THE DEVELOPMENT OF TOURIST CAVES IN THE KINGDOM OF SAUDI ARABIA

By

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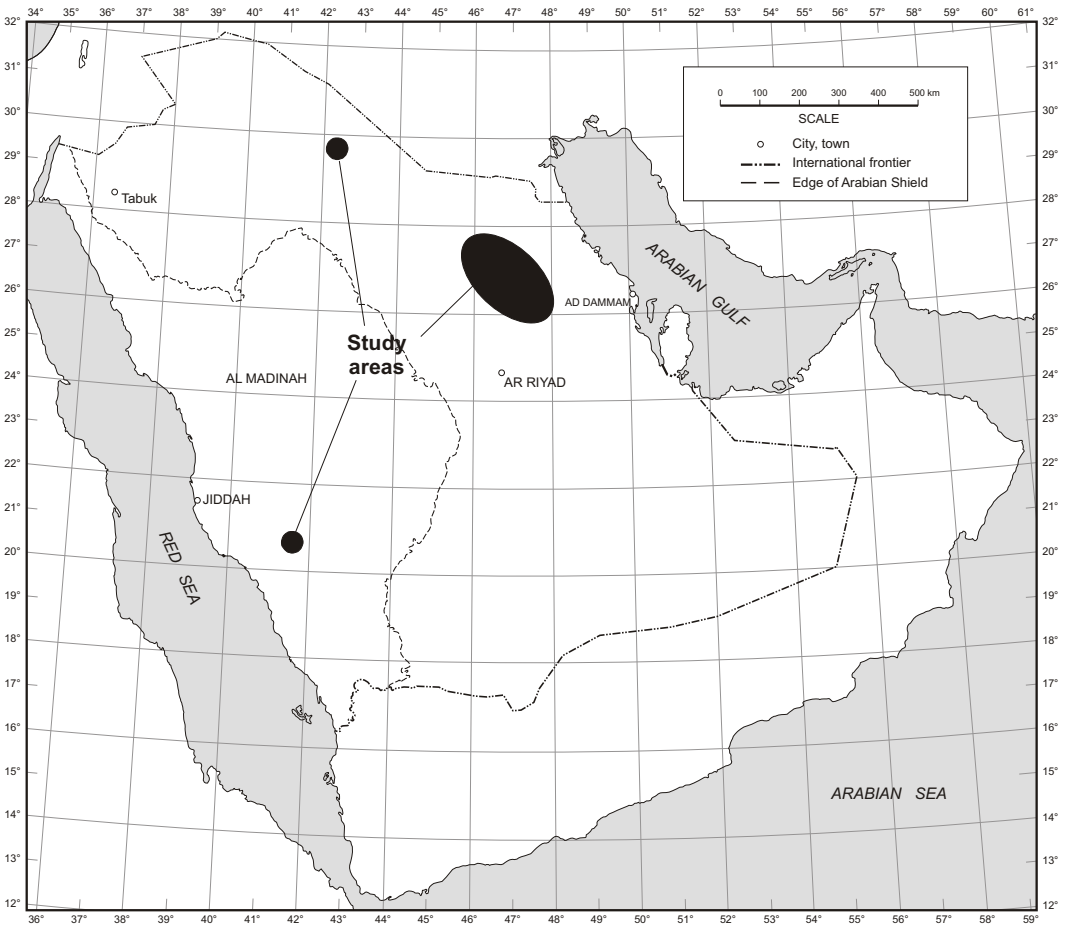

Index map of the Arabian Peninsula

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By

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ABSTRACT

Cave tourism is rapidly expanding all over the world and for many countries is a significant element of their economy. Presently, over 90 nations have show caves and their number is increasing year by year.

Saudi Arabia has large karst areas and lava fields richly endowed with natural cavities, whose size and characteristics seem to be suitable for easy transformation into show caves. On the basis of a recent survey of known caves, it is recommended that cave tourism in Saudi Arabia begin with the development – in stages – of three caves on the As Sulb Plateau, some 250 km north of Riyadh. These caves could accommodate as many as one thousand visitors per day. They could be developed at a reasonable cost and without damage to the karst environment or to the caves themselves. Besides providing a new form of family recreational activity for the Kingdom, cave tours would provide an educational insight into an underground environment almost unknown to the general public. Such show caves would be attractive to tourists because of well-developed speleothems, which most people have not hitherto seen, as well as the opportunity to have time to relax in underground cavities that have interior climates cooler and more pleasant than the climate on the surface for much of the year. Furthermore, sensitive development of show caves in the area would serve to help protect certain karst areas (which recharge important aquifers) from pollution and other damage that may occur due to natural or man-made causes.

The development project would principally aim at attracting visitors from among the millions of inhabitants of Riyadh, which is now connected to the As Sulb cave area by paved roads.

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مقترحات لتطوير الكهوف السياحية
في
المملكة العربية السعودية

إعداد

باولو فورتي وجون بنت ومحمود الشنطي وعبد الرحمن الجعيد وسعيد العمودي وسوزان بنت

خلاصة

تتوسع سياحة الكهوف بسرعة كبيرة في كافة أرجاء العالم وتمثل بالنسبة للعديد من الدول رافداً اقتصاديا هاماً. وفي الوقت الحالي تتواجد الكهوف السياحية في أكثر من ٩٠ بلداً ويتزايد هذا العدد عاماً بعد عام.
توجد بالمملكة العربية السعودية مساحات شاسعة من صخور الحجر الجيري وحقول اللابة البازلتية الغنية بالتجاويف الطبيعية ذات الأحجام والخصائص التي تبدو مناسبة بحيث يسهل تحويلها إلى كهوف سياحة.
وبناءًا على المسح الذي تم مؤخراً لبعض الكهوف فإننا نوصي بأن تبدأ سياحة الكهوف في المملكة بالتطوير المرحلي لثلاثة كهوف في هضبة الصمان على بعد حوالي ٢٥٠كيلومتراً شمال مدينة الرياض. ويمكن أن تستوعب هذه الكهوف ما يصل إلى ألف زائر في اليوم. وبالإمكان تطويرها بتكلفة معقولة ودون إلحاق أي ضرر ببيئي بها. وإضافة إلى أنها تتيح شكلاً جديداً من النشاط الترويحي للعائلات في المملكة فإن الرحلات الكهفية تعتبر مدخلاً تعليمياً للبيئة الجوفية التي تكاد تكون غير معروفة لعامة المواطنين. كما أن مثل هذه الكهوف سوف تجذب السياح نظراً لجمال مكوناتها الكاملة التطور والتي لم يشاهدها معظم الناس من قبل، إضافة إلى الفرصة التي يحظى بها زوار هذه الكهوف والتمتع داخل فجواتها التي تمتاز بدرجات حرارة داخلية معتدلة وهواء عليل مقارنة بالطقس السائد على السطح خلال معظم فصول السنة. وبالإضافة إلى ذلك فإن تطوير الكهوف السياحية في تلك المنطقة سوف يساعد على حماية مناطق معينة من صخور الحجر الجيري (تلك التي تغذي خزانات المياه الجوفية الهامة) من التلوث والتلف اللذين قد يصيبان تلك المناطق إما بفعل العوامل الطبيعية أو بفعل الإنسان.
إن الهدف الرئيسي لمشروع التطوير يجب أن ينصب على اجتذاب الزوار من بين ملايين السكان المقيمين في مدينة الرياض التي تربطها حالياً طرق معبدة بمنطقة الكهوف في هضبة الصلب.

INTRODUCTION

Over the last hundred years, social interest in cave environments has grown significantly in many parts of the world, from the scientific as well as the economic point of view, and cave tourism is rapidly expanding. At present, over 90 nations in 5 continents have tourist caves (also referred to as show caves) and their number is increasing year by year (Cigna and Burri, 2000).

Tourism related to show caves and natural parks in karst areas has grown particularly in the past 60 years and presently represents an important source of income in the budget of several countries. Table 1 gives an estimate of the present-day main parameters of cave tourism, which should be probably at least doubled if natural parks with karst attractions are also considered.

Table 1. Evaluation of the Economic Importance of Show Caves in the World (after Cigna and others 2000, modified)

Total number of show caves	~800
Number of "important" show caves (over 100,000 visitors/year)	~100
Total number of visitors/ year	~170,000,000
Money spent yearly for visiting show caves (€)	~1,700,000,000
People directly employed in show caves management	~100,000-200,000
People whose salary comes indirectly from show caves	~100,000,000

Saudi Arabia has extensive karst and volcanic areas (fig. 1) richly endowed with natural cavities, but presently none of them has been transformed into a show cave, with the exception of Ghar al Nashab or Al Qara Cave, a fissure some 160 meters long and up to 30 meters high, located in Al Hasa, in the Eastern Province.

GENERAL CHARACTERISTICS OF CAVES IN SAUDI ARABIA

Most of the known caves in Saudi Arabia are found in the limestone karst landscape of the As Sulb Plateau located 200-300 km north of Ar Riyadh. The plateau is underlain by light gray to white foraminifera-bearing, fine-grained, calcarenitic limestone, dolomitic limestone, and dolomite belonging to the Umm er Radhuma Formation (Paleocene-early Eocene) and calcareous sandstone, marl, and limestone belonging to an as yet unnamed formation of Miocene-Pliocene age.

These limestone beds extend from the northern border of Saudi Arabia to the Rub al Khali desert and west from the Gulf to the Dahna Desert. The greatest concentration of limestone caves is in a karst area located 230 kms north of the capital, Riyadh. Some of these caves are smooth-walled pits, 10-15 meters deep, formed in the Umm er Radhuma limestone. Others are horizontal passages and mazes up to several hundred meters in length, commonly with rocky protrusions from the side walls, ceiling, and floor and at some localities decorated with calcite stalactites, stalagmites, and helictites, which tend to occur in the unnamed Miocene-Pliocene formation.

Cavities elsewhere in Saudi Arabia include isolated deep pits as much 100 m deep forming one-room caves without side passages or speleothems, for example the Dharb al Najim Pit near Majma'ah; water-filled caves beneath the present-day water table, such as those near the city of Al-Kharj, one of which (Ain Hit) has been the site of several cave dives; and caves in the northern part of the country, which may have been created or influenced by the dissolution of gypsum.

Another type of cavity is represented by hollow lava tubes in the lava fields of western Saudi Arabia. The Kingdom has over 85,000 km^2 of *harrats*, or lava fields, and preliminary exploration has located five lava tubes in Harrat Kishb, and other tubes in Harrats Khaybar, Ithnayn, and Buqum, the longest measuring over 500 m in length.

Saudi caves give shelter to bats, rock doves, owls, wolves, foxes and hyenas, and in both limestone and lava caves, speleologists have found human skulls, naturally mummified animals, and possibly Neolithic artifacts.

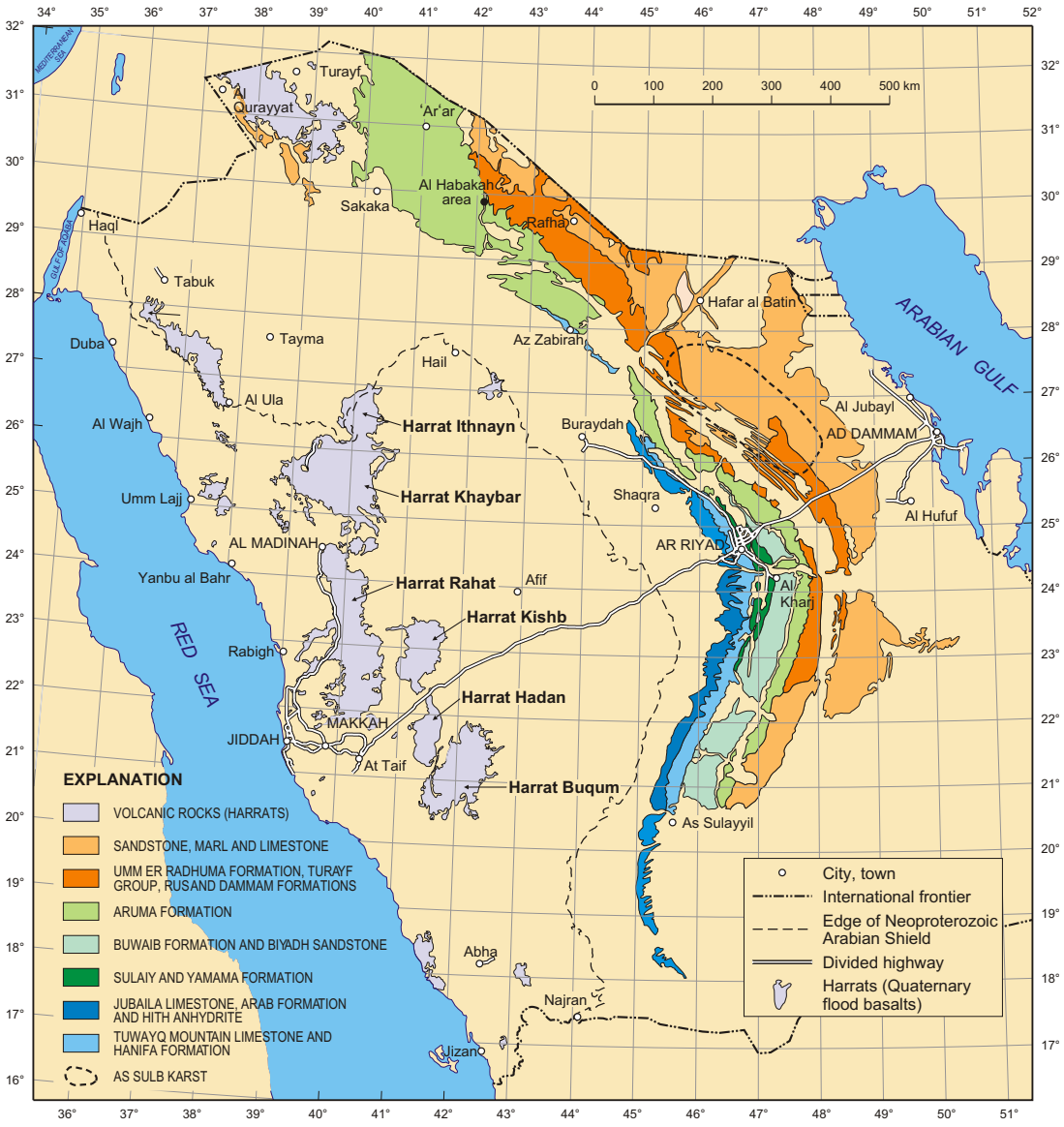


Figure 1. Geological map of Saudi Arabia showing the As Sulb karst region, the area with the highest known concentration of limestone caves.

Many of the caves in Saudi Arabia have been known for a long time by the local populations and used as sources of shelter and water (Pint, 2003), as evidenced by the presence of deep erosional furrows on the walls of many of the cave openings where ropes were used to haul water to the surface. However, speleology as a systematic discipline is a recent activity. The first explorations started only about 20 years ago, followed by more scientifically planned and organized investigations by the Austrian Academy of Sciences, King Fahd University of Petroleum and Minerals and, most recently, the Saudi Geological Survey.

In 2000, the Cave Unit of the Saudi Geological Survey began to investigate the tourist potential of several caves in the limestone karst area of the As Sulb Plateau resulting in the description of Kahf al Rutuwbah and B32 Cave (Pint and others, 2002). A subsequent expedition, described in this report, was made to the same karst area in March 2003 as a joint expedition between the Saudi Geological Survey and the Italian Institute of Speleology (SGS-ISS) in order to assess the tourist potential of selected caves and to outline a plan for their commercial development (Forti, 2003).

THE CAVES OF THE AS SULB PLATEAU

The center of the Summan plain, referred to as the As Sulb Plateau, is located some 250 km north of Riyadh, to which it is linked by a recently constructed asphalt road. The area is a flat rocky desert with local sand deposits mainly occuring within small depressions. The outcrops consist mainly

of limestone of the Um er Radhuma formation (Paleocene-lower Eocene) and younger carbonate formations (Miocene-Pliocene). Following deposition and lithifaction, the rocks underwent pervasive recrystallization and dolomitization with partial decalcification (Schifsma, 1978). The strata are normally bedded (10 cm in average) and generally display a sub horizontal dip. Rock surfaces do not show typical karst microforms: karren and solution pans are absent and small corrosion holes are present only where the outcropping rock is well cemented.

Nonetheless, the whole area is perforated by hundreds of semicircular holes, with diameters ranging between 20-30 cm and 2 m, that lead to small vertical pits caused by dissolution of the carbonate rocks and resulting in the karstic landscape of the Plateau as described by Peters and others (1990). However, few of the cavities on the As Sulb Plateau have been explored or accurately located. Fewer than one hundred caves have been documented (Pint, 2003a), but on the basis of the widespread evidence of karstic processes, it is estimated the region has potentially ten to a hundred times more caves.

In some cases, the breakdown of the superficial strata gave rise to more or less developed collapse dolines, which represent easy entrances to the underlying karst systems. Presently the longest surveyed cave in this area is approximately 1 km in length, but it is likely that further exploration will discover larger cave systems. At present, the maximum depth reached is 160.9 m below the surface, but this depth may also be exceeded in the future.

During the SGS-ISS expedition, four caves with show-cave potential were visited: Friendly, Surprise, Rutuwbah/Gecko, and Murubbeh/B7 Caves.

Figure 2. A tray speleothem found in Surprise Cave, featuring clusters of popcorn on grape coralloids and frostwork resting on a flat, horizontal tray-like surface.

The first three of these caves exhibit a network of subhorizontal galleries, with maximum diameters of 3-4 m. The structure of these cavities indicates that standing water filled these galleries for a long period of time, allowing for the evolution of corrosion features such as holes, pendants, and blades. Karstification created a bidimensional labyrinthine network of galleries all at the same level and probably interconnected to one other, which, in turn, suggests, that the entire As Sulb Plateau contained a shallow aquifer close to the surface at depths of 10-20 m below the surface. The presence of a perched water level near the surface over an extended period of time is demonstrated by the many natural wells (duhul) scattered throughout the area. These were used as sources of water, although the water table is now considerably lower and below the general level of the caves because of rapid drawdown in recent years. The cavities themselves were created prior to the evolution of the perched water table, and dating (Fleitmann, 2002) of currently inactive (Benischke and others, 1997), large speleothems suggests seepage into the caves ceased more than 400,000 years ago.

Almost all the calcite speleothems in the known caves are fossils. Among the few still active formations are gypsum speleothems presently found mainly in Surprise Cave, among which a large tray (fig. 2) and a hollow stalagmite (tremagmita) are worthy of mention. Another active formation is a small gour pool surrounded by several pockets of cave pearls, located in UPM Cave.

The presence of secondary gypsum deposits is a common feature in all the caves of Al Sulb Plateau, most commonly taking the form of millimeter-thick crusts covering the walls and ceilings. In places monocrystalline stalactites or flowers consisting of elongated fibres are also present. Why gypsum deposits are so common in these caves is not well understood, but their development is likely to be related to the presence of anhydrite in the bedrock of the catchment area.

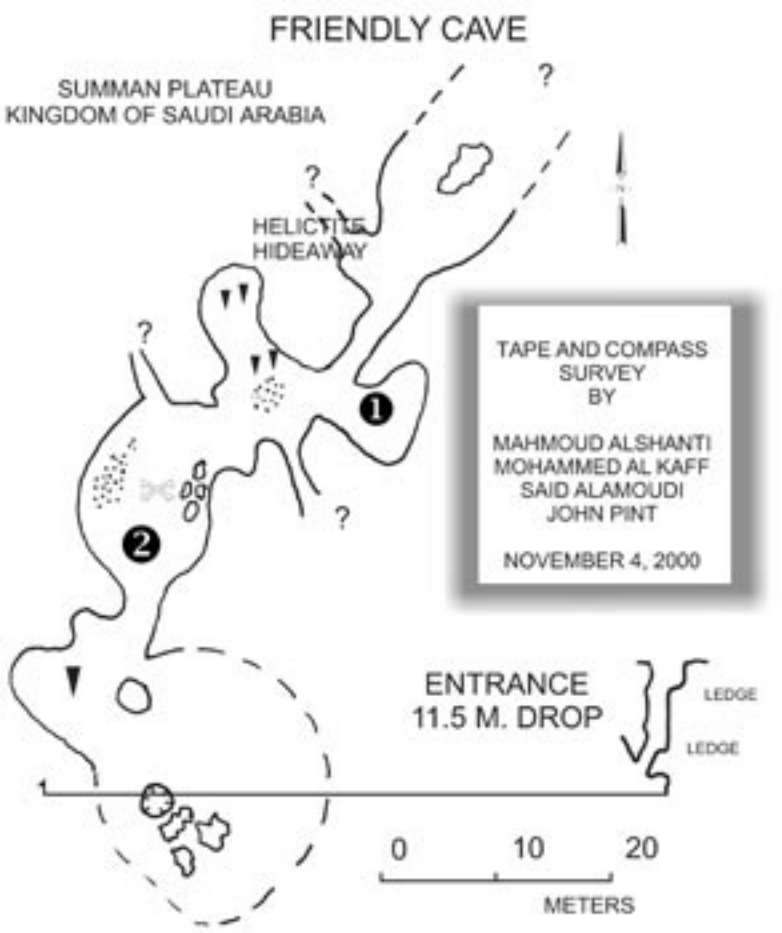


Figure 3. Map of Friendly Cave.

FRIENDLY CAVE

Friendly Cave (Pint, 2003a) is located 4.7 km northwest of Murubbeh Cave and 2 km east of the highway leading to Rumah. A map of Friendly Cave is shown as figure 3. The entrance, located in a shallow, sandy depression, is a nearly circular vertical shaft 2.5 m wide (fig. 4) that narrows to approximately 1 m in diameter near the bottom. Air flow up the shaft is strong enough to make it difficult to lower a carabiner attached to the end of a length of webbing. The distance from the surface to the bottom of the shaft is 11.5 m. The entrance shaft can be negotiated by means of two 10 m cable ladders joined together or by SRT (Single Rope Technique). The ladders or rope can be attached to a vehicle parked near the hole. A northward-trending walking passage leads down a gentle slope from the entrance room to a richly decorated area less than 40 m from the entrance. The decoration is principally calcite stalactites, stalagmites, draperies and helictites as well as small gypsum formations (figs. 5-8). The sandy floor adds to the aesthetic appeal of this area. The cave continues to the northeast but a short reconnaissance by the SGS-ISS team indicated that this passage contains few speleothems.

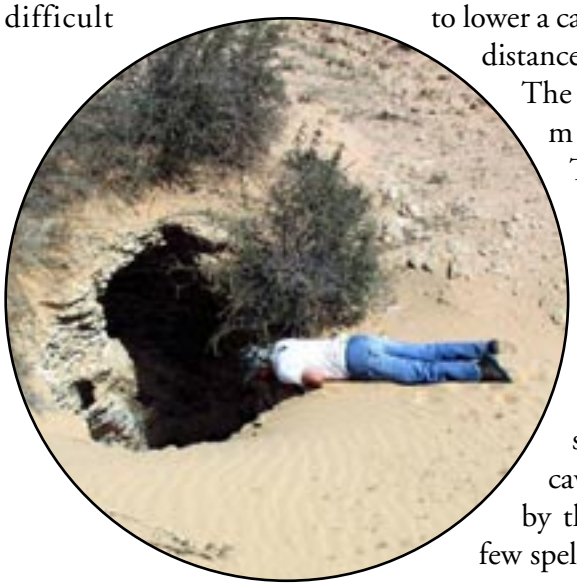


Figure 4. The entrance to Friendly Cave is large enough for the insertion of a circular staircase.

Figure 5. The strategic use of lamps in this picture demonstrates how proper lighting can make Friendly Cave very attractive for tourism. Photo courtesy of Lars Bjurström.

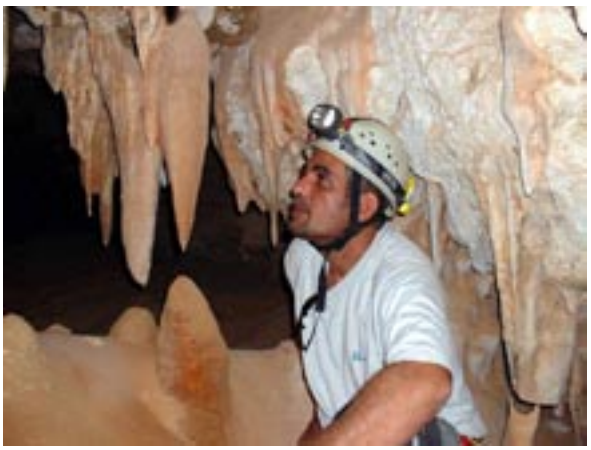


Figure 6. Drapery, stalactites, and stalagmites in Friendly Cave.

Figure 7. Helictites – which appear to "disobey the law of gravity" - are found in many nooks and crannies of Friendly Cave.

Figure 8. Delicate, endlessly varied gypsum formations decorate the ceiling and walls of Friendly Cave.

SURPRISE CAVE

Surprise Cave (Pint, 2003a) is located 7.4 km northwest of Murubbeh Cave and approximately 4 km east of the highway leading to Rumah. A map of this cave is shown in figure 9. Two entrances to Surprise Cave are known and the number of unexplored passages, plus the proliferation of holes in the general area, make it likely that other entrances will be discovered.

Entrance One, located on a flat, hardpan surface and shown in figure 10, is less than 1 m across and cannot be seen from the distance of a few meters. This entrance is 14 meters deep and can be free-climbed easily by rock or mountain climbers. Standard caving procedures would require that the climber be belayed. Two joined 10 m cable ladders or SRT may also be used. Rigging may be done from a vehicle parked at the edge of the entrance shaft. Upward airflow is noticeable at this entrance.

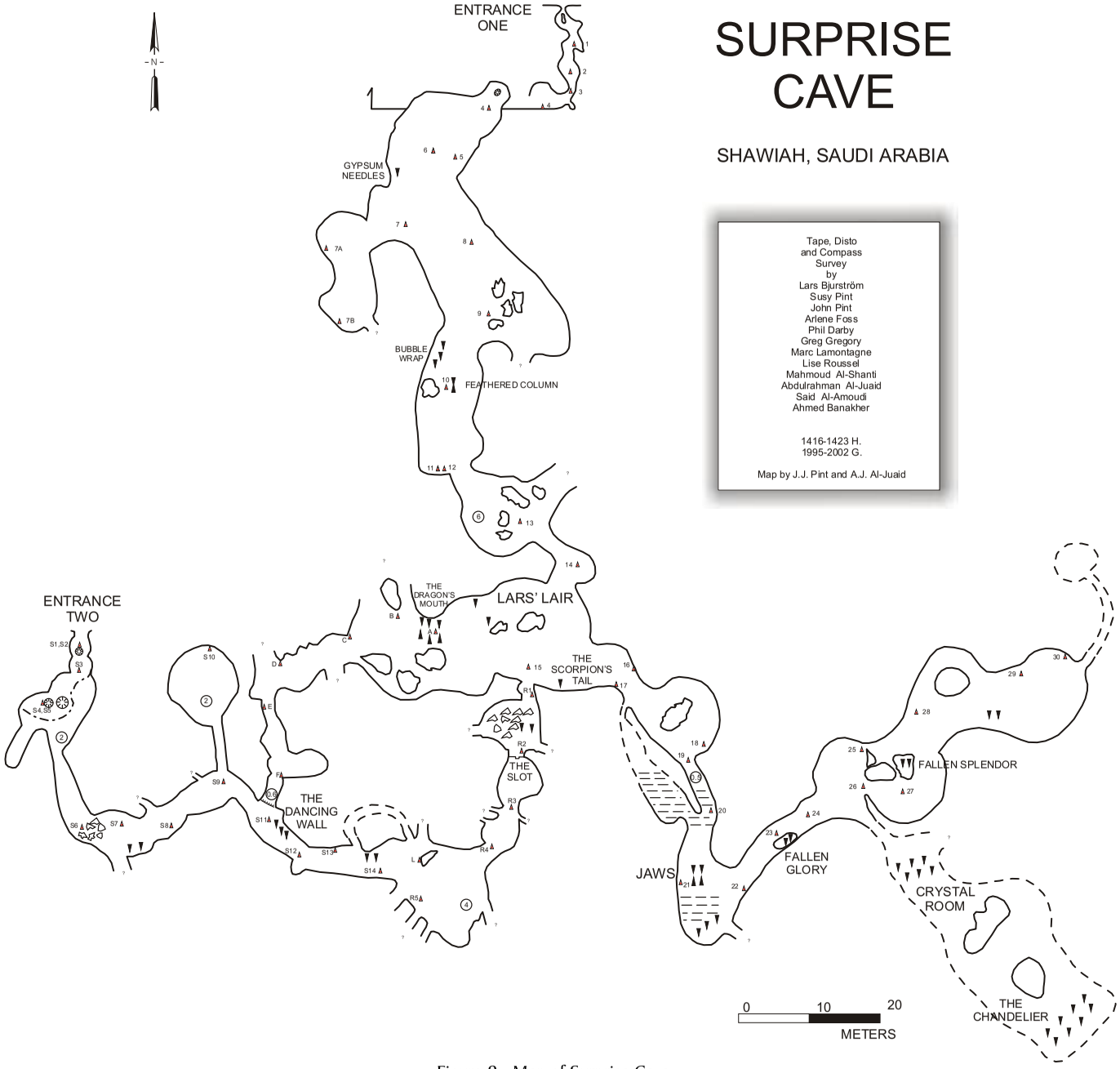


Figure 9. Map of Surprise Cave.

Entrance Two is a horizontal opening in the wall of an arroyo located 75 m southwest of Entrance One. A passage <1 m high leads southwest for 11 m to two holes that look down upon a floor 3 m below (fig. 11). Free climbing is not possible, but a cable ladder can be rigged. This, however, must be attached to a vehicle outside the cave because the columns inside the passage are weak. Air flow was not noticed.

Figure 10. Surprise Cave Entrance One is a narrow shaft 14m deep.

Entrance One was found to be preferable to Entrance Two because the latter leads into a passage whose floor is covered with a thick layer of fine loess which, when stirred up, caused considerable respiratory problems during the survey of this area and for several weeks afterward.

The most aesthetically pleasing speleothems in Surprise Cave are along the route from station 0 to station 23. Crawling through a dusty area is required from stations 3-4, beyond which only dirty stalactites and rock protrusions are encountered. Stoop-walking is required to the vicinity of station 7 where fine, milky-white gypsum needles are visible. Access farther into the cave requires climbing over or around large chunks of breakdown. Between stations 9 and 10 the cave contains old stalactites coated with a younger layer of semi-transparent calcite. Lars' Lair is a room about 20 by 25 m in size with a mainly sandy floor. Impressive stalactites and draperies are found in many parts of the room (fig. 12) as well as tiny gypsum formations of great beauty (fig. 13). A great deal of time could be spent in this room just looking for these among the nooks and crannies. This room is also one of the few places underground in Saudi Arabia where visitors can find a few stalactites still dripping and growing (fig. 14).

Figure 11. Entrance Two of Surprise Cave has a small drop of 3 m.

A passage to the SE leads to the formations called Jaws (fig. 15) and Fallen Glory as well as other fine stalactite displays (fig. 16). Crawling is required for a few meters in this passage, over a floor which is occasionally muddy. Other noteworthy decorations can be found to the east of this point (station 23) but squeezing through small spaces and crawling are required. In addition, the air is stagnant and unusually humid, especially in the passage housing The Chandelier (fig. 17) which features fossil stalactites coated with a translucent layer of calcite frequently tipped with one or two flat "ducktails" offset at approximately 30°.

Figure 12. This well-decorated archway is located in Surprise Cave and is known as the Dragon's Mouth.

Figure 13. Segmented gypsum formation found in Surprise Cave.

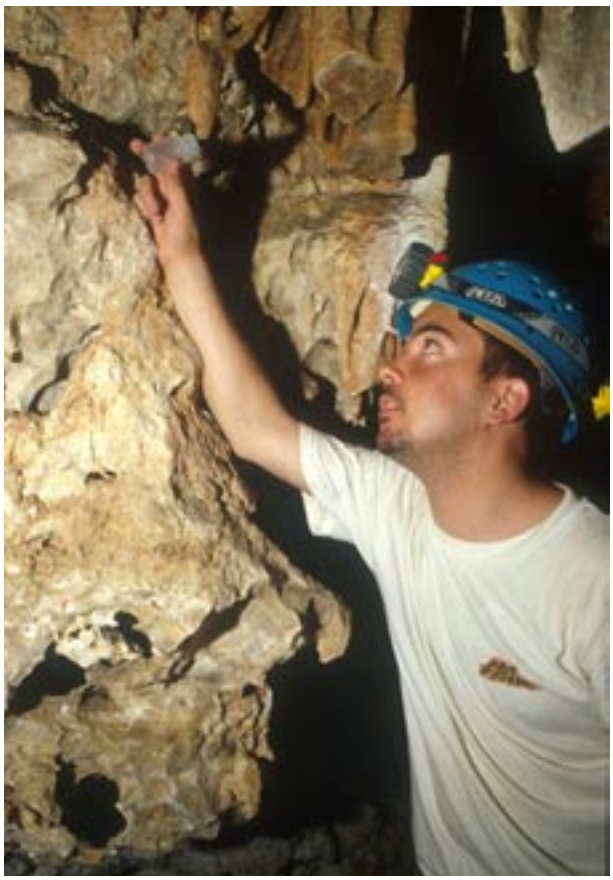


Figure 14. A geologist collects drops from a stalactite in Surprise Cave, one of the few known caves in Saudi Arabia with formations that are still growing.

Figure 15. The Jaws formation in Surprise Cave.

Figure 16. Display of stalactites in Surprise Cave.

Figure 17. The Chandelier formation in Surprise Cave features fossil stalactites coated with a translucent layer of calcite.

KAHF AL RUTUWBAH / GECKO CAVE

Kahf Al Rutuwbah, also known as Gecko Cave (Pint, 2003a) is located 4 kms north of Murubbeh Cave and 5.1 kms E of the highway leading to Rumah. The entrance (fig. 18) is located in the wall of a collapse deposit and does not require ropes or ladders to be visited. Between stations 1 and 4, the cave has a soft, sandy floor and a variety of stalactites, draperies and occasional helictites (figs. 19, 20). The ceiling, however, is mostly lower than 1.5 meters affording visitors few opportunities to stand up. The temperature averages 24° with 66 percent humidity in this area, but deeper in the cave (stations 9-18) the temperature drops to 21° although the humidity rises to a very uncomfortable 97 percent. A detailed description of this cave can be found in Pint and others (2002).

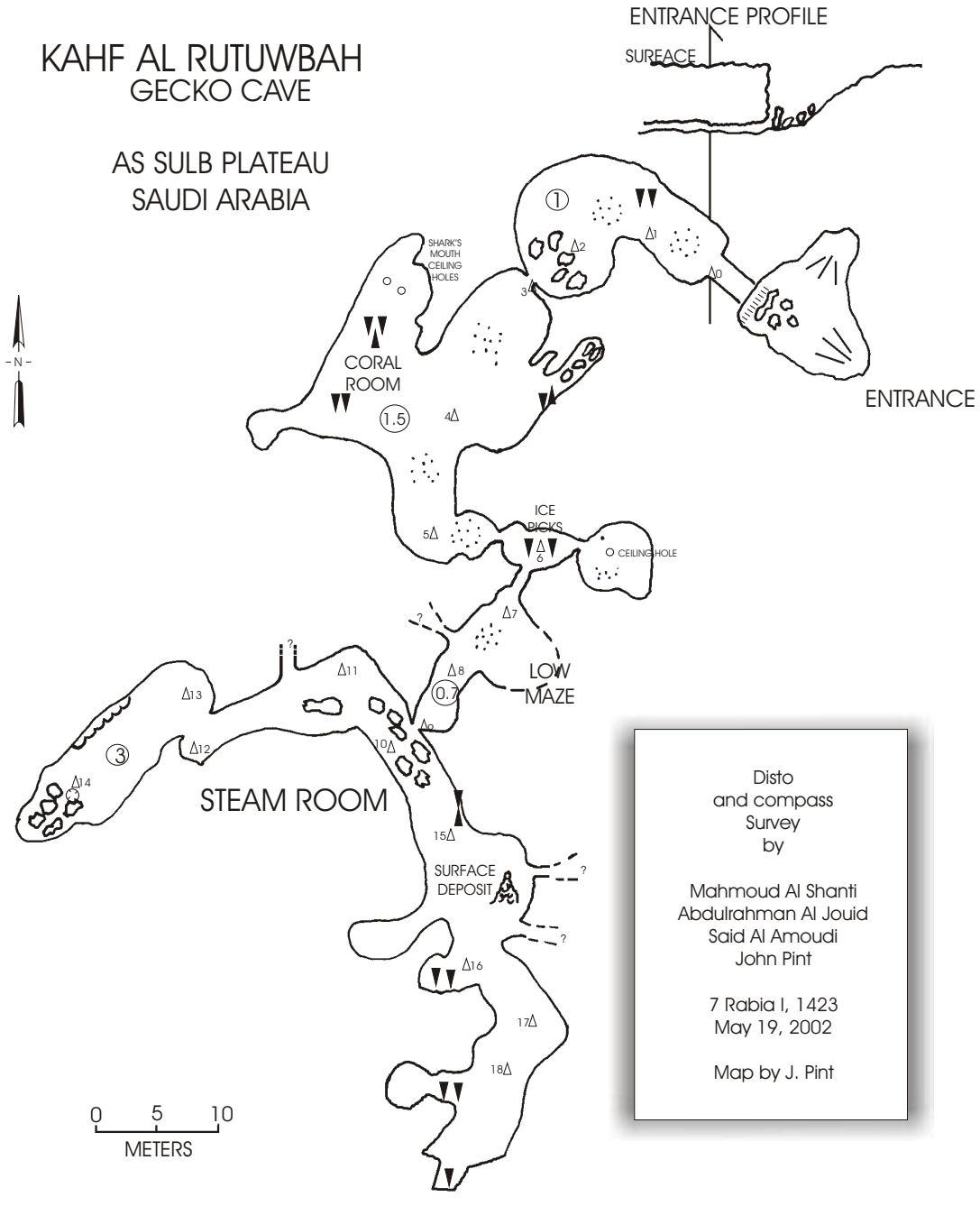


Figure 18. Map of Kahf al Rutuwbah, also known as Gecko Cave.

Figure 19. Stalactites are found just beyond the entrance of Rutuwbah/Gecko Cave

Figure 20. The Coral Room of Rutuwbah/Gecko Cave has a sandy floor and milky white speleothems, but there is no room to stand up.

THE NATURAL COOLER OF MURUBBEH CAVE

Murubbeh Cave, also known as B7 Cave and Dahl Shawiyah (Pint, 2003a) is located 3.5 kms north of the town of Shawiyah and 2.3 kms east of the highway leading to Rumah. Maps of Murubbeh/B7 Cave are shown in figures 23 and 24.

Murubbeh/B7 Cave is characterized by a large underground chamber measuring approximately 150x80x50 m (fig. 21) connected with the surface by a rather small sub-horizontal opening (10x3 m) at the bottom of a small collapse doline shown in figure 22. The large size of this room is unique among the other natural cavities presently known in the As Sulb Plateau, and is rivaled by only one other cave (UPM Cave, located only 715 m southeast of Murubbeh), which has a room similar in size to the Murubbeh chamber. Notably, the floor of the Murubbeh room consists of rock boulders fallen from the ceiling, suggesting that the cave would have been even larger prior to its partial collapse. At the present time, explorers have penetrated little over 40 m into this room, and the possibility exists that the room may go deeper, following narrow shafts inside the breakdown in the cave floor. The depth of this cave is abnormally great with respect to the depths of other cavities of the area, which typically correspond to the depth of the groundwater, 10-20 m below the surface.

In Murubbeh Cave, the bidimensional network of conduits and the enhanced erosional-corrosional forms, which characterize other cavities in the As Sulb Plateau, are lacking, and it would appear that the cave was originally occupied by a large underground lake. The surface of the lake would have been at the same level as the groundwater level in other caves of the area, but its bottom was evidently several tens of meters deeper. Also the hosted speleothems are unusual, being completely phreatic in origin. Speleothems formed by drip, namely stalactites and stalagmites, are absent except at very high levels of the cave, whereas cave clouds, boxwork, and folia (Hill and Forti, 1997) are widespread (figs. 25, 26, 27). Moreover the breakdown floor is covered by a 10 cm to over 1 m thick layer of sunken cave rafts developed during the evaporation of the water of the lake (fig. 28). The exceptional volume of this

Figure 21. The large room in Murubbeh/B7 Cave could be furnished with rugs, cushions, and tables.

Figure 22. Murubbeh/B7 Cave can be entered on foot via a steep breakdown slope.

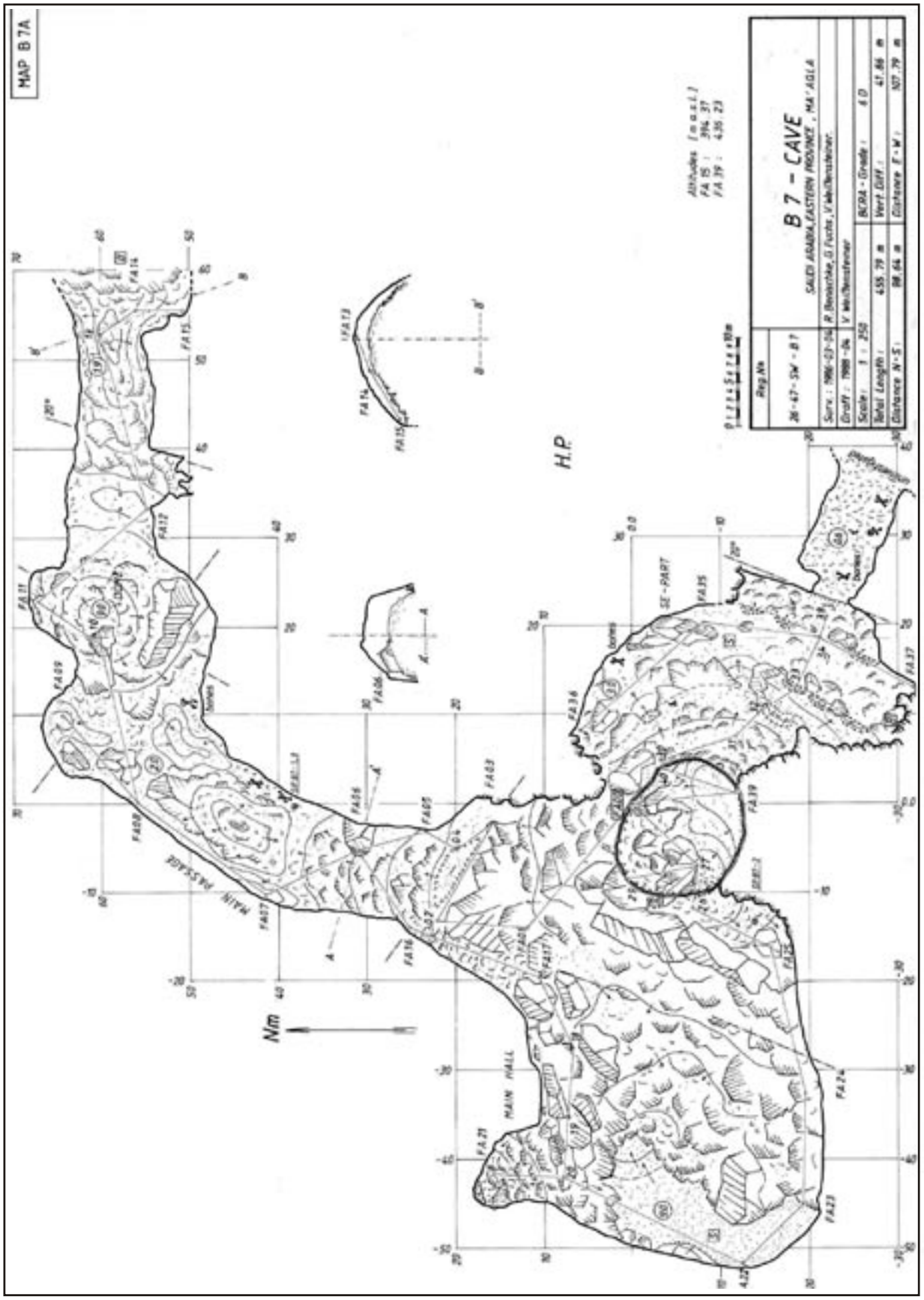


Figure 23. Plan of Murubbeh/B7 Cave courtesy of Joanneum Research, Graz, Austria.

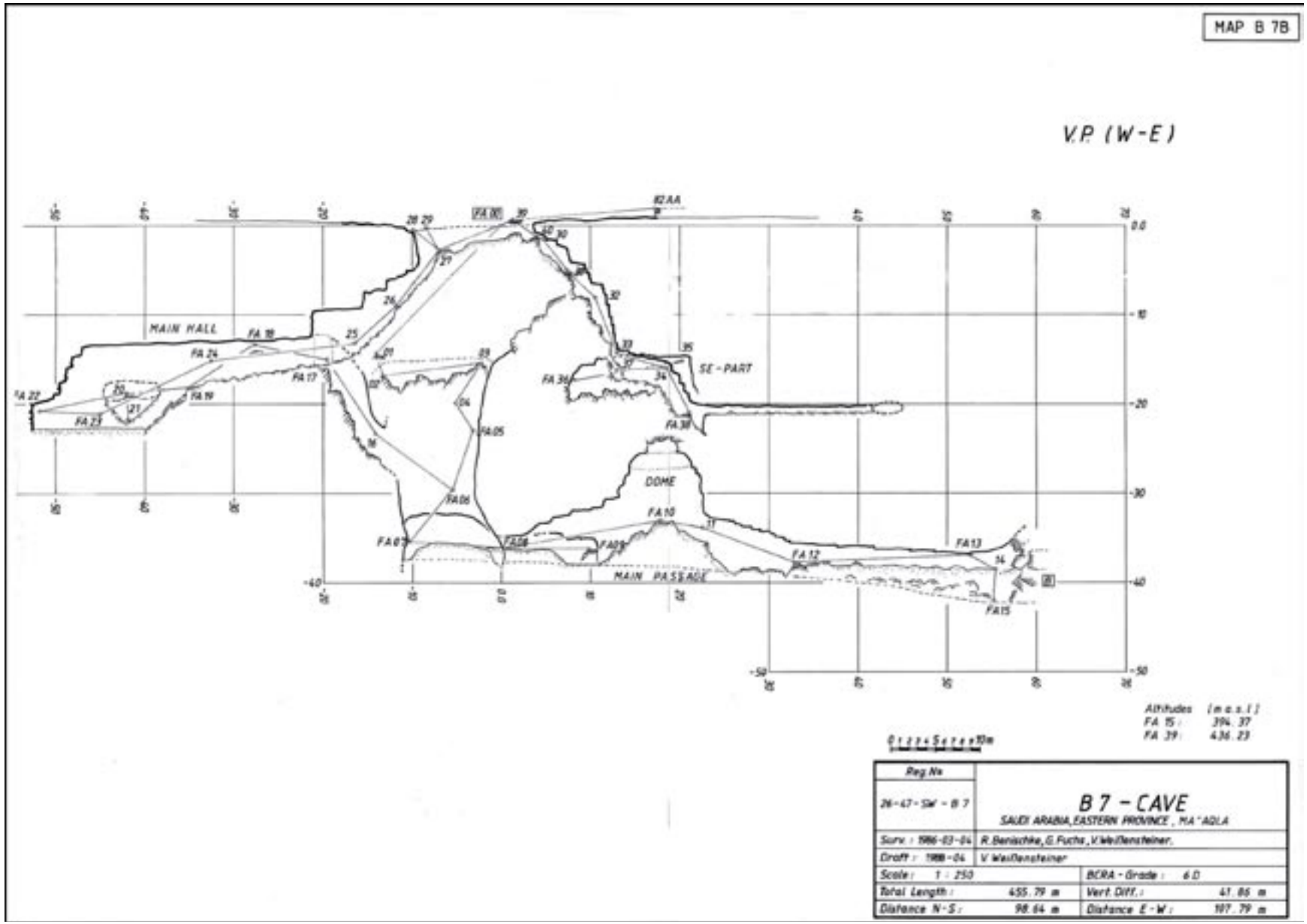


Figure 24. Profile of Murubbeh/B7 Cave courtesy of Joanneum Research, Graz, Austria

Figure 25. Sparkling cave clouds and cauliflowers cover the ceiling of some passages in Murubbeh Cave.

Figure 26. A resident of the nearby town of Shawiah examines boxwork on the walls of the big room in Murubbeh/B7 Cave.

Figure 27. Large calcite crystals, formed under water, in Murubbeh/B7 Cave.

Figure 28. Fragments of cave rafts, formed on the surface of the underground lake, now cover the floor of Murubbeh/B7 Cave

Figure 29. Calcite macrocrystals on the ceiling of Murubbeh/B7 Cave resemble flowers.

deposit suggests that the evaporation process lasted for a very long span of time.

These characteristics suggest that the genesis of the cave was driven by uprising water, which fed the lake and kept its level constant even in the presence of a strong evaporation rate in the deeper cave passages. Attractive flowers composed of calcite macrocrystals on the cave ceiling (fig. 29) suggest that the cave may, in part, have had a thermal or at least hypogenic origin (Forti and others, 2002). The long, horizontal passage of Murubbeh cave begins with natural light (fig. 30) and leads into total darkness. The passage also features a dome that could be lit for dramatic effect (fig. 31).

Murubbeh Cave is additionally noteworthy because of its paleontological and archaeological materials discovered during exploration, which suggest that the cave was known and visited during antiquity. The items found include the bones of a variety of animals of different sizes, two human skulls, a scraping tool, a large folded piece skin or leather, a great number of gazelle horns, and a well-preserved,

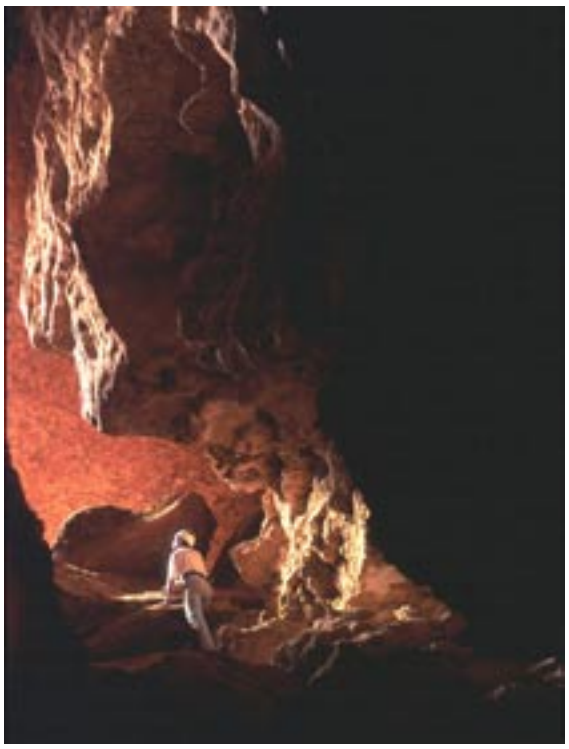


Figure 30. The last ray of sunlight seen at the beginning of the horizontal passage in Murubbeh/B7 Cave.

Figure 31. The dome in Murubbeh/B7 Cave with strategic lighting. Photo courtesy of Lars Bjurström.

Figure 33. One of two human skulls found in Murubbeh/B7 Cave.

Figure 34. This folded skin, found deep inside Murubbeh/B7 Cave, suggests that human beings once used the cave.

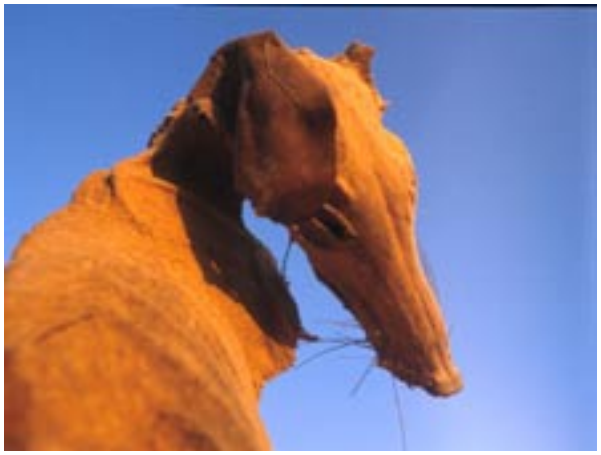
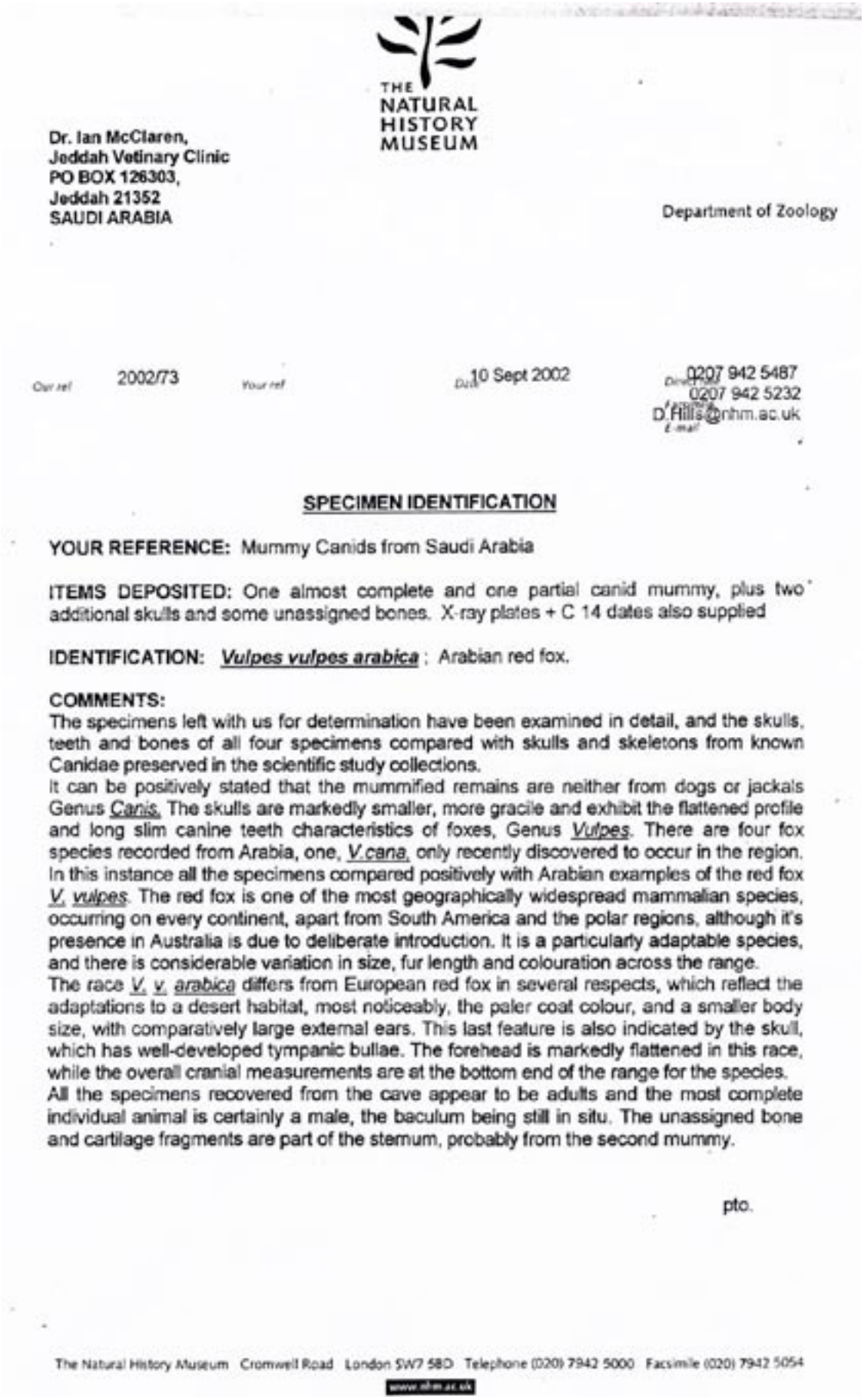


Figure 35. Naturally preserved body of an Arabian Red Fox, carbon dated at c. 2000 years BP.

naturally mummified body of an Arabian Red Fox (*Vulpes vulpes arabica*) identified as such by the Natural History Museum of London (figs. 32, 33, 34, 35). Carbon dating of some bones found in the main southeast chamber was carried out in Austria and indicates that they are about 1000 years old. The Red Fox, however, was found in an isolated lower level room whose entrance lies between FA-35 and FA-36. This mummy was carbon-dated by the Swiss Federal Institute of Technology in Zurich to approximately 1900 BP (fig. 36). Archeological investigations of Murubbeh Cave are planned for 2004. Sufficiently interesting materials may result from this study to justify the creation of a display or a small museum that could be located in or near the cave.

The large size of this cave, its morphological characteristics, the presence of rare and peculiar speleothems and its easy entrance has always attracted curious visitors and makes it attractive for development as a site for cave tourism. Unfortunately some visitors, especially in recent times, have



THE NATURAL HISTORY MUSEUM

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Department of Zoology

Our ref 2002/73 Your ref Date 10 Sept 2002

Direct line 0207 942 5487
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SPECIMEN IDENTIFICATION

YOUR REFERENCE: Mummy Canids from Saudi Arabia

ITEMS DEPOSITED: One almost complete and one partial canid mummy, plus two additional skulls and some unassigned bones. X-ray plates + C 14 dates also supplied

IDENTIFICATION: ***Vulpes vulpes arabica*** ; Arabian red fox.

COMMENTS:
The specimens left with us for determination have been examined in detail, and the skulls, teeth and bones of all four specimens compared with skulls and skeletons from known Canidae preserved in the scientific study collections.
It can be positively stated that the mummified remains are neither from dogs or jackals Genus *Canis*. The skulls are markedly smaller, more gracile and exhibit the flattened profile and long slim canine teeth characteristics of foxes, Genus *Vulpes*. There are four fox species recorded from Arabia, one, *V.cana*, only recently discovered to occur in the region. In this instance all the specimens compared positively with Arabian examples of the red fox *V. vulpes*. The red fox is one of the most geographically widespread mammalian species, occurring on every continent, apart from South America and the polar regions, although it's presence in Australia is due to deliberate introduction. It is a particularly adaptable species, and there is considerable variation in size, fur length and colouration across the range.
The race *V. v. arabica* differs from European red fox in several respects, which reflect the adaptations to a desert habitat, most noticeably, the paler coat colour, and a smaller body size, with comparatively large external ears. This last feature is also indicated by the skull, which has well-developed tympanic bullae. The forehead is markedly flattened in this race, while the overall cranial measurements are at the bottom end of the range for the species.
All the specimens recovered from the cave appear to be adults and the most complete individual animal is certainly a male, the baculum being still in situ. The unassigned bone and cartilage fragments are part of the sternum, probably from the second mummy.

pto.

The Natural History Museum Cromwell Road London SW7 5BD Telephone (020) 7942 5000 Facsimile (020) 7942 5054
www.nhm.ac.uk

Figure 32. Identification of Arabian Red Fox found inside Murubbeh/B7 Cave

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Herrn
Prof. Dr. Albert MATTER
Universität Bern
Geologisches Institut
Baltzerstrasse 1
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Zürich, 6. März 2002

Sehr geehrter Herr Prof. Matter,

Hiermit erhalten Sie die Resultate von den Analysen der beiden Proben, die Sie uns am 22.11.2001 zur ^{14}C-AMS Datierung geschickt haben:

Labor Nr.	Proben Nr.	AMS-^{14}C Alter [y BP]	$\delta^{13}C$ [o/oo]	kalib. Alter [BC/AD]
ETH-25068	BONE	1'890 ± 45	-20.3 ± 1.1	AD 26 - 42 (2.3 %) AD 53 - 240 (97.7 %)
ETH-25069	TISSUE	1'835 ± 45	-20.1 ± 1.1	AD 82 - 262 (91.0 %) AD 285 - 326 (9.0 %)

Die kalibrierten (dendrokorrigierten) Alter sind 2σ-Bereiche (95 % confidence limit) und wurden mit dem Programm CalibETH von Th.R. Niklaus, G. Bonani, M. Simonius, M. Suter und W. Wölfli berechnet (Radiocarbon, Vol 34, No. 3, 1992, p. 483 - 492).

Durch den Verlauf der Kalibrierkurve im interessierenden Bereich ergeben sich ergeben sich mehrere wahre Altersbereiche. Die Zahlen in Klammern sind die Wahrscheinlichkeiten für die einzelnen Bereiche.

Mit freundlichen Grüssen

G. Bonani

Dr. Georges Bonani

Figure 36. Results of carbon-14 dating of Red Fox found in Murubbeh/B7 Cave.

Figure 37. Many cave walls have been defaced by graffiti and the problem is getting worse.

Figure 38. Garbage left by picnickers has turned the large room of Murubbeh/B7 Cave into an unsightly, and unpleasant place.

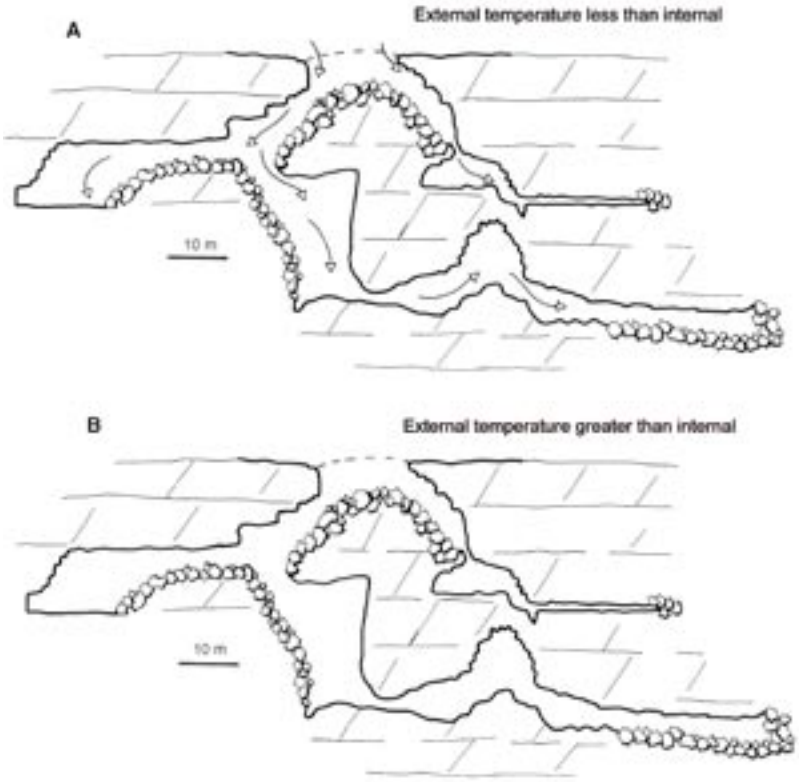

Figure 39. Vertical section of Murubbeh/B7 cave. The arrows show the air flow when the external temperature is lower than the internal (A). When the external temperature is higher, the cave behaves as a "cool trap," preventing cold air from escaping (B).

behaved poorly toward the underground environment, disfiguring it with graffiti (fig. 37) and leaving a great deal of refuse (fig. 38) inside the cave.

The cave is also potentially attractive to tourists because of its low internal temperature (18°C), which is the lowest measured in any cave in the As Sulb Plateau and is stable throughout the year. It is believed that this low temperature is a consequence of the shape of the cave, which may be schematized as a large chamber linked to the exterior by a relatively small hole at the top of the ceiling; this structure makes this cave an ideal "cold trap", whereby cold desert air, during the winter and on chilly nights even during the summer, "falls" inside the cave and among the blocks close to the floor of the chamber. As it is heavier than the ambient air of the cave, the cool air becomes trapped and prevents the entry of lighter hot summer and/or diurnal air (fig. 39).

CAVES OF THE FAR NORTH

SGS has located 16 caves in the Habakah area and 6 caves in the Munbateh area in northern Saudi Arabia less than 50 kms from the Trans-Arabian Pipeline highway (Al-Shanti and others, 2003). Some of these caves have been the subject of newspaper articles resulting in rudimentary, non-commercial, unregulated cave tourism. Serdab al Aqrab al Aswad, or Black Scorpion Cave, over 300 meters long, houses a great variety of gypsum formations (figs. 40, 41) much appreciated by visitors. Unfortunately, because these caves are not regulated or gated, they are being damaged by careless visitors (fig. 42).

Figure 40. Gypsum flower in Black Scorpion Cave, Habakah.

Figure 41. Gypsum swords and needles in Black Scorpion Cave, Habakah

LAVA-TUBE CAVES

Lava-tube exploration in Saudi Arabia is in its infancy (Roobol et al, 2002). Lava tubes do not normally contain formations as aesthetically pleasing as the calcite and gypsum speleothems featured in the world's show caves, and they might be thought to be poor candidates for cave tourism. Nonetheless, lava tubes do contain unusual, attractive natural features (figs. 43, 44, 45), and of the 14 lava-tube caves so far located by SGS, Hibashi Cave in Harrat Buqum is frequently visited by the public and has been featured in newspaper articles. The lava tubes are pleasantly cool, making them attractive for tourism. Moreover, they have particular educational value as a means of teaching about volcanoes and lava flows. Such tours have been integrated into the school curricula of some countries where lava tubes are conveniently located, for example in the Azores (Costa, 2002).

The size of lava-tube caves may also be attractive as a curiosity: the longest surveyed – Kahf al Shuwaymis – is over 500m long, frequently up to 16m wide and as high as 11m (figs. 46, 47), and it is likely that even larger tubes remain to be discovered among the 85,000 km^2 of lava fields in Saudi Arabia.

Figure 42. The entrance to Tayib al Issam Cave, one of several being defaced by graffiti in the Habakah area.

Figure 43. Lava stalactite in Kahf al Shuwaymis.

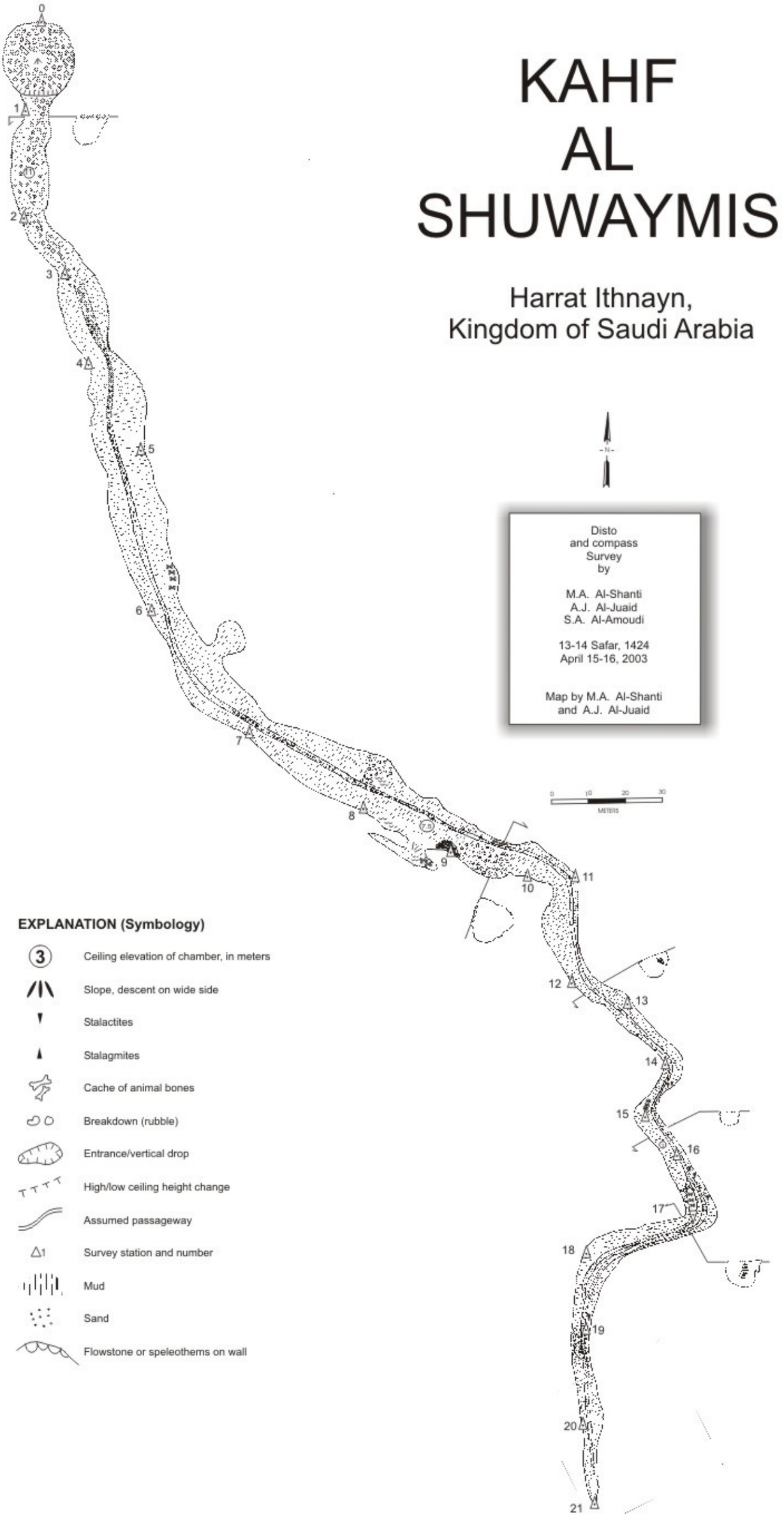

Figure 46. Map of Kahf al Shuwaymis lava tube, Harrat Ithnayn.

Figure 44. Lava channel 13 m long (now filled with bat guano) in Hibashi Cave, Harrat Buqum.

Figure 45. A lava stalagmite about 40 cms high in Hibashi Cave, Harrat Buqum.

Figure 47. A large room with a dome ceiling in Kahf al Shuwaymis.

PROBLEMS OF DEPLETION AND SAFEGUARD OF DESERT CAVES

All the natural cavities of Saudi Arabia and in particular those of the As Sulb Plateau are endangered by both natural events and human activity. Until recently, natural events had a greater negative impact than anthropogenic events. Huge quantities of desert sand are blown into and completely fill some caves. Foxhole Cave and the main entrance of Dahl Iftakh, for example, vanished beneath sand in less than 12 years (Pint, 1997). Obviously, natural phenomena such as the movement of sand dunes cannot be stopped. Nevertheless, it would be well worth the effort to build up artificial fences (walls) around the entrances of some of the main caves to minimize, if not to stop entirely, the sand influx.

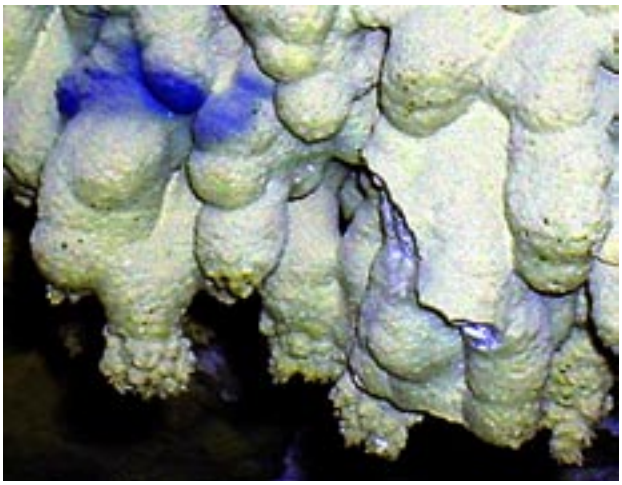

Figure 48. Fifty meters inside Tayib al Isam Cave, the beauty of these unusual, sausage-shaped formations has been compromised by blue spray paint and breakage.

Figure 49. Dharb al Najim Cave features a room 100 meters high and 100 meters wide and Saudi Arabia's biggest free drop. A local town now uses it as a garbage dump.

The other risk comes from the interaction of human beings with caves. For many years, vandalism was limited to the few caves that had easily accessed sub-horizontal entrances, but recently, cave vandals have entered shafts up to 15 m deep. Although it has been only a few years since the general public became aware of the existence of caves in Saudi Arabia, a combination of publicity, road development, the internet and the availability of Global Positioning System (GPS) receivers has caused human attacks on caves to grow significantly. Publicity has come mainly in the form of newspaper articles and books in Arabic that give the exact latitude and longitude of caves or detailed instructions regarding their locations. It should be noted that responsible cavers and caving organizations around the world avoid revealing cave locations to the general public. This practice is also observed by the Saudi Geological Survey.

In the past, finding a particular cave in a wide, flat desert was extremely difficult for all except the local people. However, today's accurate GPS units will lead anyone straight to the cave they are seeking. Desert adventurers are now in the habit of producing lists of GPS coordinates to interesting places and passing these lists on to friends via the internet. Many who make copies of these lists are interested in protecting the environment, but eventually the coordinates fall into the hands of ignorant people, insensitive to environmental concerns.

Another natural protection for desert caves in former times was their inaccessibility. For example, until 2001, a journey of more of 70 km over sand dunes or of 280 km across badlands was necessary to reach the karst and caves of the As Sulb Plateau, whereas nowadays the trip can be made from Riyadh entirely on asphalt in only three hours, leading to hard pan less than 1 km from the first entrance to a major cave. The journey can be made by ordinary two-wheel-drive passenger vehicles; not the 4-wheel drive vehicles required by former travelers.

Cave vandalism takes several forms. Graffiti are drawn over all the reachable walls, even very deep inside some caves (fig. 48), and the caves are used as the site for garbage disposal and storage. The garbage may be the remains of a picnic in a cave or, more seriously, truckloads of garbage brought from nearby towns and dumped at cave entrances (fig. 49). Animal carcasses may be dumped in caves by local shepherds, and speleothems are often broken (fig. 50) and sometimes brought out of the cave to be admired or to be sold. The depletion of the speleothem patrimony is the worst among the kinds of vandalism presently occurring inside the caves. It is feasible in the near future to restore the

natural condition of the cave with respect to graffiti and garbage, but nothing can be done to restore or replenish broken or stolen speleothems.

Figure 50. Broken stalactite dropped by visitors to Dahl Sultan.

A concern of the Saudi Geological Survey is to educate the public about the fragility of the cave environment and to protect known caves from destruction. To that end, recommendations have been made to gate some of the more interesting caves or those with the easiest entrances on the As Sulb Plateau. Gating has not yet taken place and the best safeguard, in the interim, is education about the karst landscape and environment in the region, done through interested private individuals in the form of lectures, publications such as the "Desert Caves of Saudi Arabia," and reports on the web site www.saudicaves.com, supported by SGS.

SAUDI SOCIETY AND SPELEOLOGICAL TOURISM

Until now there has been no systematic development of Saudi caves for tourism. On the one hand, public knowledge about karst phenomena in general and about Saudi caves in particular was practically nonexistent. On the other hand, the lack of a tourist infrastructure such as paved roads and facilities for traveling families made cave tourism in the As Sulb region economically unrealistic.

The situation has changed in the last few years. Cavers and speleologists have explored and mapped a number of natural cavities containing features that make them, at least partly suitable for transformation into show caves. Publication of these activities in magazines, newspapers and the internet has raised public awareness of the existence of Saudi Caves and some of their characteristics. Secondly, the road network and facilities for families, such as roadside restaurants and motels, have increased.

Given these recent changes, the time is now appropriate to consider the steps necessary to develop cave tourism, balancing the need to preserve and safeguard the cave environment and associated aquifers against the impact of opening caves to visitors, lighting, and construction. Under these constraints, access would be carefully controlled in order to avoid damage and/or pollution of the ecosystem, but made open enough to provide a satisfying and educative experience for the tourist.

THE DEVELOPMENT OF A SHOW CAVE IN A DESERT

The majority of known Saudi caves are located in desert areas. This, rather than being an obstacle, may actually represent a distinct advantage. Show caves in Europe, for example, are typically colder and more humid than the outside climate, making them comparatively uncomfortable. The coolness of a Saudi cave would make it attractive as a place more tolerable and pleasant than on the surface for most of the year.

With regard to Murubbeh Cave, its "natural cooler" makes it a potentially important tourist attraction in a region where summer temperatures easily reach 50°C and on summer nights may never fall below 28-30°C. The large sub-horizontal entrance followed by slightly more complex but still large passages makes it easy to transform into a show cave in which different trails may be selected on the basis of the request of the visitors (fig. 51). The passage between the entrance and the large room could open to family tourism, for example, and the sub-horizontal chamber could be equipped with traditional carpets and cushions as well as chairs and tables to make people comfortable so they can

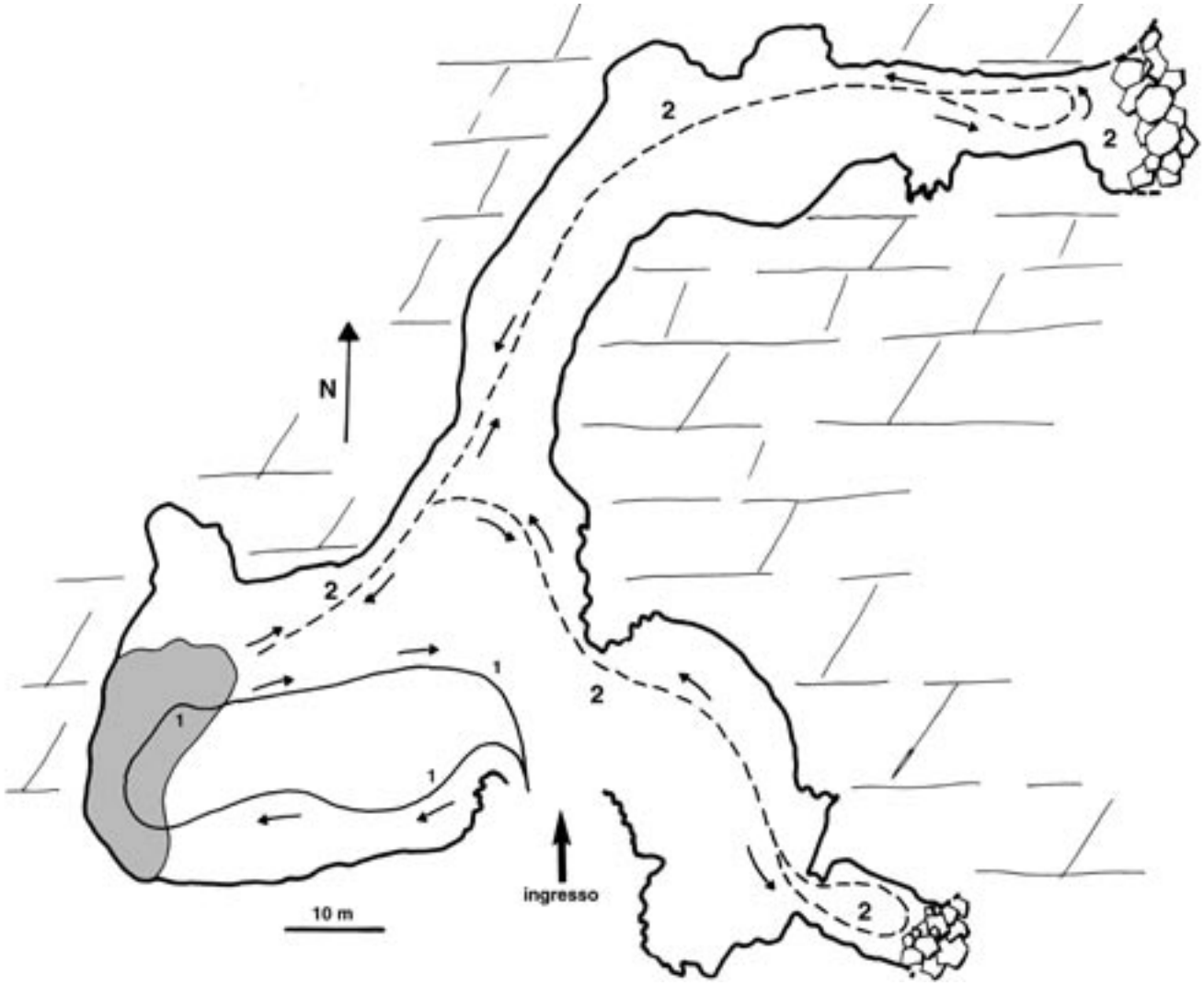

Figure 51. Horizontal plan of Murubbeh/B7 Cave in which two areas have been differentiated according to the kind of possible tourist use: 1: traditional show cave, open to the whole family; 2: walking paths

enjoy the extraordinary climate of the cave. Different trails would then start from the large chamber for people willing to hike or do adventure caving in the other parts of the cave. Of course, access to these trails should be restricted to persons whose physical and technical capacity are adequate.

Other parts of the As Sulb Plateau may equally be important in cave tourism, for example by the development of Friendly Cave and Surprise Cave, at which visitors would broaden their knowledge of karstic phenomena as well as the desert environment.

On the basis of the specific characteristics of the caves described in this report, and experience elsewhere in the world, it is projected that a tourist flow of some tens of thousands of persons/year would not seriously negatively impact the microclimate and other main environmental parameters of these natural cavities. It is likely, in fact, that the majority of tourists would concentrate exclusively on the first part of Murubbeh cave, passing time in its huge chamber, while a small minority would visit other caves and take in the external tours of the desert surroundings.

After testing the validity of cave tourism in the As Sulb Plateau, similar projects could be undertaken in different regions of the country, perhaps starting with the lava fields reachable from Jeddah or Al Madinah.

PROCEDURES REQUIRED FOR TOURIST CAVE DEVELOPMENT

The following is a general outline of steps suggested for implementing tourist-cave development in the As Sulb karst area. A more detailed outline may be seen in the Chart for Show Cave Development (Appendix 1).

1. Protect the entire area if possible.
2. Install gates on the entrances of the most important caves before beginning any work.
3. Place instruments recording temperature and humidity inside the caves at an early stage.
4. Set up an outdoor meteorological station near Murubbeh Cave to measure:
    a. Wind speed
    b. Temperature
    c. Humidity
    d. Rainfall
5. Carry out detailed studies of each cave to be opened to tourism (Cigna and others, 2000):
    a. Determine the "static stability" of all areas to be visited by tourists (to ensure that ceilings, walls, etc. will not fall or move).
    b. Map and assess the engineering problems of tourist routes within the caves
    c. Prepare a lighting plan
    d. Restore graffiti-covered walls and speleothems if possible
    e. Prepare a plan for periodic cleaning
6. Plan surface facilities that will not negatively impact the karst or the caves (including waste and water disposal plan).

The procedures listed above should be under the management of an expert in ecologically and financially sound tourist cave development. If not, the fragile cave and karst environment may be irreversibly damaged, as has often happened in many parts of the world where financial gain was the prime motive for opening a show cave. In addition, the team working under the manager should receive training in tourist cave development. Appendix Two contains an outline of a short intensive course in the development, operation, and environmental protection of a tourist cave, that might provide sufficient training for team members.

TIMETABLE FOR TOURIST CAVE DEVELOPMENT IN KSA

Based on experience with show cave development in other parts of the world, and taking into account the peculiar circumstances of Saudi Arabia's caves, it is judged feasible to accomplish development for one cave in a period of fourteen months, providing financing and government permissions are forthcoming.

Within such an ideal scenario, the following timetable could be considered for cave tourism on the As Sulb Plateau:

Stage one (at the end of 14 months)

- Murubbeh Cave:
    - Great Hall (family relaxation, museum)
    - Walking tour to Crystal Palace at far end of the cave

Stage two (at the end of 28 months)

- Murubbeh Cave:
  - Great Hall (family relaxation, museum)
  - Walking tour to Crystal Palace at far end of the cave
- Friendly Cave: Walking tour

Stage three (at the end of 42 months)

- Murubbeh Cave:
  - Great Hall (family relaxation, museum)
  - Walking tour to Crystal Palace at far end of the cave
- Friendly Cave: Walking tour
- Surprise Cave: Adventure tour

CALCULATING COSTS

The following is a list of expenses probably required for the development of tourist cave facilities in the As Sulb Plateau:

- Salaries for development team.
- Visits by advisors living abroad
- Gating/fencing the caves
- Low walls to reduce/eliminate influx of sand
- Monitoring instruments
  - Instruments located inside the cave to measure:
    - Humidity
    - Air flow
    - Temperature
  - Instruments located on the surface to measure:
    - Wind speed
    - Temperature
    - Humidity
    - Rainfall
- Detailed, engineering-quality survey of each cave
- Lighting
  - Lights
  - Wiring
  - Generator
- Construction of walkway in cave/stairway at entrance
- Preparation of "Great Hall" in Murubbeh
  - Removal of rocks
  - Rugs, cushions, chairs, tables
  - Exhibits (mummies, artifacts, etc., found in caves)
  - Video/slide show on cave origins, historical importance for water, etc.
- Surface buildings
  - Ticket booth
  - Souvenir Shop
  - Toilets
- Salaries for caretaker, guides
- Advertising

POTENTIAL TRAFFIC AND INCOME FROM TOURIST CAVES

If visitors were to stay in the large room of Murubbeh Cave for an average of two hours, the cave could accommodate 1000 or more persons per day. Any number of these people could do the walking tour of the Crystal Palace because the pathway can be set up in the form of a loop.

Friendly Cave, because of its small size, could accommodate up to 100 persons per day, in groups of 6-10 individuals staying for an average of 1.5 hours.

Surprise Cave could accommodate up to 375 people per day in groups of 10-15 individuals departing every half hour. The tour itinerary could be a loop or a one-way trip starting at one of the two known entrances and exiting the other.

The Higher Commission for the Development of Riyadh estimates that the Saudi capital will have a population of six million people by the year 2007. Riyadh is now connected to the As Sulb karst by a network of paved roads that have reduced the journey to less than three hours by car, making it possible for 1000 tourists per day to visit Murubbeh and other caves.

On an average, visitors to show caves around the world pay approximately $10 US per person (SR 37.00). If this amount were charged for cave tourism on the As Sulb Plateau, a minimum of $10,000 per day might be gained if facilities were used at full capacity. In practice, entrance fees In Saudi Arabia might be levied in relation to the average income of potential visitors.

RELATION OF TOURIST CAVE DEVELOPMENT TO AQUIFER PROTECTION

In the mid-1980s, the As Sulb karst area was chosen for study by geologists and speleologists of King Fahd University of Petroleum and Minerals and the Austrian Academy of Sciences (Benischke and others, 1986). This project focused on the relationship between the karst and the Umm er Radhuma aquifer (according to Al-Saafin and others, 1990, the most prolific aquifer in Saudi Arabia), featuring a detailed study of caves in the area and measurements of rainfall and runoff into their entrances. The average annual precipitation in this area is 75-100mm (Edgell, 1993) but this rain often falls during short, heavy storms, producing significant runoff and Al-Saafin and others (1990) calculated that the total discharge to shafts and caves was 45 percent of the yearly rainfall. The KFUPM-Austrian Academy project resulted in over 600 pages of reports and articles as well as detailed maps of 50 caves on the Summan Plateau, related to this karst zone as an important recharge area for the Umm Er Radhuma aquifer.

Until recently, this region was isolated, undeveloped and rarely visited due to a lack of paved roads. In 2003, however, a paved road from the south penetrated the area, affording an easy way for the population of Riyadh to drive to hundreds of pits and horizontal caves in this area (Pint and Al-Shanti, 2003). When this asphalt road reaches north to the TransArabian Pipeline road, the As Sulb karst may experience heavy traffic, construction of petrol stations and businesses as well as settlement expansion, all of which may result in pollution of the aquifer.

The development of tourist caves on the As Sulb Plateau could coincide with the designation of the karst as a protected area. Such a designation would benefit both the caves and the aquifer by preventing pollution in this unusually sensitive area. It should be noted that, all over the world in karst areas connected to aquifers, special laws apply in regard to road construction, petrol stations, sewage, garbage disposal and so on. Designation of the karst as a protected area would greatly simplify the application of these laws and practices.

RELATION OF TOURIST CAVE DEVELOPMENT TO CAVE AND KARST PROTECTION

As noted above, cave vandalism is a problem all over Saudi Arabia due to the loss of isolation as a result of road construction, GPS proliferation, etc. Tourist cave developers obviously have an interest in protecting wild caves from such damage and in keeping potential vandals away from places where large numbers of unexplored caves may be found. The As Sulb karst is just such a place and should be designated as a protected area.

Through their advertising and through the information given during tours, those in charge of tourist caves can do much to educate the general public about the fragility of the cave environment and the impossibility of replacing speleothems that have been carried off. Visitors to tourist caves might be expected to spread among the general public the Golden Rules of Cave Exploration:

- Take nothing but pictures
- Leave nothing but footprints
- Kill nothing but time

FINAL REMARKS

The observations elaborated above suggest that tourist development of karst and caves in Saudi Arabia may be ecologically and financially viable. Environmentally oriented surface tourism plus various levels of tourism inside caves is probably the kind of development most suitable for Saudi Arabia. However, before initiating a detailed plan for the development of show caves in Saudi Arabia, it is of fundamental importance to evaluate the kind and the amount of tourist traffic which might be possible. This will directly depend upon the direction in which the present transformation of Saudi society will go in the near future. If the trend toward family travel and local tourism evidenced in the last few years continues, then Saudi Arabia will surely join the ever-growing society of countries with well developed cave and karst tourism. In particular, the As Sulb Plateau karst area seems to be the most suitable place to realize the first tourist paths both inside and outside caves: if nothing else, because it is located at a reasonable distance from the capital city of Riyadh, thus allowing for daily trips. Moreover the huge number of caves would make it easy to establish a variety of routes in order to satisfy all kinds of tourist preferences: from easy, short walks for the whole family to adventure exploration, even of a very difficult nature, which may require true, technical knowledge of caving.

ACKNOWLEDGMENTS

Our thanks to HE Dr. Mohammed A. Tawfiq for continuous support of cave exploration in this country and of the Cave Tourism Project in particular.

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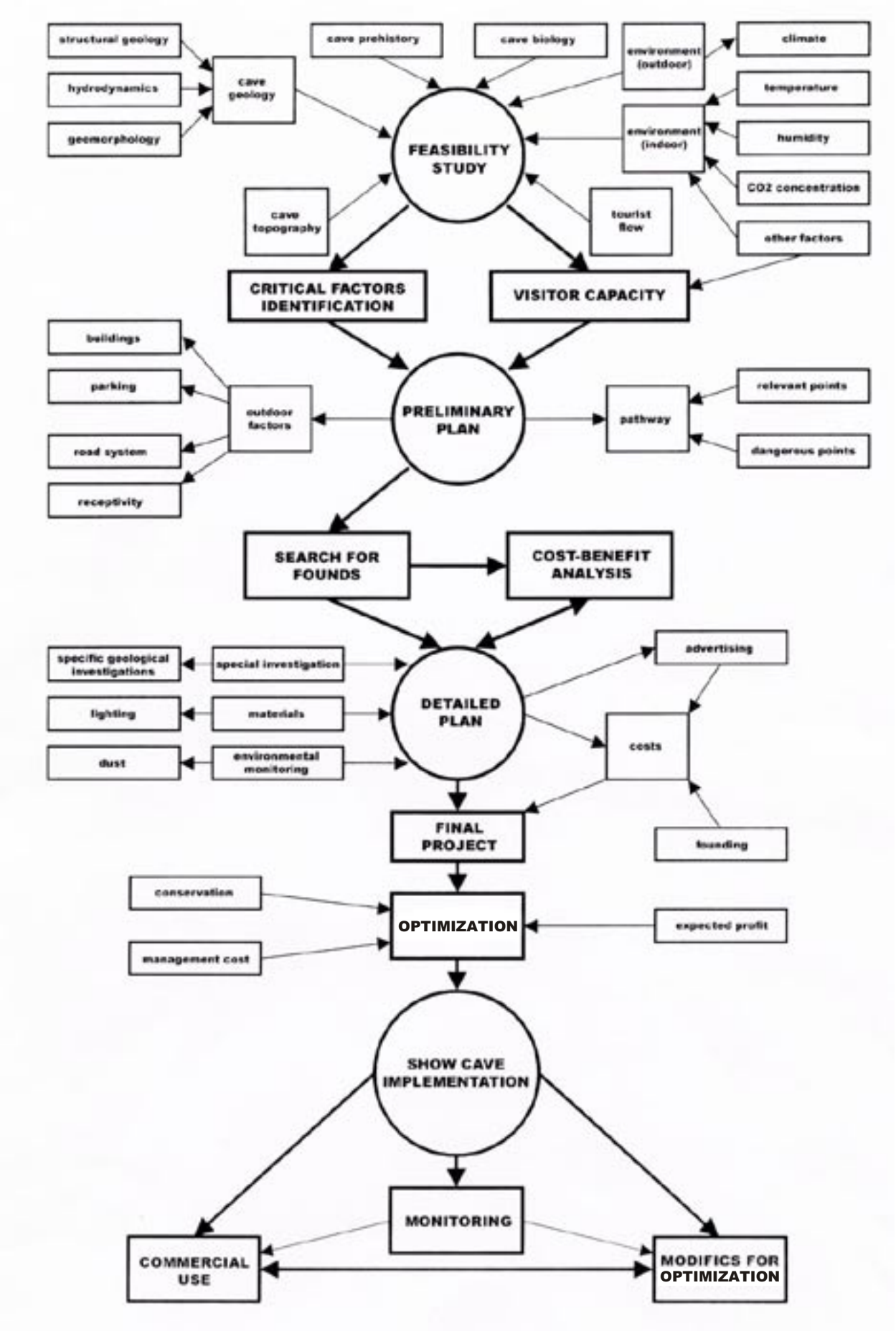
APPENDICES

Appendix 1. Chart representing the various ramifications of show cave development.



Appendix 2 . Description of a short intensive course on the development of tourist caves.

Development, Operation and Environmental Protection of a Tourist Cave

Short intensive course (4 days and a half)
Lesson of 2 hours each
2 field excursions of half a day each

1st Day
1- Introduction to the topic: Economic and Social importance of show caves in the world
2- Cave Climatology
3- Some examples of energy balance in caves characterised medium to low energy flow
4- The concept of "visitor carrying capacity"

2nd Day
5- Monitoring the main cave parameters
6- The most common sensors utilised in monitoring caves
7- Installation of monitoring devices inside and outside the cave (half a day)

3rd Day
8- Zonation of a show cave with respect to its use
9- Lighting of a show cave: problems in planning and maintenance
10- Planning of other main tourist structures inside and outside the cave
11- The income-outcome balance in planning a show cave

4th Day
12- The role of cavers
13- The cultural upgrade of the show cave employees
14- The role of the show caves in scientific research and environmental protection
15- Recovering of the cave data-loggers (half a day)

5th Day (only morning)
16- Analysis of the experimental data as a base for improving tourist development
17- General discussion and conclusions