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Geology of Ayn Al Majdoub Karstic Lake, Benghazi, NE Libya

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Highlights

- **Ayn Al Majdoub Karstic Lake belongs to Ayn Zayanah Karstic system.**
- **This lake was formed by dissolution of the soft units in the bottom of Benghazi Formation (middle Miocene).**
- **Lithology, Structure and Hydrology are main agents contributed to the formation of this karstic feature.**

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ABSTRACT

The major karstic area in Libya known as Ayn Zayanah system is a unique phenomenon of concentrated karstic surface and subsurface dolines and channels.

By focusing on Al Majdoub Lake, as a case study, we can better understand how lithology, structure and hydrology contribute to the regional formation of the Karstic system.

Geologically, the limestones of the middle Miocene, Benghazi Formation is forming the northern side of Benghazi region, which is characterized by well-developed surficial, interface, surface and subsurface karstic features that are open or filled with sediment. The formation of Ayn Majdoub doline is filled with saline water, which is attributed to the dissolution of a buried carbonate layer by fresh groundwater due to the drop of the Sea level and the associated groundwater levels. This is combined with epeirogenesis movements, which have caused the development of karstification to reach a depth of 130-150 m below present sea level in the Benghazi plain. Through this Karstic system, groundwater seeps from Benghazi Basin towards the Ayn Zayanah (The Spring) and then to the Blue Lagoon (The Lake) finally to the sea.

1. Introduction

Dolines are natural enclosed depressions found in karst landscapes (Ford and Williams, 2007). They are subcircular in plain view, tens to hundreds of meters in diameter, and can range from a few meters to about a kilometer in width. They are typically a few meters to tens of meters in depth, but some are hundreds of meters deep. Their sides range from gently sloping to vertical, and their overall form can vary from saucer-shaped to conical or even cylindrical.

Ayn Al Majdoub doline is located about ~5 km north East the center Benghazi city (Fig. 1), defined by the coordinates (32° 09' 18.1" N) and (20° 07' 44.1" E). The lake is oval shaped with a length of 250 m, width of 135 m and estimated depth of 40 m (Fig. 2). The Ayn Zayanah water system is one of several natural lakes (dolines) that has an electrical conductivity of 9,320 (µmhos/cm) recorded in 2016. This doline and the others represent the outlet of aquifer complex system flowing within the Neogene limestone. The lithology of study area represented by Middle Miocene algal limestone Benghazi Formation of Ar Rajmah Group. The aim of this study is to see how does the geological factors (lithology, structure and hydrology) are involved in forming the Ayn Majdoub lake.

Fig. 1. Satellite images show Al Majdoub Lake.

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Fig. 2. General view of Ayn Al Majdoub Lake.

2. Geology

2.1 Karstic System

The karst is formed by a solution of calcium carbonate in the rocks by water containing carbon dioxide (Bates and Jackson, 1987). The major karstic area in Libya is concentrated in AL Jabal Al Akhdar region, it is mostly composed of carbonate rocks, and it has moderate amounts of precipitation which is important for the generation of different features of karstification. These features are mostly found in the exposed rocks of the study area, and similar to those existing in other parts of the whole region. Karst landforms are characterized primarily by underground drainage in areas of massive limestone, and by the formation, at the ground surface, of hollows and pits where water enters the rock and enlarges joints and fissures by solution (Blair, 1986).

Karst development is most effective where a very thick, hard, and well-jointed limestone occurs in an area of high relief with a humid climate. Thin limestone do not permit the development of underground drainage; soft limestone such as chalk does not permit the survival of deep surface depression or the formation of caves and passages underground, and in arid regions; the water is insufficient water for such solution to occur.

2.2 Karst Development on Benghazi Plain

- **Spatial distribution**

Despite the fact that Benghazi Plain is mainly composed of Miocene limestone rocks the relatively low rainfalls have led to a very irregular development of the karstic patterns within the groundwater basin (Guerre, 1980). Although the sinkholes are numerous and generally have wide openings, especially on Miocene outcrops, horizontal karst patterns are well developed, except in the Benghazi plain where the groundwater flow from the whole basin has been concentrated. Elsewhere, karstic development below the water table remains locally related to peculiar structural conditions which are almost completely unconnected, as in the central part of Al Marj plain (Rohlich, 1974).

- **Depth of Karstification**

In the study area, due to their stratigraphic position, the Miocene limestones are more intensively karstified than the Eocene limestone's. However, the friability of the Miocene limestones and their important clay or sandy contents has led to rapid fossilization of part of the early karstic patterns by collapsing and filling up with residual materials.

2.3 Karst Controls

The control factors on karsts formation include seven main factors that contribute to the evolution of karsts terrain (lithology, structure, relief, hydrology, climate, vegetation and time) (Blair, 1986). The solution process begins with carbon dioxide combining with water to form carbonic acid, as shown in Eq. 1.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \quad (1)$$

Eq. 2. illustrates that the carbonic acid dissolves limestone, and it goes into solution,

$$C_aCO_3 + CO_2 + H_2O \leftrightarrow Ca^2 + 2HCO \quad (2)$$

2.3.1 Lithology

Although karst develops primarily on carbonate rocks (mostly limestone), not all carbonate rocks possess the proper combination of physical and chemical properties that are conductive to a generation of karst topography (Palmer, 1977). Most of the world's karst regions are developed on limestone, which by definition consists of at least 50 % calcite and/or aragonite (CaCO3). Isomorphism substitution of magnesium for calcium in the carbonate mineral structure forms the mineral dolomite, the rock is dolostone. In general, the purer the limestone (CaCO3), the greater its ability to form karst. Some evidence suggests that about 60 % CaCO3 is necessary to form karst, and about 90 % may be necessary to fully develop karst. However, even pure limestone may not produce karst because lacking the important factors. Some karst features may form on dolomite, but their permeability is typically lower than that in limestone (Herman and White, 1985). Therefore, the occurrence of karst in dolomites is usually relatively minor.

2.3.1.1 Lithostratigraphy of Ayn Majdoub

Benghazi Formation consists of bioclastic packstone grades to algal boundstone, the bioclasts are dominated by rich coralline red algae, echinoids and benthonic foraminifers with sparse bryozoan remain at some levels. This formation is partly dolomitized and shows vuggy porosity. It was deposited in a shallow neritic environment with affinity to reefal build up. This formation is well karstified, due to the low porosity and massive limestone, which is characterized by algal boundstone textures (Muftah *et al*., 2009). It is well jointed in the Kuwiffia -Ayn Zayanah region near Benghazi City and is providing weak zones for water percolation in order to develop karst (Abdulmalik *et al*., 2007). The beds of Benghazi Formation are thick and gradually become thinner upward. It is represented by five limestone units, they are from oldest to youngest as follows (Fig. 8 and Table 1):

Unit (1)

Oysterid-Algal Boundstone, white color, soft, massive with common algae (Rhodoliths) 3.5 cm in diameter, (Fig. 3. a&b) Echinoids, peleceypoda fragments also present. The thickness of this unit is about 1 meters.

Unit (2)

Pelecepoda-Echinoidal-Algal boundstone, white color, moderately hard, massive with common Rhodoliths algae ranging in size from 1.5 to 2.5 cm in diameter and echinoids (Clypeaster sp. and Scotela sp.), (Fig. 4). The thickness of this unit is about two meters.

Unit (3)

Calcarenitic grainstone, yellowish white color, moderately hard, massive with algaes, echinoid (*in situ* at the base) and commonly borrowed. The thickness of this unit is about (1.5) meters.

Unit (4)

Algal Bound stone, white color, moderately hard, massive with common Rhodoliths algae ranging in size from 3 to 5 cm diameters and corals, (Fig. 6). In addition, this unit is highly jointed with extended oblique and vertical joints with the sliding surface. The thickness of this unit is about 2.5 meters.

Unit (5)

Algal limestone Packstone texture, white color, hard, thinly bedded with algaes (Fig. 7). The thickness of this unit is about 1.33 meters.

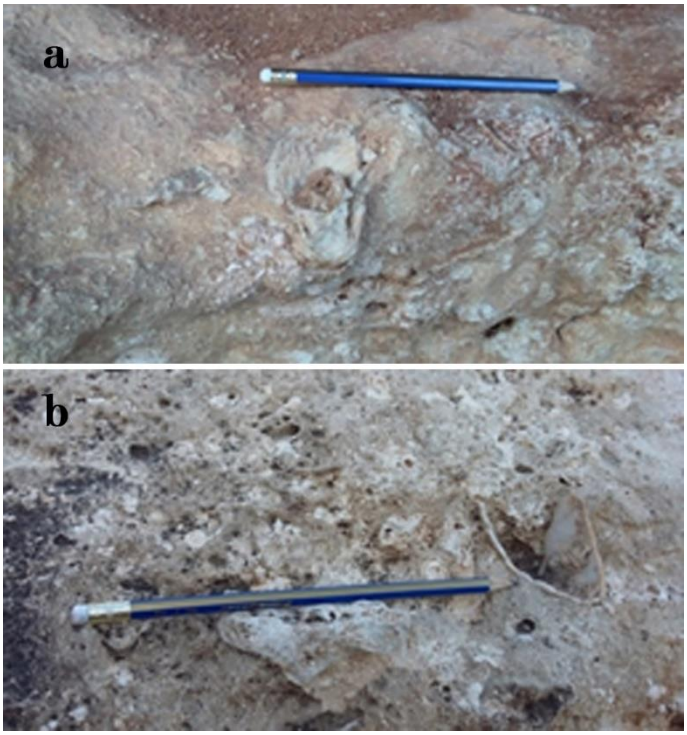

Fig. 3. Unit 1 in Benghazi Formation.

Fig. 4. Unit 2 in Benghazi Formation.

Fig. 5. Unit 3 in Benghazi Formation.

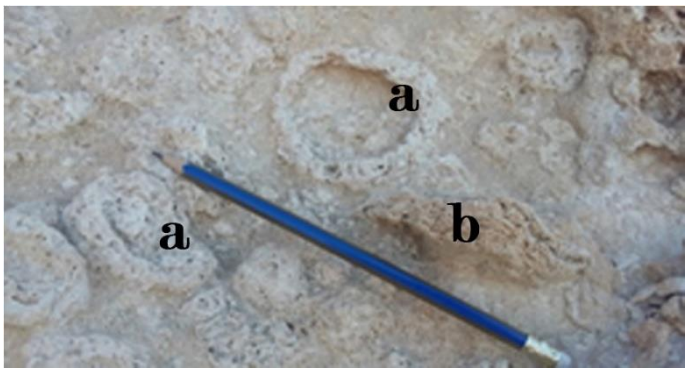

Fig. 6. Unit 4 in Benghazi Formation shows Formation (**a**) Rhodolith algaes and (**b**) corals.

Fig. 7. Hand specimen for unit 5 in Benghazi Formation.

Table 1

Description of Ayn Al Majdoub lake lithology.

	Name	Texture	Color	Hardness	General Notes
Unit 1	Oysteried-Algal Limestone	Boundstone	White	Soft	
Unit 2	Pelecepoda-Echinoidal-Algal Limestone	Boundstone	White	Moderately Hard	
Unit 3	Calcarenite	Grainstone	Yellowish White	Moderately Hard	* Because of the physical properties (such as: purity, low porosity and hardness); These units acts as a favorable rock type in forming karast. * Structurally, these rock units highly jointed.
Unit 4	Algal Limestone	Boundstone	White	Moderately Hard	
Unit 5	Algal Limestone	Packstone	White	Hard	

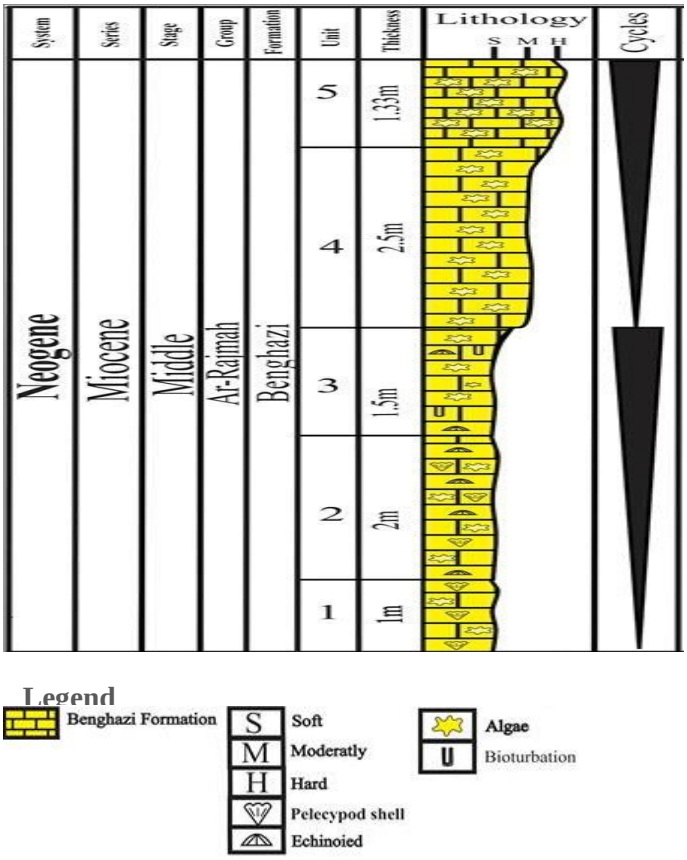

Fig. 8. Stratigraphic columnar section of Ayn Al Majdoub outcrop.

2.3.2 Structure

Geologic structure is an important factor in karst development. Palmer (1977) has stated that structure is the main factor in the development of karst features. In the study area, the carbonate rocks consist of the joints and when weathered they act as conduits for groundwater circulation. The spacing of joint sets is also important. Meaning, if intersecting joint planes are spaced at long intervals circulation is impeded; but if they are too closely spaced, the rock may be too structurally weak to support karst features, even though the rock may be highly permeable. Faults can also transmit water, but their spacing is usually much greater than that of joints, so they are not as effective in developing karst (Palmer, 1977).

Considering the above-mentioned factors, optimum lithology and structural conditions for full karst development include the following: Thick, pure calcite, crystalline limestone uninterrupted by insoluble beds. Intersecting joint sets that allow free circulation of ground water along discrete flow paths with enough discharge to create or enhance significant solution openings (Palmer, 1991).

Fig. 9. View of highly jointed sides of the lake.

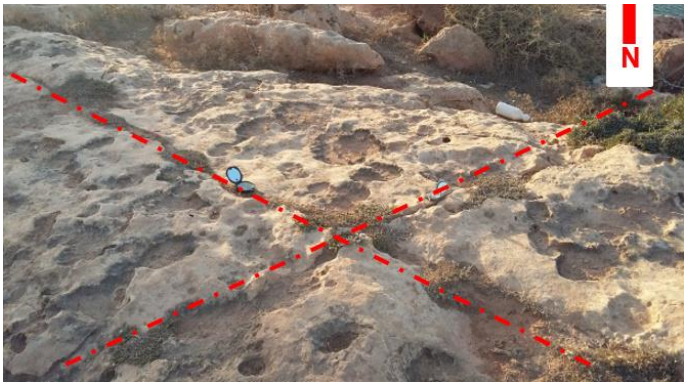

Fig. 10. The two major dip strikes.

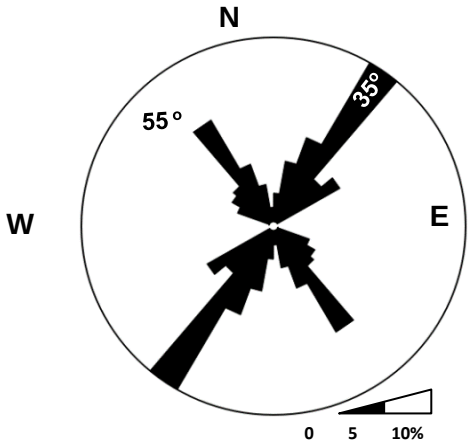

Fig. 11. Rose diagram represents the major joints.

3. Conclusions

Most of the karstologic literature explains formation of dolines through dissolution effects of rainwater discharge via fissures in the lowest (weakest) point of the doline. Herein, the development of the dolines in Benghazi Formation was originally undertaken by dissolution at the surface and infiltration by water and collapse in depth due to change (from wet to dry seasons) in the water level. Since the most dominant process on karst is dissolution. Ayn Al Majdoub doline was formed by dissolution of the soft units in the bottom of Benghazi Formation followed by the collapse of overlying strata. To sum up, the development of Ayn Al Majdoub karstic feature is mainly controlled by the followings:

a) Lithology, the rock formation in the study area possess horizontal, well bedded, well-jointed, hard limestone as the fundamental condition for karst. Elsewhere, this limestone is rich in fossils and coral reefs that give chance for a selective solution and, in turn, voids and more effective by percolating water.

b) Structure, this doline was formed along or at the intersection points of joints, which greatly enhanced the circulation of the solution by water at the surface, which aided the collapse in depth. Collapse or slumping noted on the doline sides is created from the free surface expansion of the walls inward the dolines due to stress relief and opening up of the surrounded structural lines.

c) Hydrology, the change of groundwater level depends on the amount of recharge and amount rain-water leaking vertically through faults and joints. Continuous seasonal variations in rainfall, from wet to dry, reflect in-depth fluctuation of groundwater levels on the lower part of Benghazi Formation, leading to discernible differences in hydraulic pressure and hence induce the collapse more likely within the zone of water-table change.

4. Recommendations

Karstic areas are always representing the major source of land instability; therefore, hazards resulted from this have to be taken into the government's consideration. However, the study is an only a small portion of the huge active karstic phenomena, in other words, karstic features are dangerous in NE Benghazi near Al Kuwafia and north Al Laithi areas. Serious studies and control should be considered in near future.

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