SOLUTION CAVERNS IN THE DAMMAM DOME, DHAHRAN, SAUDI ARABIA

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INTRODUCTION

In late April 1981, workmen excavating the foundations for new buildings on the campus of the University of Petroleum and Minerals uncovered a 'cave' or solution cavern, and a few days later they encountered another larger 'cave' nearby. Excavation was immediately halted at that place until geophysical tests could be made to determine whether other caverns were present on the site. The rock involved is the Rus Formation of early Eocene age. This formation is full of vugs and cavities from a few millimeters to nearly a meter in size, arranged in several horizons, and similar caverns have been found in other places in the Rus and Dammam formations during construction work in the Dhahran area (ARAMCO personnel, oral communications).

We were invited to examine the 'caves' and report our observations here, as no reports on similar caverns in the area have been published. At the time of writing the geophysical report has not been received, but we have been informed orally that resistivity evidence indicates the existence of other caverns generally along the trend line established by the two already found.

GEOLOGIC SETTING

The two large cavities occur within the Rus Formation which crops out at the core at the Dammam Dome where the University of Petroleum and Minerals Campus is located. The academic buildings of the University are located on a small hill in the central elevated area of the dome. The dome is a broad elliptically shaped structure elongated in the NW–SE direction. The longer and shorter axes are approximately 14 km and 10 km respectively, and the area is close to 150 km^2. The highest point on the dome is 150 m above sea level and is located on top of the hill called Umm Er Rus.

Rus and Dammam formations are the two main rock units exposed in the Dhahran area except for 3 m of Umm er Radhuma Formation [4] in a small area (now covered) in a topographic low along the core of a small anticline forming the Dammam Dome. The remaining area surrounding the dome is covered by eolian sand and sabkha deposits.

Stratigraphy

Figure 1 is a simplified geologic map of the

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Dhahran area. The geology has been adequately covered by several authors [1, 2, 4]. The following is a summary of the Paleocene and Eocene Stratigraphic Sequence. From bottom to top, the formations are: Umm er-Radhuma, Rus, and Dammam.

Umm er-Radhuma Formation is 243 m thick and is divided into a Paleocene lower unit and an early Eocene upper unit. The former consists of light-grey, aphanitic limestone with several persistent beds of gray to brown shale or shaly limestone. The latter consists of tan to brown, crystalline, granular, aphanitic limestone.

Rus Formation is 56 m thick and is of early Eocene age. In the outcrop the lithology varies from compact limestone at the bottom to marl, gypsum, and geodal quartz in the middle to soft, chalky limestone at the top. Sub-surface sequence, however, is highly variable and generally shows content of anhydrite and shale.

Dammam Formation is 33 m thick at the type section, and is of early and middle Eocene age. The lithology is generally light-colored limestone, marl, and shale.

STRUCTURAL AND GEOMORPHIC DEVELOPMENT OF THE DOME

The Dammam Dome is located on the stable platform of the Arabian Peninsula. The dome is believed to be the result of a deep-seated salt intrusion as indicated by the strong negative anomaly and the elliptical shape [4].

The deep-seated salt intrusion seems to have resulted in some small anticlinal and synclinal folds superimposed on the dome, but no observable faults at the surface. Several recently slumped blocks are observed in many places within the dome. The occurrence of these slumps is possibly due to one of two reasons:

(a) undercutting of soft chalky beds within the Rus Formation, or

(b) solution of anhydrite and/or gypsum layers also within the Rus Formation.

Chapman [1] believes that the Tertiary gentle doming was followed, probably during Pliocene–Pleistocene, by regional uplift, leading to the present-time dissection and small, isolated hills-and-valleys topography. According to Chapman 'the dome was denuded by combined fluvial erosion and pedimentation'. The fluvial erosion must have taken place during past periods of heavier rainfall, a deduction supported by the presence of freshwater lake beds in nearby areas [13].

DESCRIPTION OF THE CAVERNS

Although they are called 'caves' by the construction

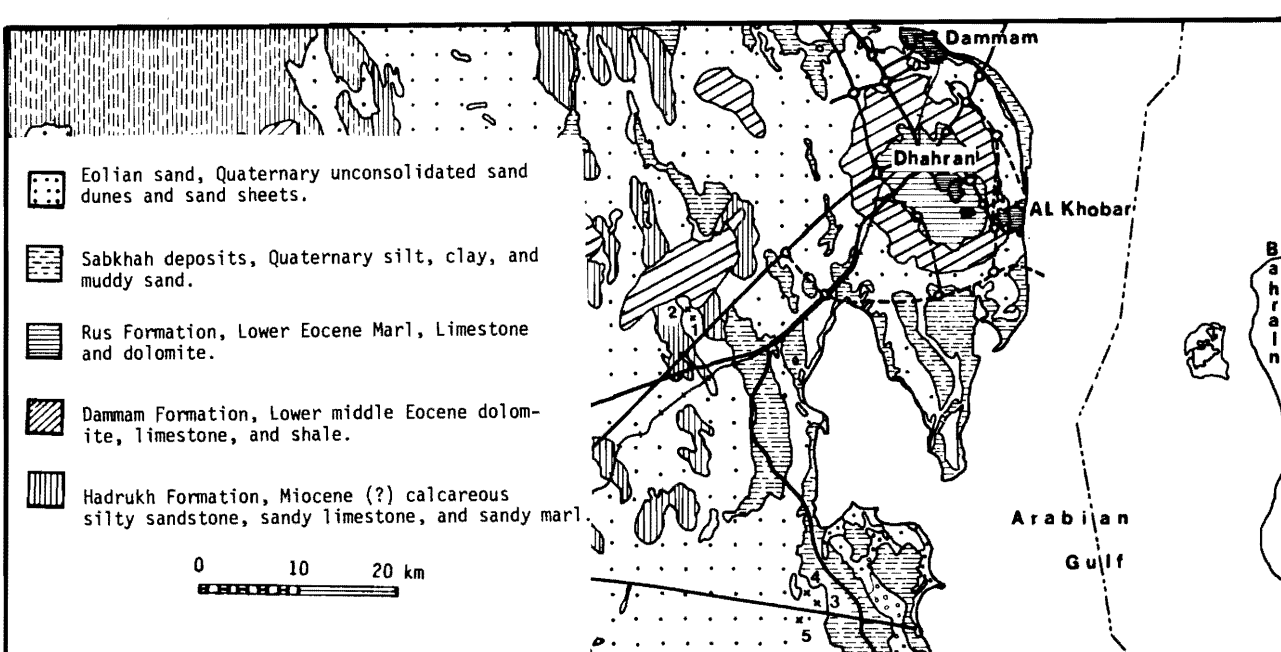

Figure 1. Simplified Geologic Map of the Dhahran Area, Eastern Province, Saudi Arabia

personnel, the holes were never actually open to the surface, but appeared only after their tops were cut open by removal of several meters of overlying limestone. The 'caves' are in fact large solution cavities or caverns rather than true caves. In each cavern a roughly circular chimney extended 1 to 2 m above the main chamber, and when the tops of the chimneys were cut, openings about a meter across appeared.

The caverns were entered by ladders, and were found to be lenticular cavities 1 to 2 m wide, 3 to 5 m high, and several meters long (Figures 2 and 3). 'Cave number one' contained a single 'room', but 'cave number two' contained two 'rooms' with a constricted passage in between, and there was a narrow, boulder-choked passage continuing downward and southerly from the southern 'room' an unknown distance, but more than 3 m. The caverns were completely dry although the air inside was quite humid. In each 'cave' there was a pile of rubble immediately under the opening. Part of this material had obviously fallen in when the cavity was broken open, but part of each pile represented collapse fragments and residue from the solution chimney above it.

When we saw the caverns, the floors had been trampled down by a number of visitors, but originally the floors seem to have been covered by soft loose solution residue and rubble.

The walls of the caverns were coated from the floor nearly to the roof with a layer of white, finely crystalline gypsum. The coating was generally 2 to 3 cm thick, but some parts were as thin as 1 cm and others as thick as 10 cm. In most places the surface had a smooth frosty aspect like compressed confectioner's sugar, but in places the surface was covered with randomly-oriented 1 to 2 mm crystals with a thin flaky habit and ragged terminations. Well-formed crystals were not observed.

In most places the gypsum coating adhered rather firmly to the limestone wall, but several patches of $\frac{1}{2}$ to 1 m^2 were found where there was a space of 1 to 3 cm between the coating and the wall. Some of these spaces

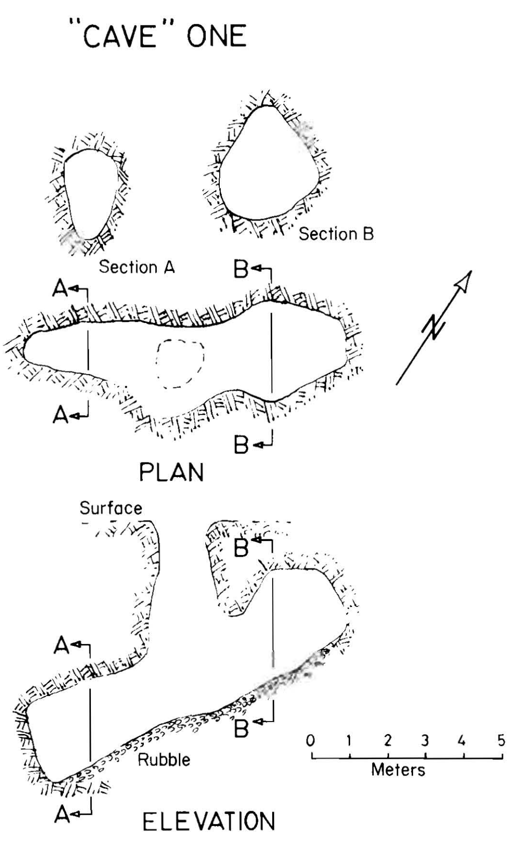

Figure 2. Illustrations of Cave Number One

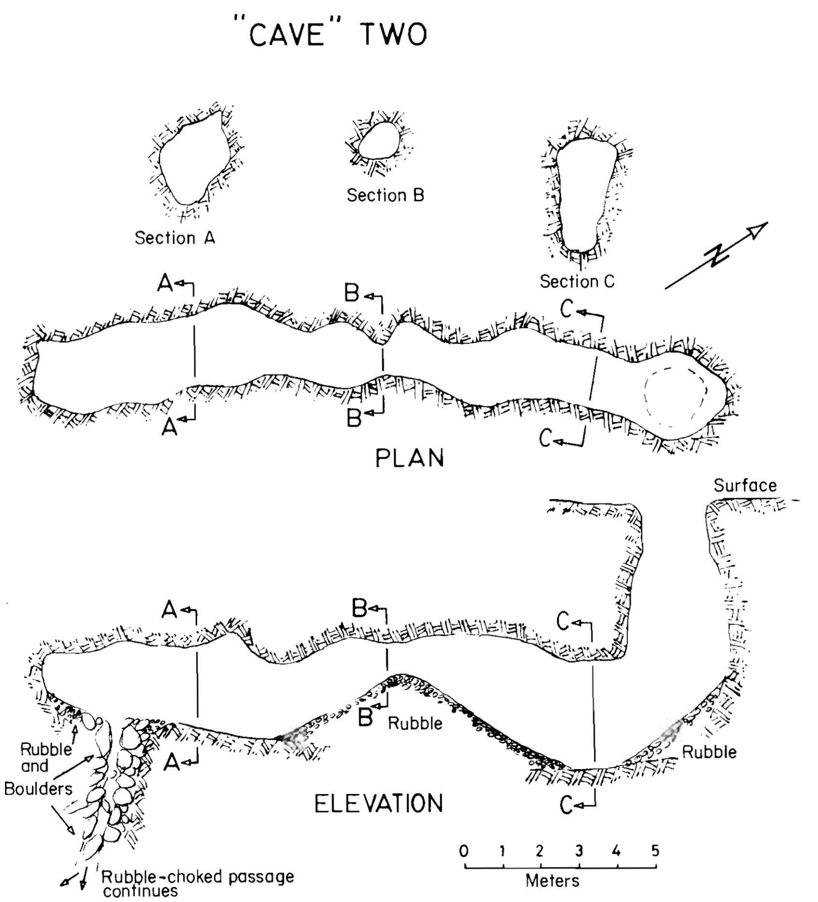

Figure 3. Illustrations of Cave Number Two

were partially filled with a soft, carbonate, silty or clayey material, apparently a residue from dissolving limestone.

The gypsum coating generally stopped below the roofs of the caverns in an irregular, more or less horizontal line which might be related to the land surface as it was when the caverns formed or perhaps to groundwater level at some later time.

In the rubble on the floor of the southern end of the north chamber of 'cave number two', a 5 × 10 × 15 cm piece of leached limestone contained what appeared to be a very poorly preserved colonial hexacoral. No other evidence of fossils was seen; the Rus Formation is poorly fossiliferous [2, 4].

Fractures were visible in the roofs of both caverns. In 'cave number one' the major fracture appeared to strike N 50° W with a dip of vertical to 85° W. In 'cave number two' the attitudes could not be measured, but appeared to be more or less parallel to the length of the cavern and near vertical. In places the fractures formed brecciated zones up to 30 cm wide in the limestone roofs of the caverns. It is not known whether the breccia was caused by faulting or by solution collapse. No evidence of fault movement was seen, but such evidence might well have been destroyed by solution.

No systematic jointing is reported in the Rus Formation and there is no apparent areal grouping or alignment of cavities such as would be expected from joint systems. Therefore, it is believed the fractures represent random joints or faults of small displacement, produced by slumping in the Rus Formation as the result of dissolution of underlying anhydrite and other evaporites after uplift of the Dammam Dome. A few hundred meters north and west of the UPM campus are large slump blocks of Rus Formation produced by this process.

ORIGIN OF THE CAVERNS

The Rus Formation in this area contains a multitude of small (1–2 mm) to large (more than 1 m) vugs or cavities attributed to solution of organic remains [2]. The vugs are largely concentrated in a number of fairly thin (10–50 cm) horizons with somewhat more massive limestone in between. Many of the vugs contain Puartz- or calcite-bearing geodes that typically occupy certain horizons. In general the upper layers contain calcite geodes, the middle layers contain quartz and chalcedony geodes, and the lower layers contain calcite geodes. Some of the middle layer geodes contain calcite as well as quartz, and many geodes in all horizons contain sparse to abundant skeletal crystals of gypsum. The filling sequence seems to be quartz, calcite, gypsum.

The vugs and cavities in the Rus Formation were formed through solution of limestone by groundwater charged with atmospheric carbon dioxide. Along fractures, much larger volumes of water would circulate than through the unbroken parts of the formation and large cavities would form in places. Dispersed silica and anhydrite would be dissolved from the limestone and reprecipitated as linings of the vugs.

The caverns are believed to have formed during periods of high rainfall, probably during late Pliocene or Pleistocene time. Large volumes of water moved through the fractures downward to the water table. Where the flow was essentially vertical, chimney-like openings formed, but where there was largely horizontal flow, lenticular caverns oriented along the fractures formed. As the climate became more arid, solution stopped and in places slump and collapse breccia partially filled the caverns. The gypsum wall coatings probably formed later, during the relatively wetter periods that correlate with the formation of freshwater lake deposits in the Rub' al Khali. At present the climate is so arid and the water table so low that little or no solution and reprecipitation takes place.

SUMMARY AND CONCLUSIONS

Solution caverns of the type described here occur in several places in the Dhahran area. They appear to be controlled by fractures that formed when the formations slumped after dissolution of underlying anhydrite. During periods of high rainfall (late Pliocene and Pleistocene), copious flows of groundwater dissolved the limestone in places along the fractures to form solution caverns. A less intense pluvial period during the Holocene, when freshwater lake deposits formed in the Rub' al Khali, probably deposited the gypsum coatings on the cavern walls.

The caverns were disclosed when overlying rock was stripped off during excavation for building foundations. The caverns are too small and lack stalactites and stalagmites to be of interest speleologically, but they are large enough to form important hazards to construction work. The caverns occur too haphazardly to be predictable from ordinary surface geology or routine drilling during site investigations. Resistivity surveys may disclose the probable existence of concealed caverns which can then be proved or disproved by careful drilling.

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