Dr. Attila Kósa

THE BIR AL GHANAM KARST AND CAVES

Tripolitania, Libya

Budapest, 2001

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CHAPTER 1

INTRODUCTION

This volume is the revised and enlarged edition of Bir al Ghanam Karst and Caves based mainly on the "Bir al Ghanam Karst Study Project, Final report" that was prepared in 1981. The original format has been retained although the text has been updated, abridged at points and increased with data, maps, text published elsewhere or in other than the English language, previously unpublished illustrations, as well as copies of selected relevant references or parts thereof.

Preliminary research on the Bir al Ghanam Karst was started by the author in 1977-79. Several caves were explored and surveyed during that period. Previous references had not mentioned the karstic nature or caves of the gypsum outcrop. However, observations on the climate, hydrology, geology, and cave hydrology etc. suggested that detailed research into the karstic nature of this particular gypsum area would be worthwhile. It was also suggested that detailed research be focused on hydrology and water resources, and investigation undertaken into the possibilities of subsurface water storage in the caves of the area.

The NIKEX-OVIBER Drilling Co. was contracted by the Secretariat of Agricultural Reclamation and Land Development, Department of Water and Soil to undertake the research work under the title of the Bir al Ghanam Karst Study Project, managed by the author. The field work for the project was carried out between 25th March and 4th June, 1981. During that period the geography, hydrography, geology, and karst morphology of the locality were studied using available maps, aerial photographs and through field work. Owing to the short duration of the field work, climate and hydrology were studied using only references. Samples of rock and water were taken for analysis both during and following the field work.

The main aim of the field work was to discover, explore and survey all the caves of the gypsum outcrop.

As a result of the Project, the karstified and caverniferous areas of the Bir al Ghanam Formation were located (Zakhrat al Ghar, Abu an Niran, South Wadi Fasat, Bir Ayyad) and surveyed. Roughly seven kilometers of cave passages are located in the listed areas representing a total volume of subsurface space of 5.400 m^3. The longest cave system of those surveyed is, Umm al Masabih ("Mother of Lanterns", ZG-I) cave, with a length of 3.593 m, and a volume of 13.350 m^3.

The outcome of the field investigation, together with the surveys, laboratory analyses, and study of the references are described in the following chapters. As for the main aim of the Project, providing water supplies for this arid area, it was calculated that two major cave systems, the Umm al Masabih and the AN-1 caves would be suitable for development as subsurface reservoirs. Their combined storage capacity of 15.180 m^3 is 60% of the total passage volume that was surveyed in the area. Calculations show that water storage in the gypsum caves would be possible but only with an experimental trial in a smaller cave (AN-4) and by taking care to respect and protect the geological, biological, historical etc. infrastructure of the area.

Other speleological features of Tripolitania were explored, among them the Ain al Mizraq pothole southeast of the town of Mizdah.

CHAPTER 2

GEOGRAPHY AND HYDROGRAPHY

The geographical center of the study area – the Bir al Ghanam Gypsum Karst – lies almost precisely at co-ordinates North 32°10' and East 12°35', 110 km southeast of Tripoli. The area is accessible via a modern hard surfaced road on the Tripoli-al Aziziya-Bir Ayyad (Nalut) route. The town of Bir al Ghanam (Well of the Sheep) after which the gypsum formation is named, is 90 km away and is shown on the Tripoli Road map.

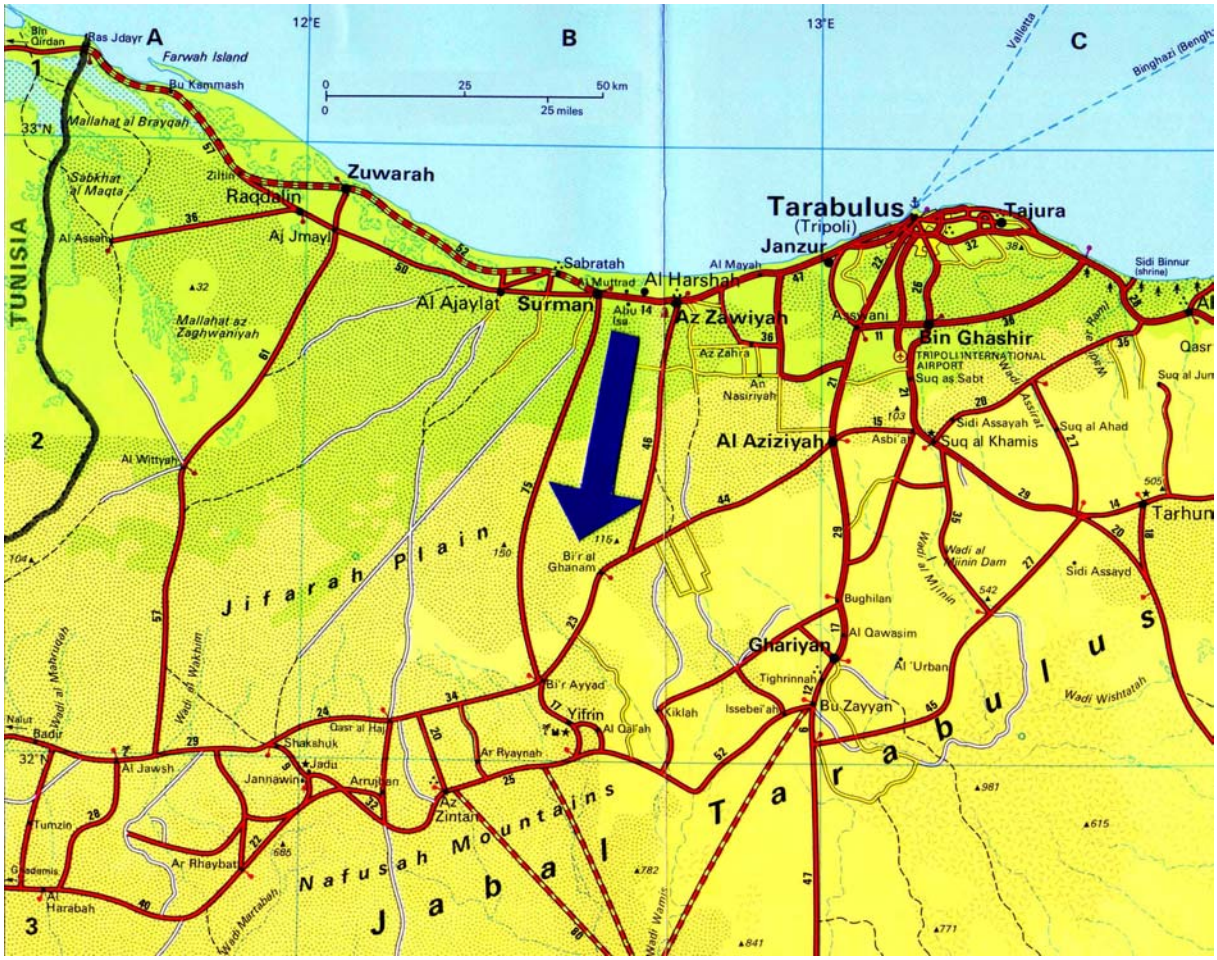


Figure 1: Part of the official road map (Fig01.jpg)

Approaching Bir al Ghanam, situated to the north, at the eastern foot of the formation, the outcrop appears as a low, light colored range rising towards the dark mass of Jabal Nefusa (Jabal Tarabulus on Figure1) escarpment, merging with it to the south.

Leaving Bir al Ghanam behind, the road enters the range which now appears as a multitude of conical hills.

The road crosses the gypsum area through a series of cuttings, before once again descending to a wide, quaternary filled valley - the Wadi at Tall. The road reaches Bir Ayyad, a small hamlet at the western end of the gypsum outcrop. Here the highway goes west to Nalut and south to the town of Yafrin following the edge of the formation.

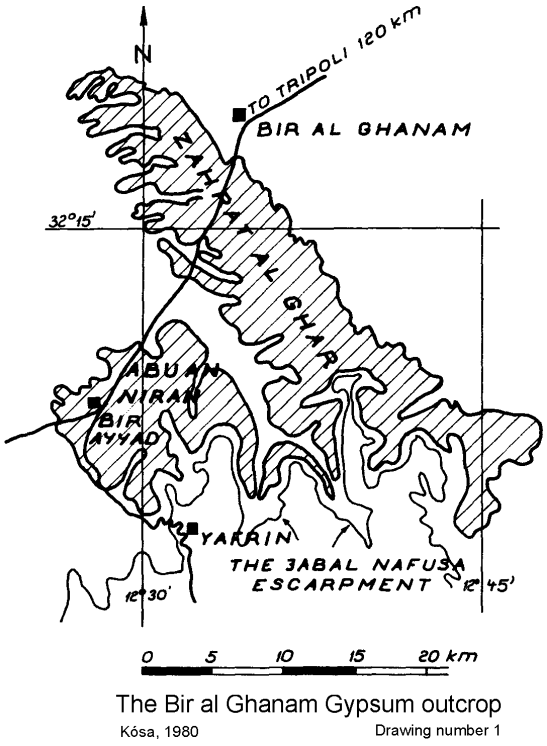
The central area of the outcrop is accessible via the road which runs east to Takbal, and on the dirt (graded) road which runs west to Yafrin, through Abu an Niran ("Father of Lights", a ghost town with ancient ruins).

Photograph 1: General view of the outcrop of the Bir al Ghanam Formation (pic01.jpg)

Photograph 2: Cone hills of the Bir al Ghanam Formation (pic02.jpg)

The outcrop of the Bir al Ghanam Formation is divided by the Wadi at Tall which marks the low flat zone between the two elevated areas of gypsum karst. The flat bed of the Wadi at Tall crosses the Bir al Ghanam-Bir Ayyad road just north of Qasr Abu an Niran. The eastern part of the outcrop, a northwest-southeast range, known as Zakhrat al Ghar (Cave Hills), gently rises towards the Jabal Nefusa escarpment and is topped by the Qaf Sidrar-Ras Aliyawah promontory. The 25 km long range rises from the 150 m elevation in the Jeffara (Jifarah) plain at its north-western end to 600 m in the Jabal escarpment.

Photograph 3: The Qasr Abu an Niran ghost town (pic03.jpg)



Drawing 1: The Bir al Ghanam Gypsum outcrop (Draw01.tif)

The range is crowned by the ancient ruins of Qasr al Mahmal (546 m). The western section known as the Abu an Niran Karst is a smaller area topped by the pointed peak of Ras Tamallah (Tamallilt, Tamallalah), an isolated remnant of the main Jabal escarpment.

The hydrography of the area is dominated by the Wadi at Tall (shown as Wadi ash Shaykh on the Geological map). Its two main tributaries (lower Takbal and lower Tigrinnah) originate on the Jabal and their erosion has been responsible for the development of deep valleys reaching into the scarp and which bisect the gypsum outcrop. Some streams of lesser importance originate on the slopes of the escarpment. The streams that originate outside the gypsum area are referred to as "transit runoff". The majority of the runoff in the study area originates within the hills of the outcrop.

The relief and features of the Bir al Ghanam Gypsum Formation were studied and the hydrographic map was drawn using aerial photographs. The study of the aerial photographs of the area under consideration was carried out with two aims:

- the study of the hydrography and morphology of the outcrop of the Bir al Ghanam Formation

- the study of the geology of the outcrop.

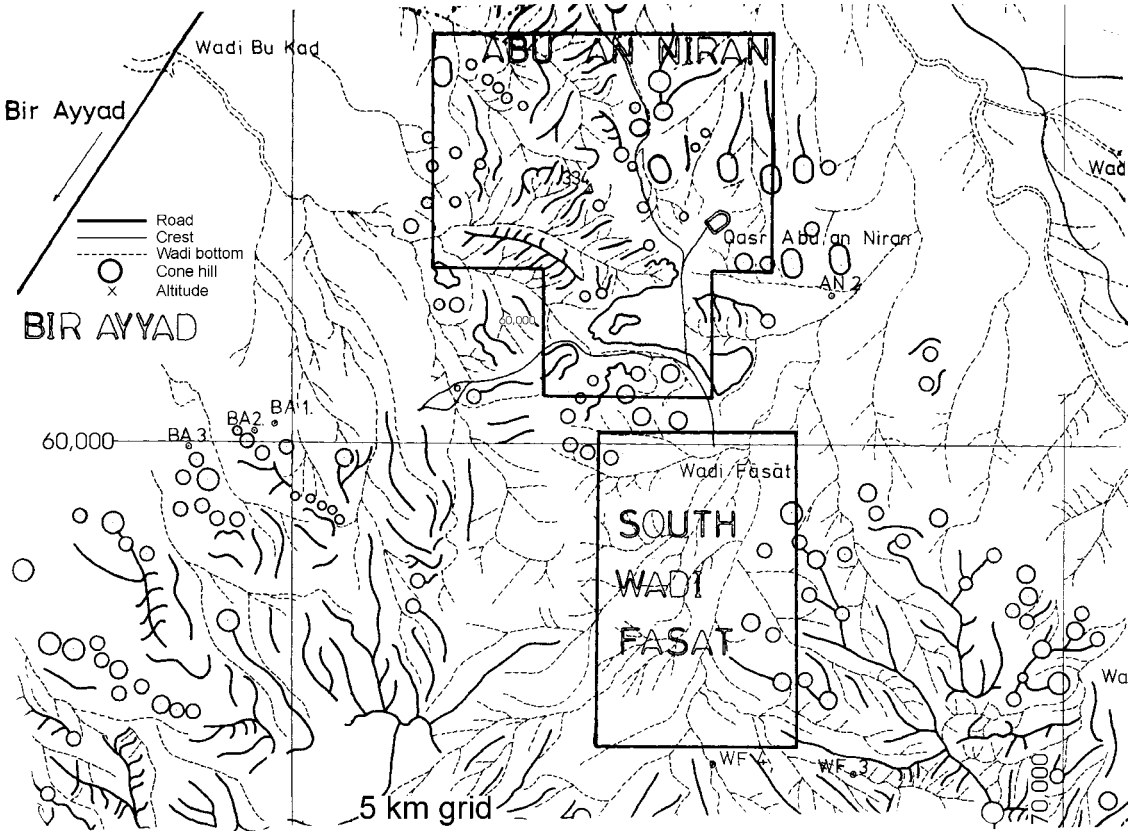
The ultimate aims of the project were the location of karstic phenomena that are visible from the air and may indicate sizable caves, and the location of such hydrographic and geological features that may indicate or exclude the occurrence of caves.

For the preparation of the hydrographic maps, 32 pairs of aerial photographs were used and, in cases of uncertainty, photographs of flights over adjacent areas were used for confirmation. Thus, the study of aerial photographs necessitated the interpretation of 73 frames.

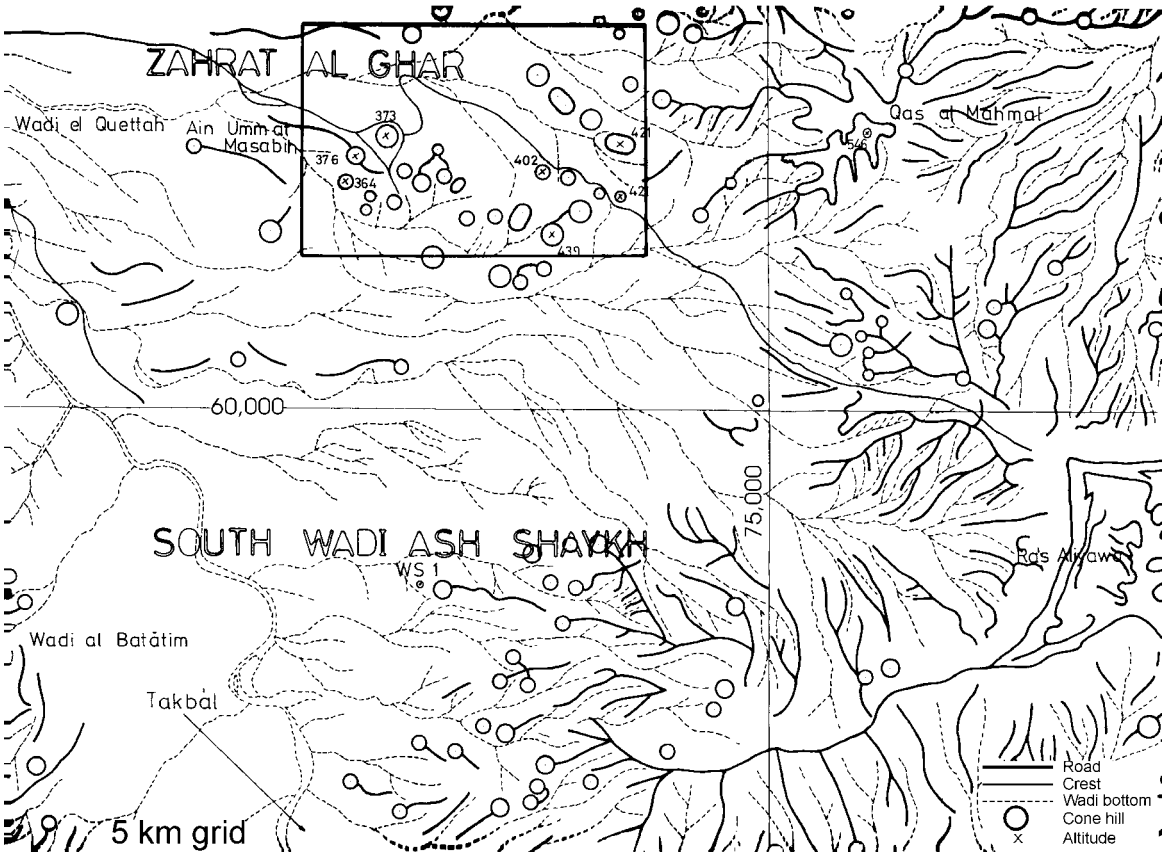
During the flights, generally two frames were taken of every point in the area. This facilitated the study of the subject area with the help of a stereo-viewer. This method was necessary because, depending on the angle of the photography and lighting, the same surface object could appear differently in shade and shape. The utilization of stereo pairs minimized errors in interpretation. A further reason for making double coverage was so that the center of each frame depicted the most precise, sharp and undistorted projection of the surface objects, as quality tends to deplete towards the edges. To make the necessary corrections, the central areas of the frames were used in the making of the hydrographic map which was copied onto transparent paper thus defining the characteristic shapes on the surface.

During the interpretation, firstly the hills, ranges and the characteristic gypsum cone hills were drawn representing the hydrological divides. Recognition of the ranges was relatively easy but description of the real forms was difficult. In numerous cases ranges under the stereoscope proved to be series of cone hills. In cases like these the most likely representation was adopted and checked in the field. In the case of single cone hills, the base line was used to represent the feature. In the case of plateaus the easily recognizable borderline of the rim was drawn. Due to the fact that the map in question was intended to facilitate the study of the gypsum outcrop, the description of other formations was largely ignored.

The network of valleys is easily traceable on the photographs, all of them represented by dashed lines on the map. In the case of very wide wadis, both banks were indicated with dashed lines. The beds of the streams and their networks were traced from their source to the main sinks. Roads existing at the date of the flights were included on the map. Only details of the large map relating to the caves discovered are shown in the figures in this volume.



Drawing 2-1 and 2-2: Caverniferous areas of the Bir al Ghanam Karst, topographic map (Draw0201.tif and Draw0202.tif)



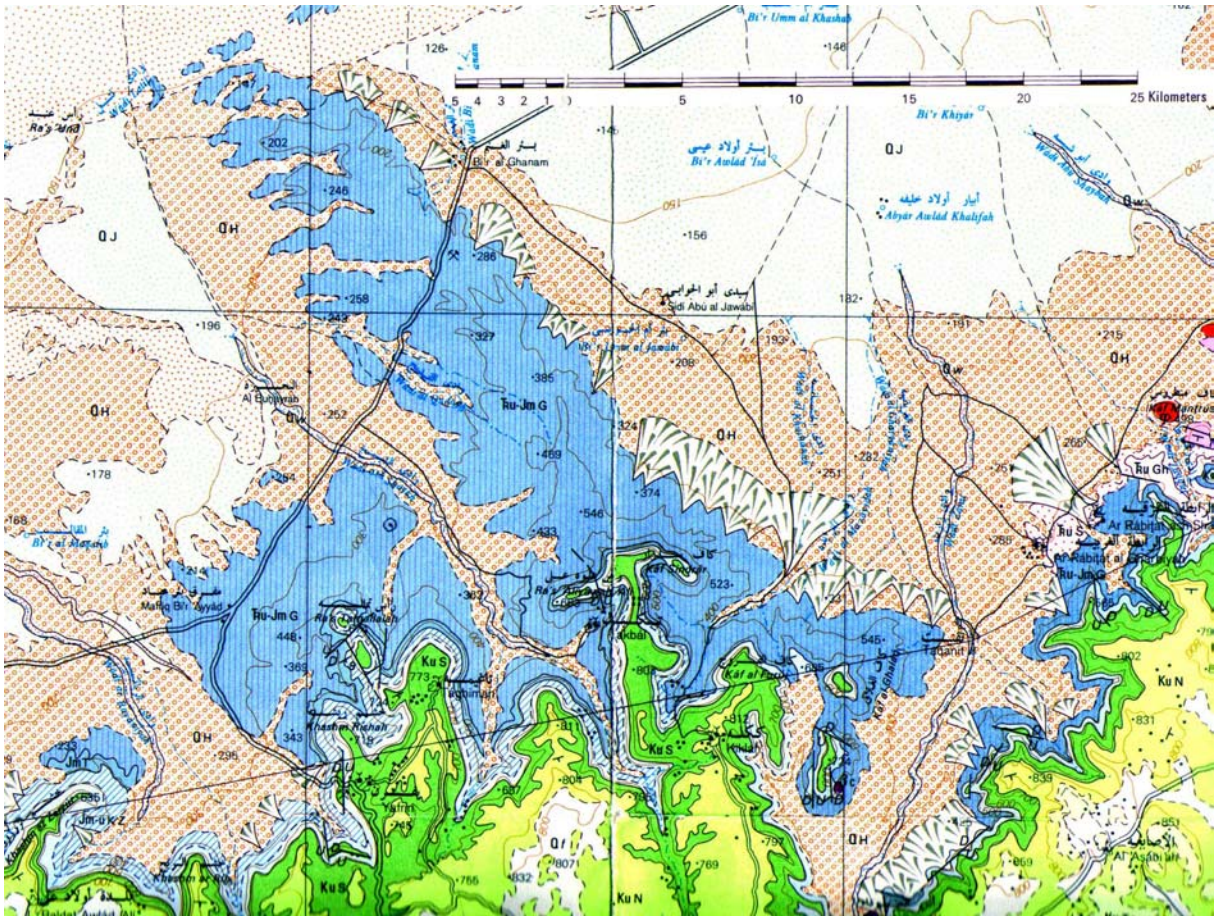
Drawing 2-2:

(The methods of locating karstic phenomena are described in detail in Chapter 3 on geology.)

CHAPTER 3

GEOLOGY

The aims of the geological survey were the location and subdivision of the Bir al Ghanam Formation, and location and classification of karstic phenomena in the gypsum outcrop. Based on the stereoscopic study of the aerial photographs and from the interpretation of available topographic and geological documents, a geological map was prepared. Determining the limits of the surface area of the formation meant its separation from the overlying Takbal and Kiklah formations and the outcrop of underlying strata, the Abu Shaybah Formation (mostly missing) and from the Quaternary cover.



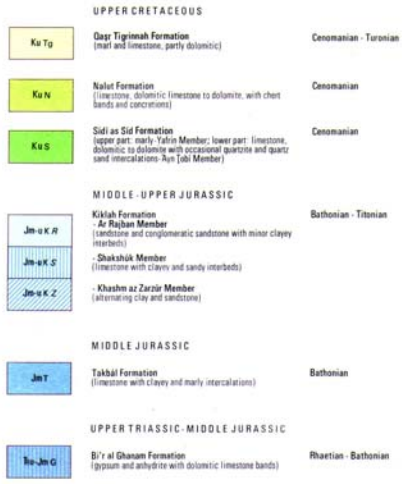


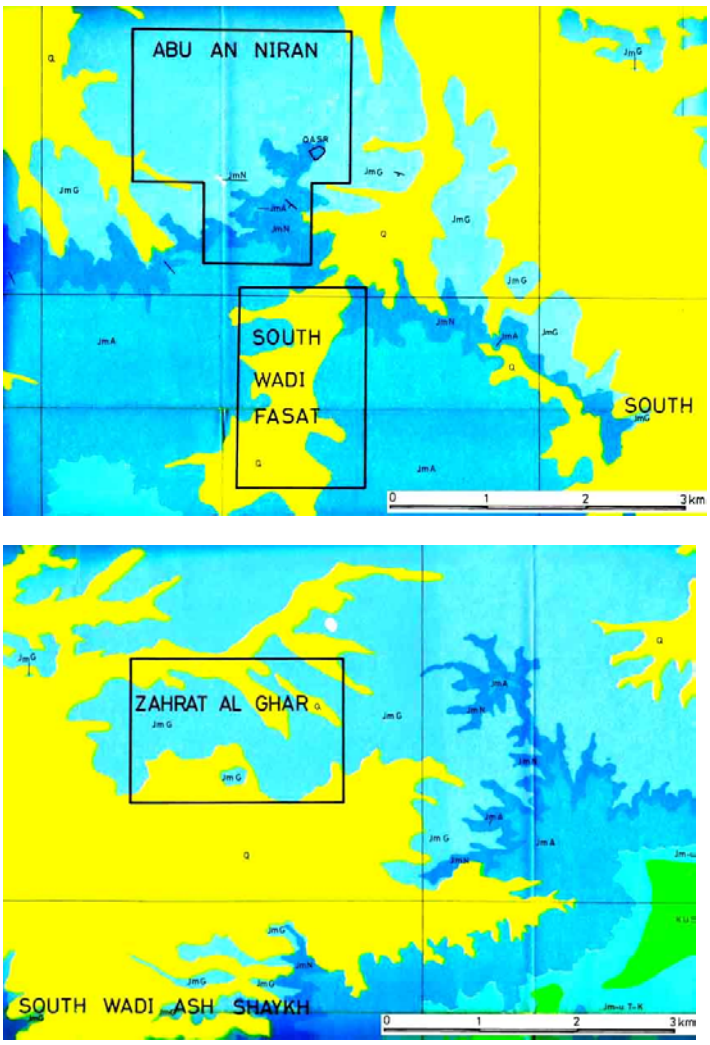
Figure 2.1, and Figure 2.2: Geological map and color code (Fig0201.jpg and Fig0202.jpg).

A detailed geological survey was completed in 1981, details are given below.

3.1 Extension of the Bir al Ghanam Formation

The Formation is observable on the surface in the Jabal Nefusa Escarpment from Ar Rabitat to Bir Ayyad, and as far as the Tunisian border and beyond at the foot of the escarpment on the Jeffara Plain. The great surface extension of the exposure is not uniform. It appears in a larger continuous area only in its Ar Rabitat-Bir al Ghanam-Bir Ayyad section, the rest of the exposure emerges only as isolated outcrops at the same level as the Jeffara. The formation is exposed only as a stripe several hundred meters wide in the scarp west of Ar Rabitat to Wadi Zarat. The main mass of the outcrop is found as a

"spur" starting in the escarpment under the town of Kiklah (Kaf Sidrar) and reaching 35 km north west until it is level with the Jeffara. The other site of the main massif is exposed under the town of Yafrin. (Ras Tamallah or Tamallalah, Tamallilt on other maps). The two sites are separated by the 2-4 km wide Quaternary sediment fill of the Wadi at Tall. The surface area of the main part of the gypsum outcrop is about 350 km^2.



Drawing 3-1, 3-2, 3-3: Geological map and color code of the caverniferous areas of the Bir al Ghanam Karst (Draw0301-0302-0303.jpg)

3.2 Stratigraphy

The Bir al Ghanam Formation lies above the red and green clays of the terrestrial Abu Shaybah Formation interbedded by red sandstones. This formation is visible on the surface in the vicinity of Ar Rabitat. There is no transition between the two formations and there is possibly a sediment gap as the ages of the two formations are different. The underlying formation is not observable west of Ar Rabitat on the surface, but the same structure was proved in a borehole near Bir al Ghanam.

The overlying formation of the Bir al Ghanam Formation is the Takbal Formation which consists mainly of greenish-gray clayey marl, and some dolomite and marl. The sedimentation is continuous. The transition is observable west of Takbal. East of Takbal the Takbal Formation and the top of the Bir al Ghanam Formation has been eroded by weathering. Here the reddish-brown clays and sandstones of the Kiklah Formation overlie the Bir al Ghanam Formation. From the aerial photographs, it was not possible to distinguish accurately and consistently the two types of overlying formations and thus these are drawn simultaneously on the geological map.

The thickness of the Bir al Ghanam Formation is about 400 m. This somewhat indeterminate assessment has been arrived at by logical extrapolation, as nowhere is the full thickness of the formation exposed.

The stratigraphy of the study area is monoclinic, its strike south-southwest (approx. 200-210°) dipping at 1-2°. The measurement of the dip is somewhat unreliable because of the tilted, corroded bedding planes and the convoluted nature of gypsum substrata.

The Bir al Ghanam Formation, as studied on the surface and in the caves, consists, in the main, of gypsum, intercalated by thin layers of clays, clayey marls, dolomite, dolomitic and calcareous marls. It must be emphasized that this observation is the result of research on the surface and in the caves. Acknowledging the widely accepted theory, that gypsum ($CaS0_4$ + $2H_20$), originates from anhydrite ($CaS0_4$), as an effect of descending waters, it must be supposed that in the depths of this formation, anhydrite will prevail (traversed by drilling at the upper edge of the Jabal), but that this plays an unimportant role both on the surface and in the caves. The formation was subdivided from top to bottom into sulfate and non-sulfate parts:

- Bir al Ghanam Gypsum
- Bu an Niran Member
- Abregh Gypsum

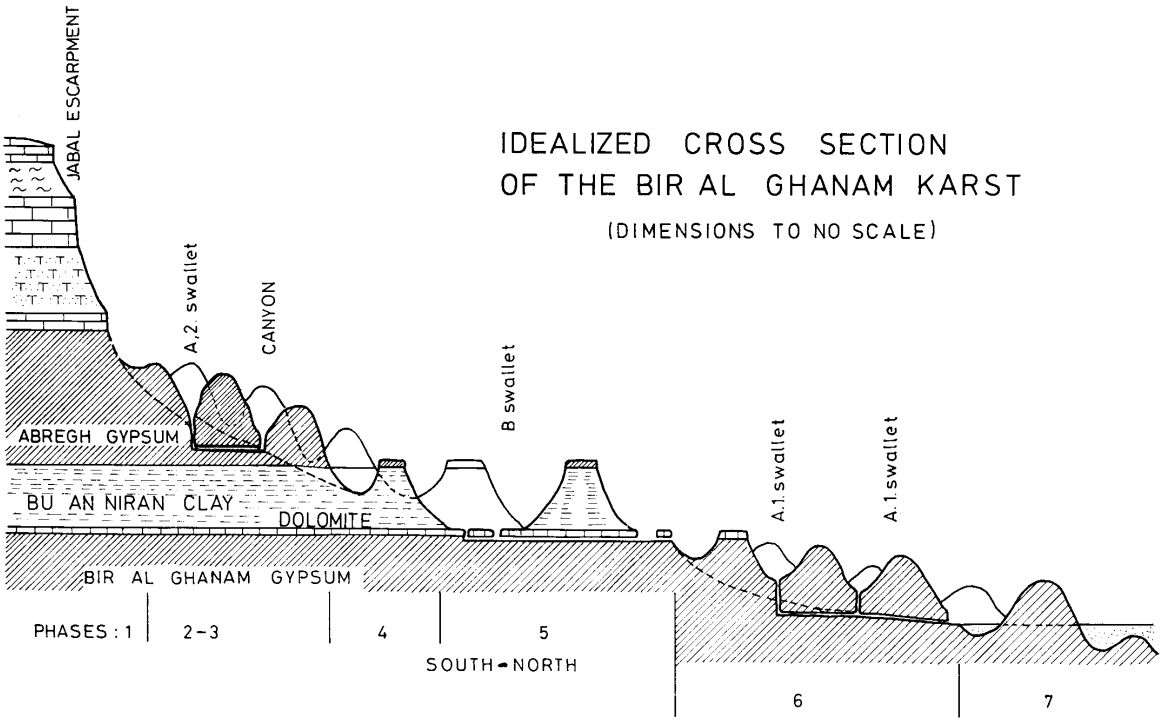
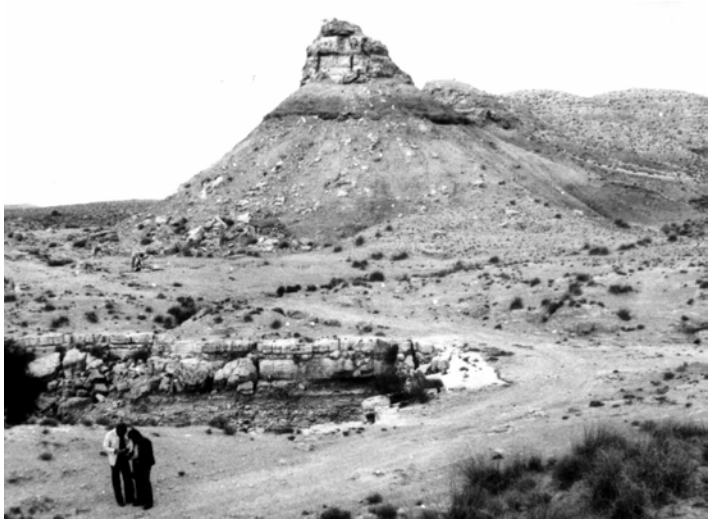


Figure 3: Stratigraphic section of the Jabal Nafusa (see explanation later) (Fig03.tif)



Photograph 4: The view of all three members: Bir al Ghanam gypsum in the trench, topped by Bu and Niran dolomite. Bu an Niran clay in the butte, Abregh gypsum topping it. (pic04.jpg)

3.3 The Bir al-Ghanam Gypsum Member

Because of its thickness the Bir al Ghanam Gypsum comprises the largest surface extension. Starting at Ar Rabitat only this member can be located. It makes up the northern flank of the outcrop in the main mass of the formation. The thickness of the member is an estimated 300 m making up about three quarters of the whole formation. Near to the surface, the member consists mainly of gypsum. The lower 200-250 m of the member is frequently intercalated by

layers of dolomite and dolomitic marl found in increasing quantities as the strata goes lower. The dolomites are generally brownish-gray, gray, scaly or scallopy fractured, micro-crystalline, and containing flinty lenses. The fractures of the dolomitic-marl are scaly, and scallopy.

The dolomite and marl intercalations make up a maximum of 10% of the said lower strata, but, owing to their relative resistance, only debris of these can be found on the hillsides west of Bir al Ghanam, while gypsum layers are observable only in the steepest slopes as cliffs.

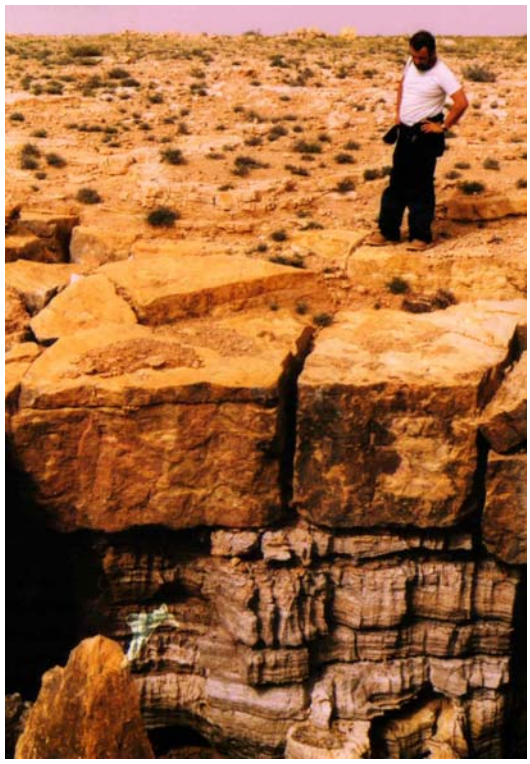
The color of the gypsum layers is light brown-gray, "smoky" gray, grayish white, dark gray, yellowish gray, pink or red. Alternating light and dark gray colored occurrences with 1-5 cm stripes are common.

The sequence of the varieties described makes the member typically layered. The stripes, in places, are irregularly bent, and crumpled ("Snake gypsum"). As there is no visible occurrence of this nature in the neighboring layers, it is obvious that the bending is of non-tectonic origin. However, it is possibly a result of the swelling of the rock during the anhydrite-gypsum transformation.

The physical nature of the gypsum rock is generally fine to small crystalline, less commonly medium grained. The light gray and faint yellowish gray varieties frequently contain ideomorphic 5 to 30 mm twinning gypsum crystals always darker than the matrix of the rock. These porphyric gypsum varieties are abundant in the upper part of the member. The crystals are to be found in numerous stripes which are several centimeters thick. The individual porphyric crystals are not orientated. Intraclastic gypsum material is also frequent and where the intraclastic material is dark, the basic matrix is light gray colored.

Practically all varieties of gypsum are thoroughly fissured. The 1 mm to 1-2 cm clefts are filled by watery clear fibrous gypsum. The fibers are always at right angles to the planes of the clefts. The clefts are often parallel to the bedding planes and thus these give an accentuated layered appearance to the rock. Fibrous gypsum filling is frequent in the darker gray varieties of gypsum rock. Intercalations of dolomite lenses and ribbons are frequent. These intercalations are relatively more resistant to weathering, and they protrude from the surrounding weathered rock. More frequent are the greenish gray clayey-marly 1 mm to 10 mm cleft fillings which, being washed out, are not visible on the corroded surfaces, but appear clearly in fresh fractures.

X-ray diffraction and DTA analyses showed that the rock contains 91-98% gypsum. Dolomite is ubiquitous in 1-7%. Celestite and anhydrite make up a maximum 3% or appear only as traces. It is no surprise to find anhydrite in the rock as it was probably the main constituent of the original sulfate mass of evaporites. Knowing the rapid process by which anhydrite-gypsum is transformed upon exposure to water, it is most surprising to find 1 cm to 1 m thick intercalations of anhydrite in the central section of the Umm al Masabih cave which is located in the upper part of the member. This fact is most intriguing, as the rock is very broken here, and might have occurred because of the presence of brittle anhydrite. Also maximum contact with water is possible due to the presence of the intermittent cave stream, but the transformation to gypsum has not taken place. Owing to the fact that anhydrite is relatively less soluble, layers of it protrude from the walls, making the cave passage very narrow in this section. Clay and marl intercalations are typical in the member. They appear most frequently at the top of the member in 10 cm to 1 m thick layers only a few meters under the Bu an Niran Member. The intercalations are grainy in structure thoroughly interwoven by veins of gypsum. In the walls of the caves and the steep canyon walls only the boxwork of the gypsum is visible, as the loose clayey material has been washed out. The erosion of these clays by streams flowing though the caves has resulted in the formation of some large cave passages. (e.g. AN-3 cave).



Photograph 5: Bir al Ghanam gypsum with rain channels topped by the Bu an Niran dolomite. (The ghost town in the background) (pic05.jpg)

Owing to its high solubility, gypsum rock appears on the surface either as weathered spongy surfaced blocks or as intensively corroded bedding planes. Rocks on the surface are composed of the most resistant materials. The most soluble and clayey rocks have been washed away and depressions have developed, filled with clayey debris making

kind of a conglomerate with the loessy sediment of ever falling dust. These depressions contain some soil on which sparse vegetation grows thus making it easy, using aerial photographs, to distinguish between the gypsum and other formations on the outcrops. Fresh gypsum rocks can be found only in caves and steep canyon walls. The gypsum appears with scallopy surfaces in the caves and marked with sharp vertical rain channels on the surface.

The weathering of the thicker 0,5-1,0 m gypsum layers is retarded. These layers appear as small plateaus easily visible on the aerial photographs in the upper part of the member where they are less frequent. They occur more frequently in the lower part of the formation and are thus less visible.

3.4 The Bu an Niran Member

The surface exposure of the member is observable west of the Wadi Zarat to Bir Ayyad road parallel to the escarpment of the Jabal Nefusa. It comprises the middle member of the Bir al Ghanam Formation between the Bir al Ghanam and the Abregh gypsum. The thickness of the Bu an Niran Member is about 20 m. It is visible on the face of the escarpment as a thin red stripe. The lower dolomite part of the member has formed plateaus under the Kaf Sidrar promontory and under Ras Tamallilt. The sharp edges of both plateaus are capped by ancient ruins, Qasr al Mahmal and Qasr Abu an Niran.

Photograph 6: Plain formed by the Bu an Niran dolomite. Bu an Niran clay topped by Abregh gypsum forms the butte in the background. The Ras Tamallilt rises at left top (pic06.jpg)

The Bu an Niran Member represents a characteristic non-sulfate intercalation in the Bir al Ghanam Formation. Its petrographic composition is almost consistent horizontally. The lower part of the member comprises of a 2-3 m thick, yellowish-gray, hard, scallopy, fractured dolomite layer which has remained firm in spite of its thinness following the weathering of the overlying rocks. The lower part of the dolomite bed contains cores and imprints of gastropodes. The thick dolomite layer is connected to the upper, pelitic part by a 1-2 m thick, thinly layered, transitional zone. This upper part appears as a steep slope owing to its weak resistance to the weathering forces. The clayey part is preserved in places as buttes or mesas capped by the lowermost gypsum layer of the Abregh Member. The lower 12-13 m thick sequence of the pelitic layers consist of greenish yellowish gray clayey marl of which, according to mineralogical analysis, the carbonate constituent is dolomite.

Gypsum concretions consisting of 1-10 cm diameter lenses of light to deep red coloration (rosettes) are common in these layers. The upper 2-3 m of the member is reddish brown clay which is very conspicuous since, in spite of its thinness, its debris covers the lower slope, painting it red. Numerous watery, clear, fibrous gypsum ribbons vary the sequence of sub strata. According to analyses the clay minerals of the rock are kaolinite, illite and montmorillonite.

The Bu an Niran member is tilted westwards by about 2%. Its altitude is about 500 m at Qasr al Mahmal but it dips under the surface at Bir Ayyad (200 m).

Photograph 7: Gypsum rosettes, two still growing in clay. (pic07.jpg)

3.5 The Abregh Gypsum Member

The surface extension of this member is limited to the southern section of the study area. It is divided by a sharp border from the underlying Bu an Niran Member, but the stratigraphic continuity is unbroken. The transition to the overlying Takbal formation is also continuous. The thickness of the Abregh Formation is 80-100 m. Rocks making up the member are rather similar to those in the Bir al Ghanam Gypsum, primarily gypsum, followed by dolomite, dolomitic marl, calcareous marl and clay. Gypsum is dominant in the lower part of the member, non sulfate intercalations are scarce and not thicker than 10-20 cm. The lower part is 20-30 m thick. The non sulfate layers increase in number and thickness higher up in the member until the gypsum disappears and the sequence gradually becomes incorporated into the overlying formation.

The varieties of gypsum in this member are similar to those found in the Bir al Ghanam Gypsum. A 6-10 cm thick red colored layer is its only outstanding feature. The dolomitic intercalations are various. Their color is light gray to yellowish gray, and the micro texture is fine grained. Some intercalations contain ooids in rock building quantities. Flinty varieties are also frequent. The marly intercalations are 20-50 cm thick interspersed by gypsum, greenish gray in color, which is observable both in the steep slopes and in the cave walls.

3.6 Age of the Bir al Ghanam Formation

The latest publication dealing with the stratigraphy of the area (Hinnawy-Chestitev, 1975) determined the age of the formation as upper Triassic-middle Jurassic considering its stratigraphical position and its fossils. The geological map included in this book indicates a narrower interval and establishes the whole sequence within the Dogger. Paleontological evidence in both the Bu an Niran and the Takbal formations hint at middle Jurassic origins, the Bajocian and Bathonian – a narrow interval. Based on these facts, it is believed that evidence proving a Triassic age younger than Carnian or Liassic does not exist. Fauna found in the dolomite of the Bu an Niran Member indicates a temporary open sea connection for the lagunal evaporitic gypsum formation and thus it can be attributed to the Dogger. Nothing suggests an extension of the age of the 300 m thick lower member to the Liassic, or even to the upper Triassic, but, based on the aforesaid narrow intervals, it is believed that the age of a lagunal sequence of such thickness falls within the parameters of the Bajocian, or is, at its deepest, in the Aalen period of the Dogger.

3.7 Karstic Phenomena in the Outcrop

It is clear from the foregoing that gypsum suitable for karstification can only be found in two horizons, the upper zone, approximately 50 m of the Bir al Ghanam Gypsum, and in the lower 20-30 m of the Abregh Gypsum. Other parts of the formation under or above those referred to previously, owing to the presence of what is only a small percentage of the non-sulfate intercalations, have developed into characteristic karstic terrain. This terrain resembles tropical cone karst in appearance but is not suitable for the development of underground drainage. Swallets and underground karst systems have developed only in relatively level areas – even in the aforementioned well karstifiable zones. On steep terrain, deeply cut canyons appear as the only means of runoff. Bearing in mind these criteria, penetrable caves have primarily only developed in the level inner zone of the main outcrop of the formation on both sides of the Wadi at Tall: the Zakhrat el Ghar and Abu an Niran - South Wadi Fasat areas.

As a result of the study of the aerial photographs karstic phenomena, which hint at the existence of caves, were identified in all three members of the formation. These phenomena included engulfment points in the rock for intermittent streams (swallets) and collapses of cavities (sinkholes). It must be noted here that the resurgences of underground streams (springs) appear as short extensions to major wadis but most of these were later not identified as springs.

Also many springs open at the foot of cliffs and are invisible from above. Thus the identification of springs on aerial photographs is possible only when based on previously gathered field data. The karst conduits originating at identifiable sinkholes or swallets developed in gypsum, but their openings are also observable on other surfaces.

Karstic phenomena on gypsum surfaces occur in the upper part of the Bir al Ghanam Gypsum and at the lower part of the Abregh Gypsum as the most pure gypsum sequences of the formation. The karstic phenomena show as impressions on the surface on the aerial photographs and are accentuated by the enlarged image shown by the stereoscope. Directly observed objects are successions of steep walled funnels 5-15 m in diameter. Swallets with important catchment areas develop at the ends of "blind" valleys. The cave opening itself is rarely visible on the aerial photograph but, in many cases, vegetation in relatively wetter places indicates the presence of karstic phenomena.

Gypsum terrain swallets occur in three separate locations in the following areas:

- Zakhrat al Ghar,
- Abu an Niran,
- South Wadi Fasat,
- Wadi ash Shaykh,
- Bir Ayyad

Of these areas the first three are of real significance. Only two swallets in this category are situated outside the above mentioned areas. (BA-4, WS-1).

Karstic phenomena on dolomite surfaces occur on the top of the plateaus of dolomite which are themselves the top of the exposed lower layer of the Bu an Niran Member. The phenomena include irregularly shaped collapses – sinkholes 5-20 m wide – accentuated by accompanying vegetation, such as the sinkholes on the dolomite plateau west of the Qasr Abu an Niran. Two minor sinkholes were also observed on the plateau of the Qasr al Mahmal.

Karstic phenomena on the surface of the Quaternary cover appear as large funnels in loessy material. Most typical are WF-5-2 and AN-1-4. The loessy sediment fills depressions and valleys.

(See more details in Chapter 7)