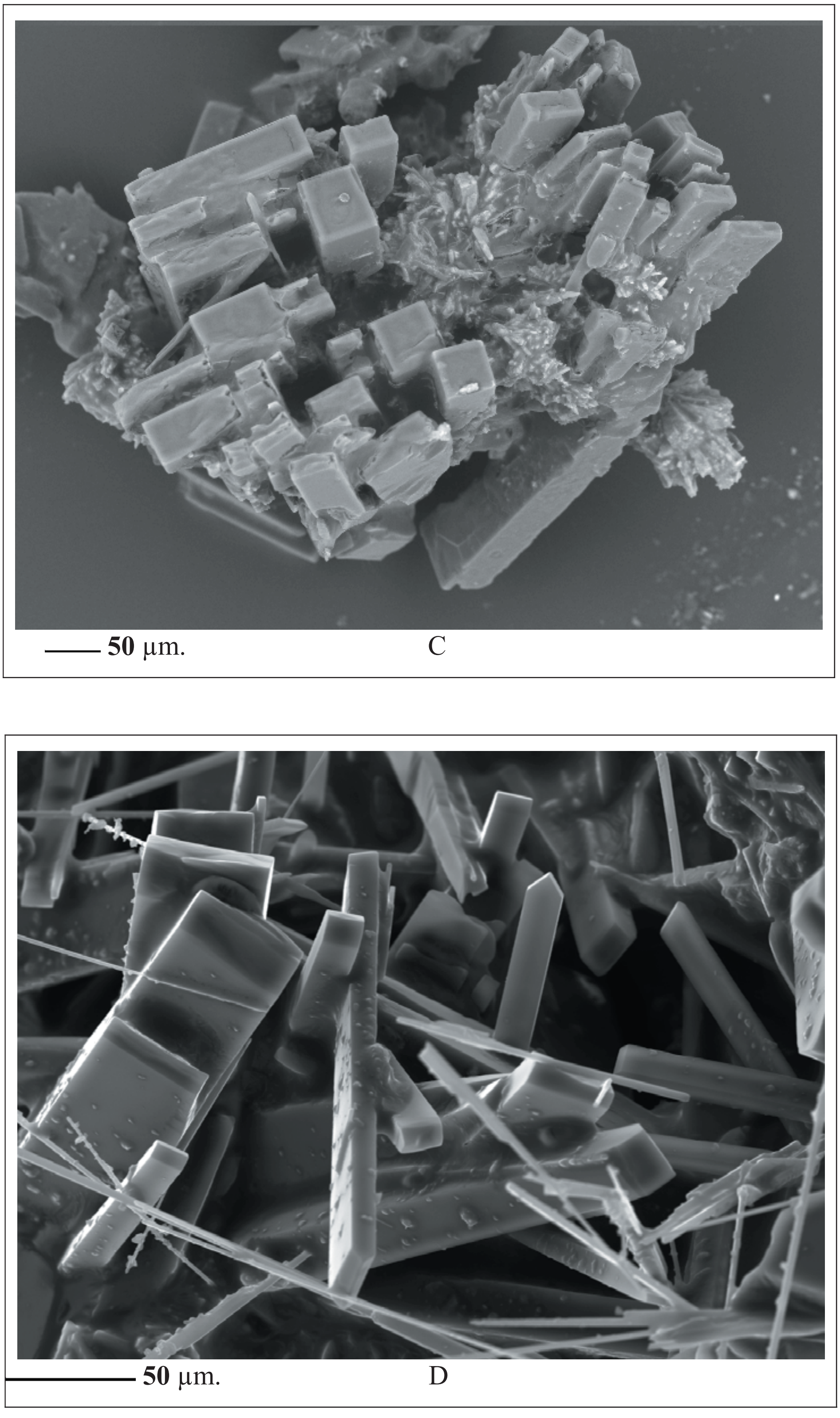


Figure 38. SEM images of Hibashi cave minerals: **C-** tetragonal prismatic crystals of urea (Hi15); **D-** tetragonal prismatic crystals of urea with thin elongated crystals of a still unknown compound (Hi15).

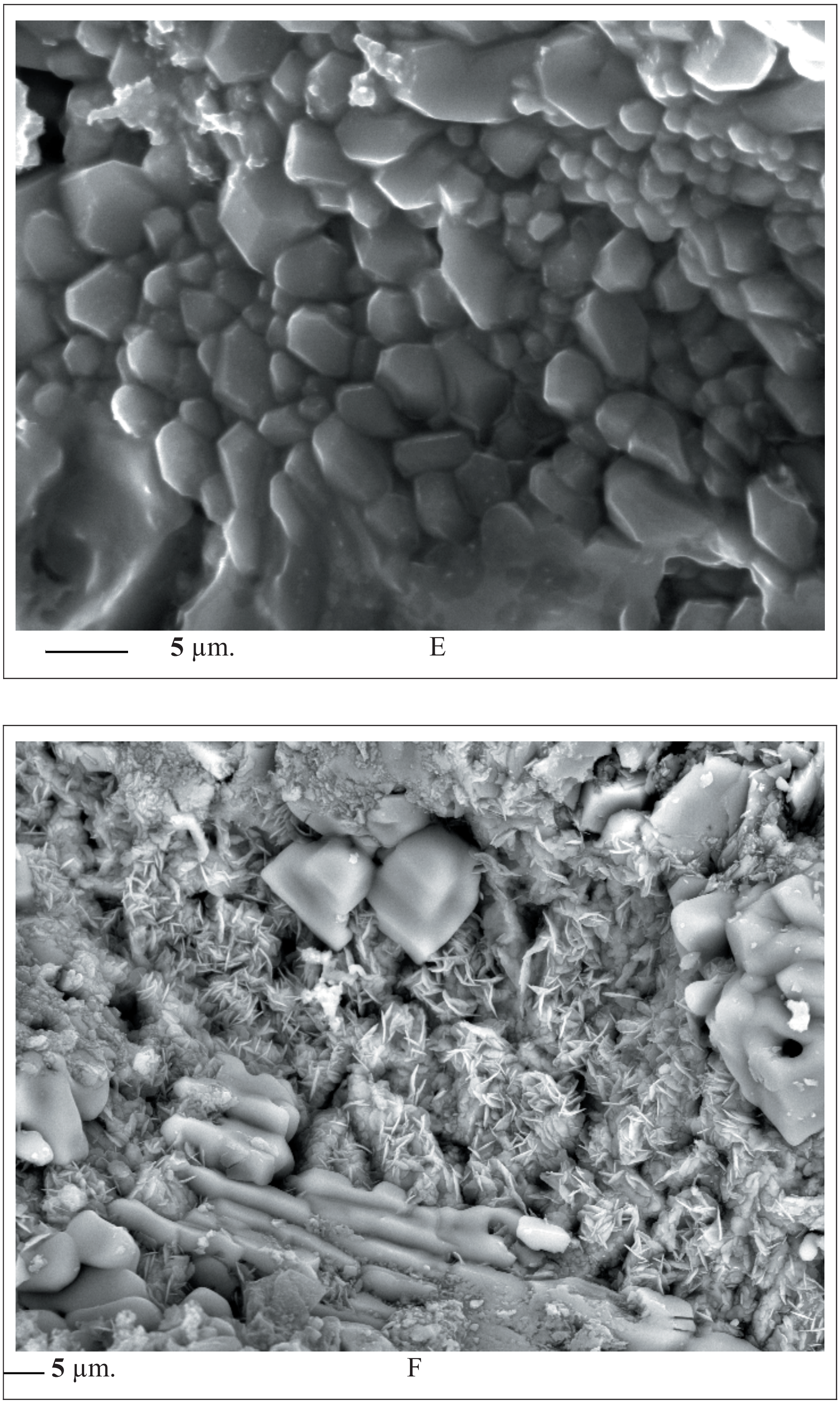


Figure 38. SEM images of Hibashi cave minerals: **E-** crust of globular crystals of Mg-rich whitlockite (Hizz); **F-** felt of thin platy crystals of pyrocoproite with large auhedral still undetermined crystals (Hi8).

Figure 39. Dried mud on the floor of Romahah Lava Cave in Harrat Khaybar.

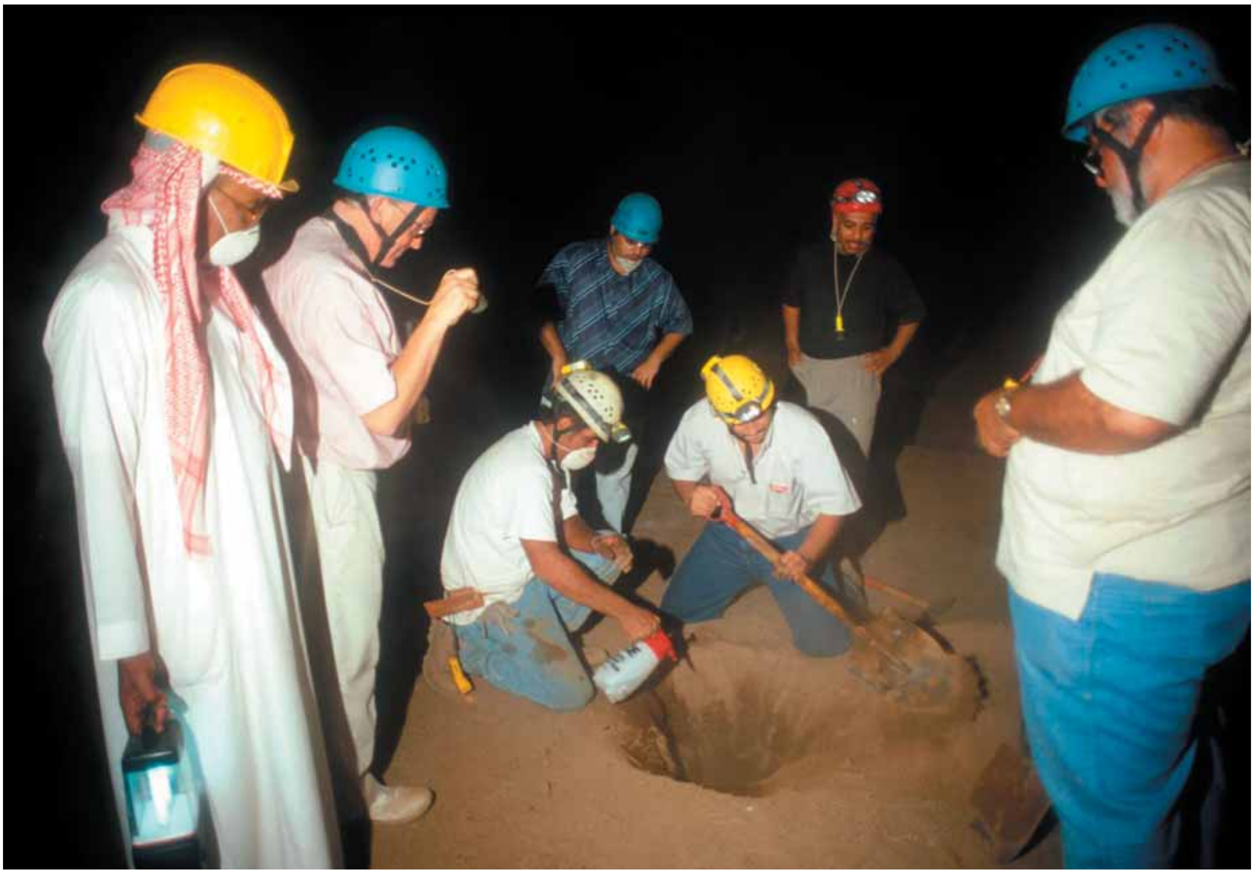


Figure 40. Pressurized water sprayer used to prevent collapse of loess walls.

Figure 41. Loess sample pushed into PVC tube for later OSL age dating.

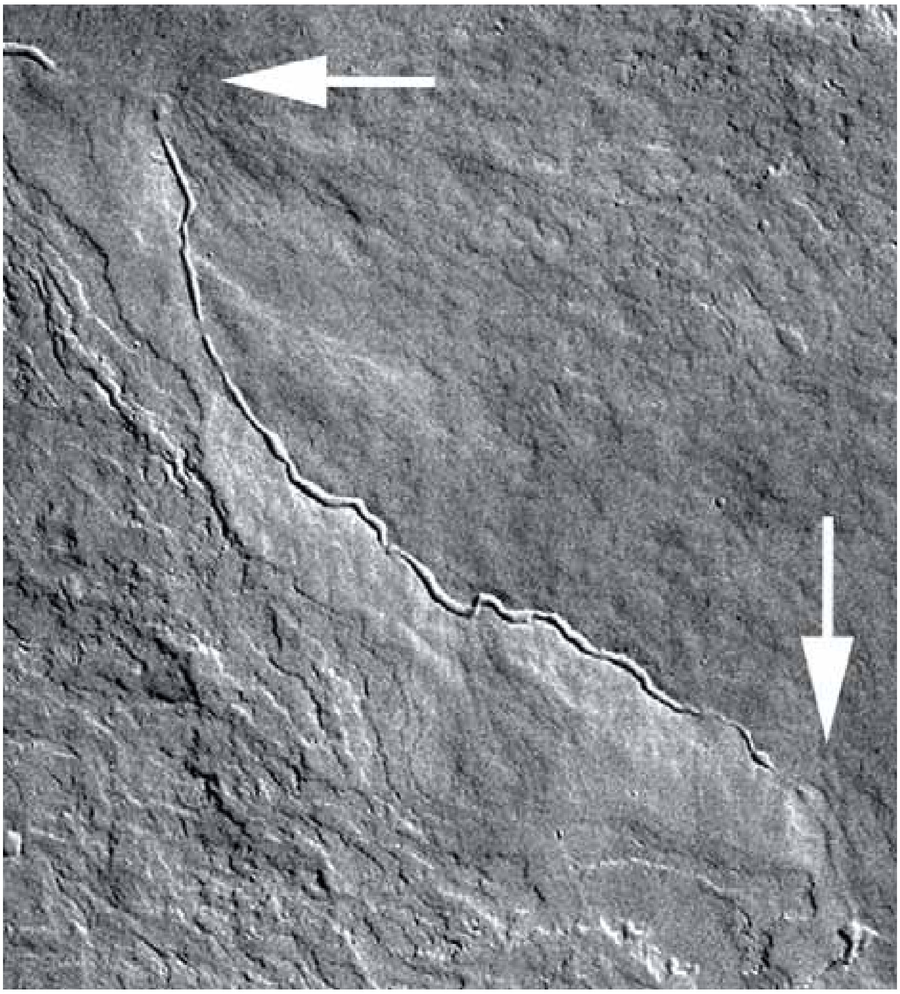


Figure 43. A visible light THEMIS image from the East lower flank of Olympus-Mons on Mars, showing clearly visible collapsed lava channels. Arrows indicate non-collapsed portions with extended channels beyond. The channel width averages around 100 to 200 meters and the upper non-collapsed lava tube is about 20 km long. Because of its thick bed of loess, Hibashi Cave is being used as a model for testing microrobots which will be sent into Martian caves. Photo courtesy NASA/JPL/ASU (THEMIS Frame V01028006).

Figure 42. Iron rod used to measure depth of loess (1.5m) at second hole.

APPENDICES

APPENDIX 1

ANIMAL AND AVIAN EXCRETA IN GHAR AL HIBASHI

The arid climate of Saudi Arabia results in relatively low humidity within most of the country's caves and, therefore, the preservation of much of the caves' contents which, under wetter conditions, would be destroyed by decomposition or water movement. The humidity of Hibashi Cave, for example, is typically 48 percent.

Animal and avian excreta introduced into the cave environment have been remarkably well preserved in Hibashi Cave and merit study, as will be explained below. In contrast, so little evidence of the presence of fauna has been found inside most of the world's caves, that the official List of Cave Symbols of the International Union of Speleology (UIS) has only one symbol for excreta, a v-shaped drawing which represents the guano of bats or birds. Hibashi Cave, however, contains the desiccated excreta of at least six species in such quantity that they are useful not only as landmarks, but also for understanding the history, climate, flora and fauna of the area, both inside and outside the cave. Unlike typical coprolites, this dry scat can easily be broken apart and its contents examined.

By far the most frequently found type of scat is tan, sometimes white, in color, less than 4 cm long and less than 2 cms wide, sometimes tapered at one end (fig. A1-1). Benischke found large quantities of similar scat in B7 (or Murubbeh) Cave, located on Saudi Arabia's Summan Plateau. Toothmarks on bones found near these droppings led experts in Austria to identify them as hyena scat (Benischke and others, 1988). Although hyenas are not normally found in most parts of Saudi Arabia today, they can still be seen in the southwestern part of the kingdom where they are considered unwelcome predators. In 1998, speleologists observed the body of a recently killed hyena hanging in the air near Al Jawah village, approximately 103 kms SSW of Hibashi Cave (fig. A1-2). The great amount of hyena scat found in caves all over Saudi Arabia (Pint and Pint, 2004, Pint, 2000; Roobol and others, 2002; Al-Shanti and others, 2003) indicates that these animals were more prevalent in the past than they are today. Larger, cylindrically shaped scat, brownish in color, is less frequently found in Hibashi Cave. This is thought to be wolf scat, based on the opinions of local people regarding scat of similar size, shape and color found in other Saudi limestone and lava caves (Al-Shanti and others, 2003). Figure A1-3 shows the three types of animal feces most frequently found in Saudi caves. Hyena scat is seen on the left and wolf scat on the right. It seems likely that the scat in the middle is from a fox. Similar scat was found in Black Scorpion cave where foxes were observed outside the cave, at night. Live foxes were also seen near and inside Murubbeh/B7 cave where the desiccated body of an Arabian Red Fox was found (fig. A1-4). Carbon dating indicated the remains to be 1890±45 years old, suggesting that foxes have long lived deep inside caves in Saudi Arabia.

A bed of mixed sheep and goat droppings covers the area between stations 4 and 7 of the cave (fig. 10).

Bat guano covers large areas of the eastern and western extremes of the cave and played a key role in the development of hosted minerals inside the cave, as described above under Secondary Minerals of the Cave.

Mounds of rock-dove guano (fig. A1-5) are found between stations 3 and 4 and probably once covered a much larger part of the sun-lit portion of the cave, but have been destroyed, probably by human traffic.

Although most lists of cave symbols include only guano, the authors feel that the maps of certain desert caves should indicate the location of animal scat as well, and should differentiate between bat and bird guano. The rationale for this is the usefulness of these deposits for navigating in caves and the scientific value of excreta either as catalysts for the production of unusual minerals or as repositories of plant and animal remains. Hair and fur are often found in scat. In addition, P.Vincent (written commun., Nov. 2004) states that pollen has been found in hyena scat from Hibashi cave by researchers at Oxford University, U.K. The same researchers have also found phytoliths in plant fibers taken from the same source. According to Mulder and Ellis (2000), plant opal-phytoliths are of great value for the study of aridification, desertification, wind patterns, etc. Phytoliths are microscopic bodies that occur in the leaves, roots, etc. of plants. They are composed of opaline silica or calcium oxalates and have unique shapes that act as signatures for the plants that produced them.

In Ghar al Hibashi, the age of phytoliths may be determined from the vertical position of the scat in the bed of loess or by carbon-dating scat samples. Since plant fibers are commonly found in hyena and wolf scat (fig. A1-6), caves in Saudi Arabia and Hibashi Cave in particular, may provide a sufficient source of phytoliths for the study of climate change and desertification on the Arabian peninsula.

In keeping with the established usage of a bat/bird symbol to represent guano, symbols suggesting six animals or birds (fig. A1-7) were used in the map of Ghar al Hibashi to represent significant scat deposits. These symbols may also be useful for maps of other caves located in Saudi Arabia or areas with similar environmental conditions.

Figure A1-1. Presumed hyena scat, found lying on original floor at the bottom of 40 cms of loess.

Figure A1-2. Dead hyena near Al Jawah village, displayed high in the air, according to local custom.

Figure A1-3. Examples of typical scat found in Saudi caves: presumably hyena on the left, fox in the center and wolf on the right.

Figure A1-4. Desiccated Arabian Red Fox (Vulpes vulpes arabica) nearly 2000 years old, found in Murubbeh Cave.

Figure A1-5. Mounds of Rock-dove guano found in the twilight zone of Hibashi Cave.

Figure A1- 6. Plant fibers found inside hyena scat.

Figure A1- 7. Symbols suggested for caves containing significant animal scat; from the left: bat, bird, hyena, wolf, fox, sheep/goat.

APPENDIX 2

OBSERVATIONS ON A HUMAN SKULL FOUND IN GHAR AL HIBASHI

Parts of a human skull were found in Ghar al Hibashi by SGS geologist and author Abdulrahman Al-Juaid on January 7, 2003 (fig. A2-1). The two pieces were lying at the edge of a patch of sand 8 m NE of station 26 near the far eastern end of the cave. Because human skulls previously had been stolen from Murubbeh-B7 cave (see Forti and others, 2003, pp 18-19) and because Hibashi Cave has no gate and is occasionally visited by the general public, as indicated by graffiti at the cave entrance and inside, it was decided to remove the skull parts from the cave for safekeeping.

Photographs of the skull parts (figs. A2-2 and A2-3) were shown to Donald A. McFarlane, Associate Professor at the W. M. Keck Science Center, Claremont Colleges, California. McFarlane stated that both pieces were obviously human and appeared to be in quite good condition, even though the parietal and occipitals of the cranium were missing (D.A. McFarlane, written commun., 2003). He identified the smaller fragment as the back of the cranium, the hole being the magnum foramen into which the spinal column connects. McFarlane noted the cranium had apparently split off along the coronal and squamosal sutures, possibly suggesting a relatively young (adult) individual, since these sutures increasingly fuse with age. He also noted that the skull appeared to have only seven teeth per quadrate (fig. A2-4). The 3 molar which typically develops between 15 -21 years of age appeared to be un-erupted. Since the second molar comes through at about 11-12 years, McFarlane was of the opinion that the individual had been about 14-18 years old at the time of death.

Photographs of the teeth were also shown to Dr. Erik Bjurström, dental consultant, who noted that in this skull the canines were not fully erupted and baby tooth 5 was still in place. Bjurström estimated that the skull belonged to a person 12 to 14 years old, using norms that apply to modern man (L. Bjurström, written commun., 2003).

In 2003, samples were taken from the larger skull piece and sent to the Gliwice Radiocarbon Laboratory at the Institute of Physics of the Silesian University of Technology, Gilwice Poland. Collagen was successfully extracted from the sample and a radiocarbon age of 425±30 years BP was established (figs. A2-5 and A2-6).

As may be noted in figs. A2-7 and A2-8, the upper portion of the skull appears to have been removed with the help of a flat blade, such as from a sword or axe, suggesting the possibility of foul play in the death of this individual.

Figure A2-1. Human skull found deep inside eastern passage of Ghar al Hibashi.

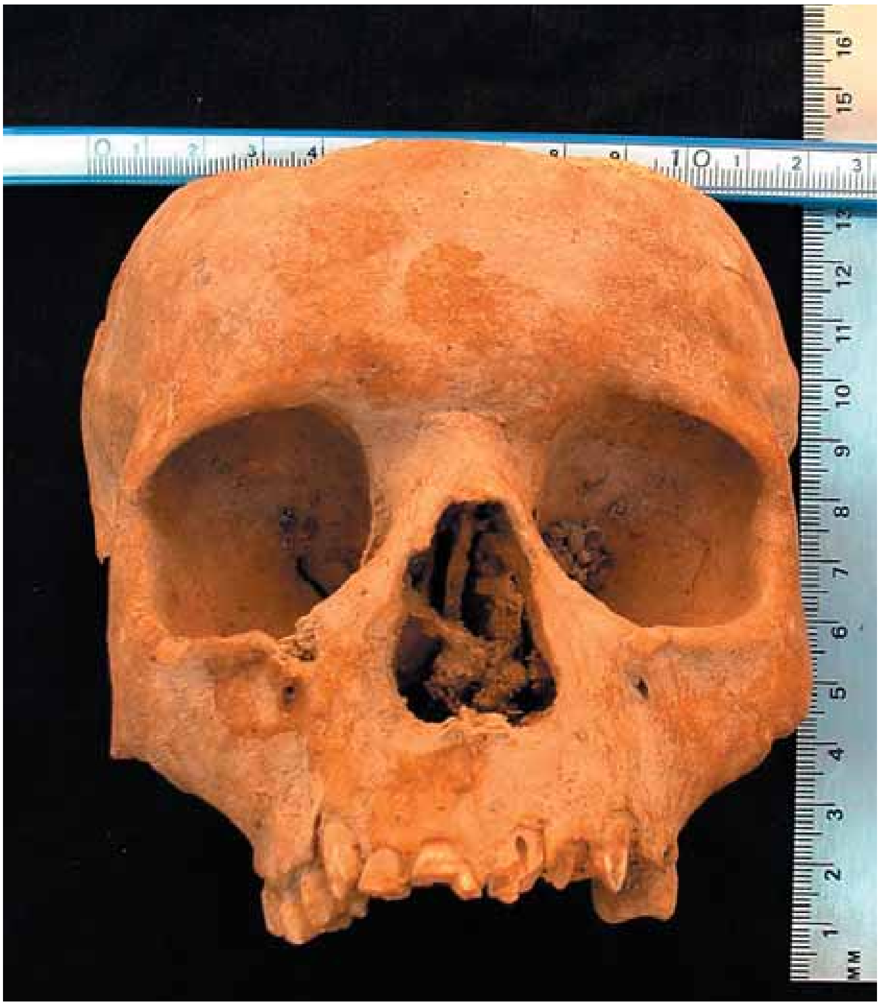


Figure A2- 2. Front view of cranium.

Figure A2-3. Skull fragment identified as back of cranium.

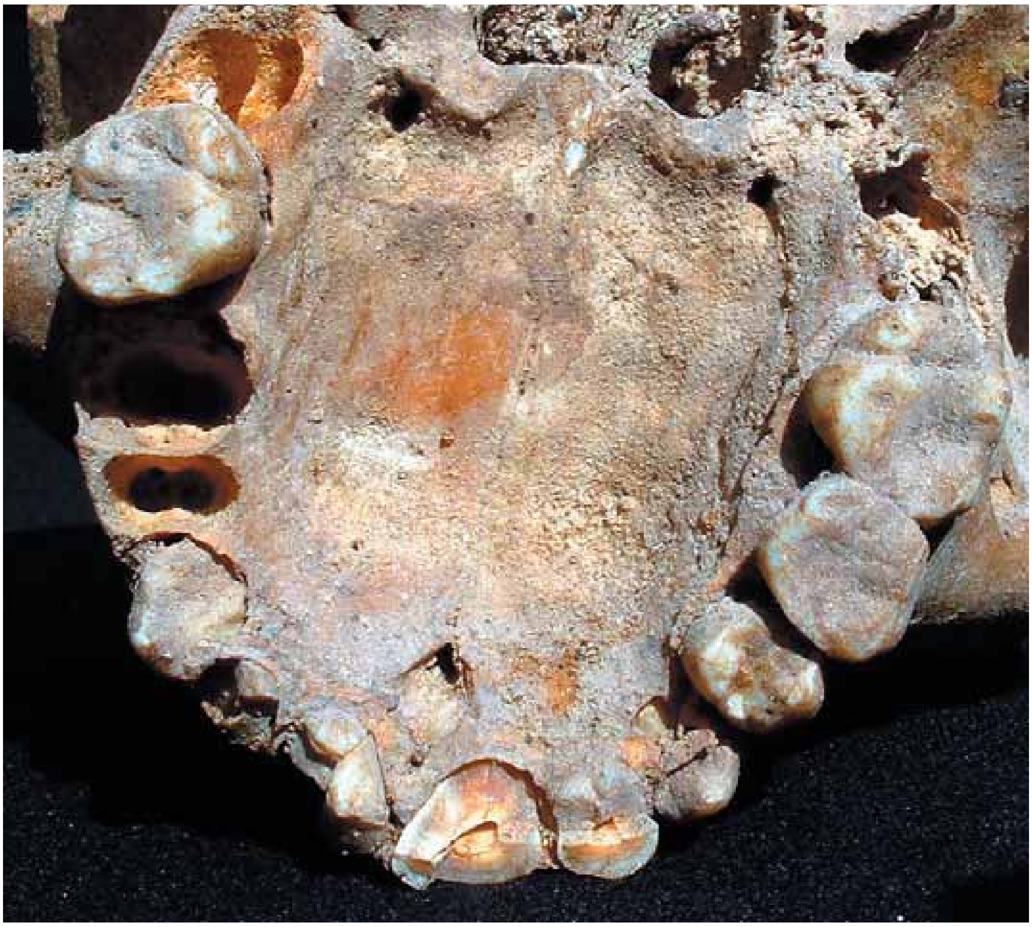


Figure A2-4. Teeth suggest this skull belonged to a person 14-18 years old.

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Gliwice, December 3rd, 2003

LABORATORY REPORT 45/2003

Submitter:

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Cave Exploration Unit
Saudi Geological Survey
P.O. Box 54141
21514 Jeddah
Saudi Arabia

Sample register number: 2139
Job number:

Sample name	Laboratory number	Radiocarbon age [years BP]
Hibashi Cave	GdA- 326	425 ± 30

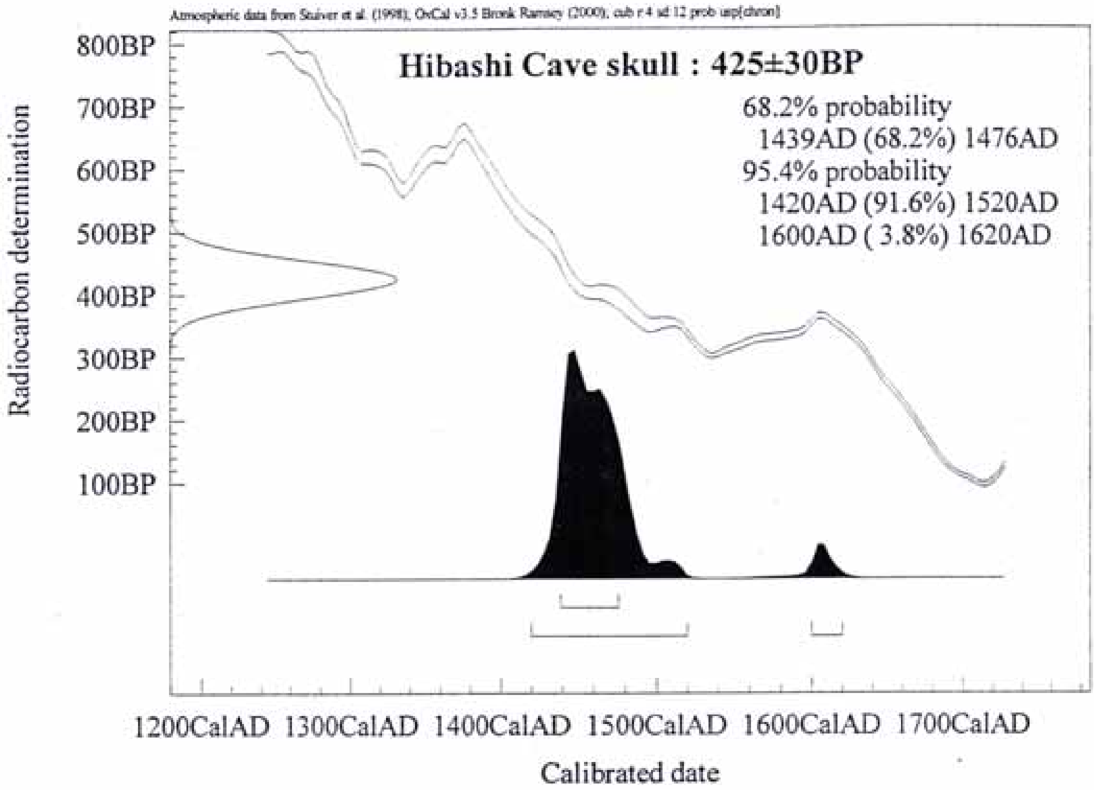
Head of Gliwice Radiocarbon Laboratory

Prof. dr hab. Anna Pazdur

Figure A2-5. Report from Gliwice Radiocarbon Laboratory on age of Ghar al Hibashi skull.

RESULTS OF CALIBRATION

References - Atmospheric data from Stuiver et al. (1998)
Programme: OxCal v3.5



Hibashi Cave skull: 425±30BP
68.2% probability
1439AD (68.2%) 1476AD
95.4% probability
1420AD (91.6%) 1520AD
1600AD (3.8%) 1620AD

Figure A2-6. Calibration results on age-dating of skull found in Ghar al Hibashi.

Figure A2-7. Side view of cranium; top appears to have been sliced off.

Figure A2-8. Top view of cranium.