AJMAS
https://journal.utripoli.edu.ly/index.php/Alqalam eISSN 2707-7179

Original Article

Geological and Geomorphic Assessment of Wadi Al-Battum, Al Jabal Al Akhdar, Libya

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ARTICLE INFO
Corresponding Email. *alzubair.abousaif@omu.edu.ly*
Received: *11-03-2022* ***Accepted:*** *23-03-2022* ***Published:*** *26-03-2022*
Keywords: *Structural Analysis, Deformation, Stratigraphic Column, Karst Features.*

ABSTRACT

Background and aims. *Al Jabal Al Akhdar basin formed from an active continental on the African platform in the late Triassic period. It is a vast sedimentary region in northeast Libya with North East/South West trending mobile component in Northern Cyrenaica province. Al-Battum Valley is located along the east coast of Libya, in the Northeastern part of Al Jabal Al Akhdar, and far 8 km west of Sousa City. The valley is one of many valleys that trend deeply toward the Mediterranean Sea. It consists mainly of Dernah formation (Eocene) and Quaternary deposits. The objectives of this study were to determine the relationship between structural controls and geomorphic characteristics in the study area, as well as the impact of lithology on the morphology and distribution of various karst features.* ***Methods.*** *This study included GDEM (Global Digital Elevation Model), field trips, aerial images; topographic maps, geological maps, and laboratory work were used to compile the data and results reported. The morphometric analysis of the GDEM performed by a geographic information system environment through spatial analyst tool of ArcGIS to extracted hydrological information like drainage networks.* ***Results.*** *The valley enclosed between two sinistral strike slip faults that trend almost NWN-SES; and a dextral strike slip fault that trend nearly East-West on the southern part of the Al Battum valley. The dominant type of joints are systemic joints that are oriented almost NE and their density increases in the main valley. Dernah formation is divided into three units based on hardness, color, size, concentration of the fossils, thickness of units, and Dunham classification. Three different types of Karren have been identified in the study area, and their distribution is predominantly controlled by lithology and structural factors. Solution basins are usually rounded to the oval in plain view, and their sides tend to be vertical to gently inclined, while the bottom is smooth and flat. Caves are karstic topography that appear in the study area as horizontally extending holes in sediment. Cave formation aided by structural features that act as a conduit for solution and karst formation. These strike slip faults affect the drainage pattern of the valley; and systemic joints set reveal the orientations of the principal stresses.* ***Conclusion****. This valley's drainage system is sub-parallel to the dendritic drainage pattern, indicating that the area has been influenced by strike-slip action. The movement within the structure developed zones of broken and crushed rock fragments of various sizes, making surface and subsurface water dissolving easier. Darnah Formation (Middle-Late Eocene) Tertiary strata show noticeable and remarkable diverse shapes and sizes of karst (karren, solution basins and caves).*

Cite this article: *Abousaif A, Abuharara A, Bousayf A, Atia M. Geological and Geomorphic Assessment of Wadi Al-Battum, Al Jabal Al Akhdar, Libya. Alq J Med App Sci. 2022;5(1):177-184.* https://doi.org/10.5281/zenodo.6386790

INTRODUCTION

Al Jabal Al Akhdar (Green Mountain) is a small mountain chain that is located NE of Libya. It is bounded by Sirte basin on the west and Gulf of Bumbah on the east, and it has a steep slope toward the coast; its edge consists of steep cliffs separating it from the Mediterranean Sea by a low bar that varies in width from place to another. Al-Battum Valley (Wadi Al-Battum) located in the north-eastern part of Al Jabal Al Akhdar along the east coast and far 3.5 km west of Sousa city (Figure 1).

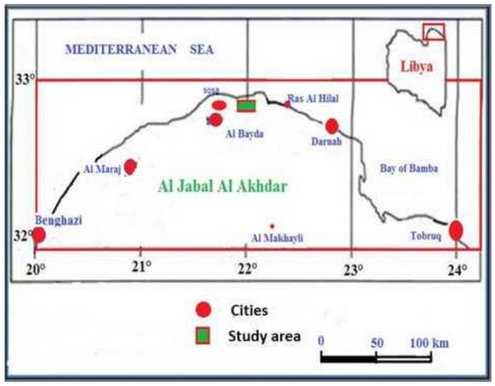

Figure 1. Location of the study area (Wadi Al Battum)

Although Al Jabal Al Akhdar is one of the structural belts defined by intra-Senonian compressional structures, it is included in the Syrian Arc belt, which stretches from northeastern Libya to Syria. The Santonian generated an inverted E-W to NE-SW-trending fold belt in Cyrenaica, which significantly enhanced by the Tertiary [19,5,1]. Al Jabal Al Akhdar is an 'Alpine' Deformed region; during the Late Cretaceous, rifting in the northern Atlantic caused an abrupt change in the motion of the European Plate, which began to migrate eastwards in relation to Africa [9,4]. According to previous geological investigations, Al Jabal Al Akhdar was formed on a rifted continental margin in the late Triassic-early Cretaceous period, which was followed by structural inversion in the late Cretaceous-Eocene period [1,6-8,10].

Al Jabal Al Akhdar is comprised of three elevations, the first ranging from 250 to 300 m above sea level in the city of Al Marj. It runs parallel to the beach with a non-uniform width and rises to 420 m in the area between Sousa and Ras Al Hilal. On the north, this plateau is cut by deep, steep valleys that lead to the Mediterranean Sea. The second height in the city of Shahat, Al Bayda, ranging from 450 to 600 m above sea level. It runs NE-SW in the western portions and E-W in the eastern parts of the plateau as a hill, simple slope, intersected by numerous large streams (wadis). The third is the highest part of the plateaus near Salantah town, with an elevation of 880 m above sea level in the Side Alhumri area, but no obvious linear structure like the first and second elevations. The flat of the plateaus covered by red soil (terra rossa), which allows it to be partially cultivated; however, vegetation covers two-thirds of the plateaus and the plateaus fall gently to the southwest [9].

Al Jabal Al Ahkdar's stratigraphic succession represented by a thick sequence of carbonate rocks ranging in age from Late Cretaceous to Early Miocene. There were several historical geologic events separated by unconformity surfaces that mark Al Jabal Al Akhdar. Deposition of extremely thick sediments took place during Jurassic and Cretaceous times. Three particular formations deposited at that time; these include Serwal, Al Qahash and Deranah subsurface formations. The most recent sediments deposited during quaternary period at top of Al Jabal Al Akhdar. Late Eocene deposits (Deranah formation) and Quaternary sediments cover the study area [11,14]. Karstic features are present and developed in the study area, because Al Jabal Al Akhdar is primarily made up of carbonate rocks. This attribute to the appropriate conditions that lead to the development of karstic features; these conditions must be present at or near the surface of soluble rocks that are thick and heavily jointed, as well as a climate with moderate rainfall [3,12,13]. The geomorphic properties of the Al Jabal Al Akhdar region are linked to tectonic activity characterized by the Late Cretaceous to late Miocene. Due to differential weathering processes and climatic conditions during winter seasons, where chemical weathering is remarkably facilitated by rainfall, the Battum Valley displays diverse geomorphic features. The objective of this study to assess the significant influence of structures on karst morphology, distribution, and development.

METHODS

Fieldwork was conducted based on morphometric and geological features of the Al-Battum valley. Global Digital Elevation Model (GDEM), aerial images, topographic maps, geological maps, and laboratory work were used to compile the data and results reported in this study.

The morphometric analysis of the GDEM was performed in a GIS environment through spatial analyst tool of ArcGIS to extracted hydrological information such as drainage networks, shaded maps and contour maps. The main source of this study was GDEM and spatial resolution, which was acquired from United States Geological Survey (USGS).

RESULTS AND DISCUSSION

Geological Analysis

The stratigraphic sequence of Al Jabal Al Akhdar in the central part represented by eight formations of carbonate rocks, and the age is from Late Cretaceous-Middle Miocene. Furthermore, these formations from the oldest to youngest are: Al Hilal, Al Athrun, Al Uwailyah, Apollonia, Darnah, Al Bayda, Al Abraq, and Al Faidiayh formations [8,18]. All beds are inclined at an angle ranging from 11 to 12 degrees towards the SSW. One formation has been recognized in the study area; this formation is the Darnah Formation. Pieterz first named the Darnah Formation (late Eocene) In general, the rocks in the Darnah Formation are limestone, grey, white, whitish cream, and grey in color, massive, hard to moderately hard and possessing karst landforms at different levels [1]. In addition, the Darnah Formation contains fossils such as nummulites of different sizes, as well as gastropods, bivalves, corals, shell fragments, and echinoids that embedded in micrite cement. The bioclastic is dominated by large-sized nummulites, operculinids, orbitolitescomplanatus, and rare fragmented discocyclinids [11].

According to the field work and sample collection, the Dernah formation in the study area (Al Battum valley) was divided into 3 units depending on hardness, color, size and concentration of the fossils (nummulites), thickness of units, and Dunham classification.

Unit I: Nummulitic wacke stone to pack stone, Nummulites gizehensis are sand size, yellowish white to grayish white, and moderately to well sorted; Nummulites and Discocyclina account for at least 40 to 70% of the total rock. The total thickness of this unit is about 11.4 m (Figure 3a). Different geometries of bioturbation were observed. It has a gradational contact with the lower Apollonia Formation and a sharp relationship with the overlying grain stone facies; the lithofacies are massive, and the grain abundance suggests a moderate to high-energy environment.

Unit II: It mainly contains nummulitic wacke stone to pack stone. Nummulites are silt to sand size, white to yellowish, and moderately to well sorted. Nummulites and discocyclina represent at least 20 to 45% of the total rock. Different geometries of bioturbation were observed. The total thickness of this unit is around 9.5 m (Figure 3b). It has sharp contact with the lower wacke stone to pack stone facies and a gradational relationship with the overlying pack stone facies. This matrix-supported lithofacies suggests a quiet environment and restrictions on grain-producing organisms, probably in a low-energy regime.

Unint III: This unit is light to dark gray, occasionally yellowish white to grayish white, dense, poorly to moderately sorted, and poorly to moderately cemented. Most grains are skeletons of benthic foraminiferas (mostly Nummulites gizehensis and Discocyclina), and some gastropods. The skeletal grains form at least 60–80% of this unit. It has a thickness of 19m (Figure 2c). It has a sharp contact with the lower wackestone facies and a sharp relationship with the overlying quaternary deposits. It was probably formed as a result of submarine reworking of carbonate sediments, suggesting a high-energy depositional regime.

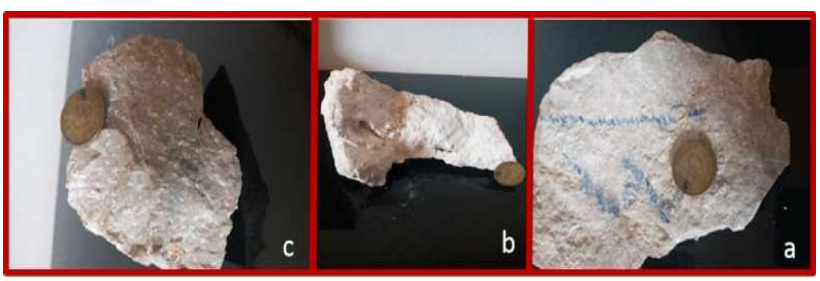

Figure 2.a, b.c) Three units of Dernah formatiom samples

The Quaternary sediments cover a large part of the study area, consisting of mixtures of unconsolidated rocks such as conglomerates and breccia. The stratigraphic columnar was represented to describe the vertical location of rock units in the study area (Figure 3).

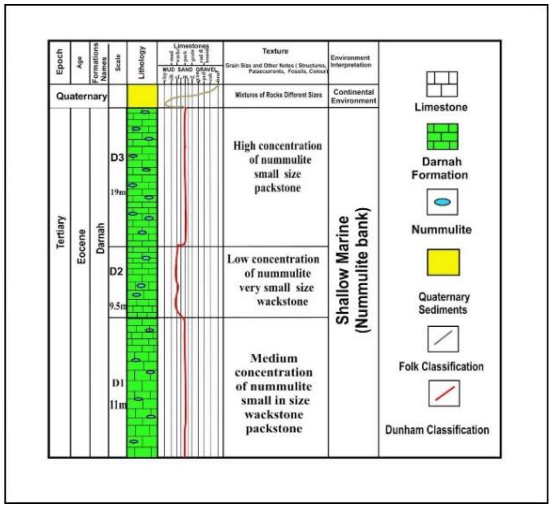

Figure 3. Stratigraphic column of study area showing the main three units identified within Dernah Formation. The subdivision was mainly based on Nummulite abundance and size. Dunham classification was used to subdivide limestone facies, whereas Folk classification was used to define the quaternary deposits

Structural Characteristics

Northern African active margin evolved after the Neotethys opened, and Al Jabal Al Akhdar was a part of it (Klitzsch 1986). The northern coastal plain was formed by down faulting Al Jabal Al Akhdar inverse anticlinorium; which extended into the steep, narrow, and strongly faulted and folded a continental coastline offshore. Three significant strike-slip fault zones run across Al Jabal Al Akhdar's three escarpments. Between the first and second escarpments lies the greatest fault zone in the area. A vast number of minor scale strike-slip faults and normal faults accompany these zones. Deformation dominated by ductile and brittle structures exists in the upper half of the Apollonia formation. Although it merely extends moderately upward and with brittleness as the significant factor within the Darnah formation [5,6], characterized the domain stress field as compressional deformation. Most of the valleys in the Al Jabal Al Akhdar region including the study area, allowed their streams running through faults; which allowed the water to degrade hard and rapidly reach geological structures, then to end up in the sea.

The Al-Battum valley is placed between two sinistral strike slip faults that run through the Al Mainshyah, Ruja valleys and they run in parallel direction to the local valleys. The evidence of sinistral movement was extended part of the main valleys were straight. Locally, bedding attitudes show moderate variation in comparing with surrounding valleys. Dips range from 12º to roughly 27º and the main directions for these faults are N-S, NEN-SWS (Figure 4).

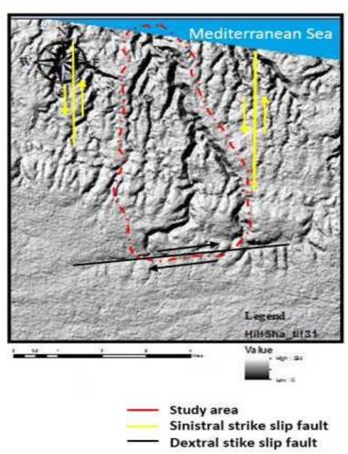

Figure 4. The red polygon denotes the study area, the two yellow lines denote sinistral strike slip faults and black line denotes dextral strike slip fault

Moreover, there is a dextral strike slip fault to the south of the valley, which influenced the drainage system. At the main valley, the density of joints and brecciation increases due to the effect of strike slip faults in the surrounding valleys. The main directions for these faults are (East-West). The evidence of dextral movement along the fault zone is the presence of abundant breccia, rock fragments, steps on the fault plane, and nearly horizontal slicken lines. Joints are the most existing structural features in the study area; systemic joints set play a significant role in the development of karst features in the Al-Battum valley (Figure 5).

Figure 5. Photographic of the systemic joints in the study area; Rose diagram of the direction of the joints, the domain direction is NE

The systematic joint sets have provided the most efficient initial routes for surface water infiltration into the Darnah formation, exhibiting little primary porosity and permeability. Infiltration concentrated at points of multiple joint intersections allows the enormous volume of water to move into the subsurface.

Geomorphic analysis

The tectonic activity that dominated from the Upper Cretaceous to the Upper Miocene periods is linked to the geomorphic features of the Al Jabal Al Akhdar region. On the other hand, they are linked to the lithology of Al Jabal Al Akhdar. It is primarily composed of carbonate rocks with a range of hardness from soft to hard; on which differential weathering processes occur, as well as climatic conditions during the winter seasons, when chemical weathering is greatly aided by rainfall [12].

Wadi Al-Battum runs from the south to the north, ending in the Mediterranean Sea, with tributaries that run parallel to each other into the sea (Figure 6 a, b). The drainage pattern in this valley varies from dendritic (upstream) to sub-parallel (in the heart of the basin), indicating that strike-slip movement, joints and steep slopes have all had an impact.

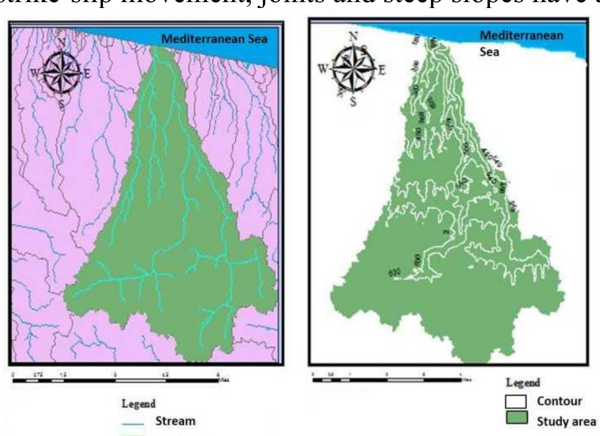

Figure 6. a) Drainage map of the study area. b) Contour map of the study area shows the different elevations

Since Al Jabal Al Akhdar is primarily composed of carbonate rocks, karstic features are present and developed. This attributes to the appropriate conditions that lead to the development of karstic features; these conditions must be present at or near the surface of soluble rocks that are thick and heavily jointed, as well as a climate with moderate rainfall. Therefore, karst landforms and the processes that influenced their distribution are now distinct in the current area. More information about their variety and development can be found in the following sections:

1. karren: it is a small-scale dissolution pit, groove and channel forms at the surface and underground. The factors that control Karren formation are the nature of limestone, the dip and slope of limestone, and the former climate [20]. Three types of karren have been recognized in the study area which they are common in Darnah Formation.

a. Rillen Karren: it is bigger than Rillen Karren, where its depth is greater than 20 cm, and its width varies between 10-50 cm in length and up to several meters. Its edges are as sharp as a knife; it distinguishes steep slopes where the slope angle is large. It is also found on limestone surfaces that do not have vegetation cover (Figure 7 a).

b. Rinnen karren: these are finely carved grooves with rounded troughs and sharp fine ridges that commonly appear in groups on roof-like projections of limestone on slopes of 40º-80º. They are usually 1-3 cm deep, 1-2 cm wide, and less than 20 cm long (Figure 7 b).

C. Spongy karren: cavities of different sizes and lengths characterize this karren type. These cavities extend deep through the rock, generating a web of crossed channels that give the rock a sponge-like look (Figure 7 c).

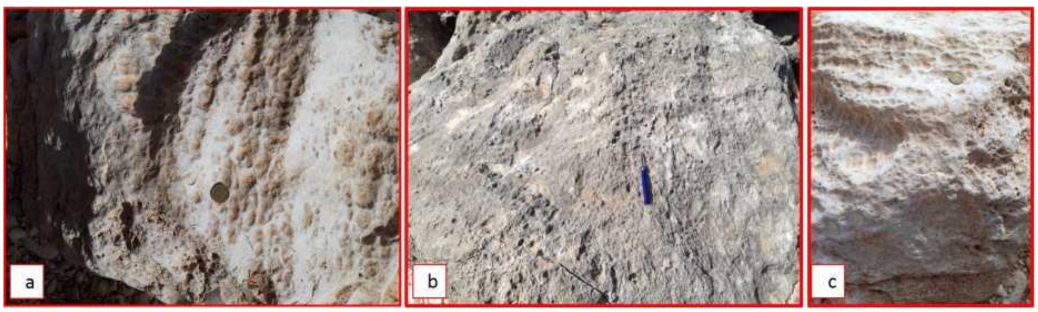

Figure 7. a) Rillen karren in study area. b) Rinnen karren in the study area. c) Spongy karren with different diameters in the study area.

2. Solution basins: water accumulated in pools and basins where rocks were more or less horizontal. These basins developed as a result of stagnant water solutions; they are ranging in size from a few centimeters to two meters in diameter and a few millimeters to 50 cm deep. In plain view, they are commonly rounded to an oval; with vertical to gently sloping sides and smooth, flat bottoms (Figure 8).

Figure 8. Solution basins in Dernah formation

3. Caves: caves can be found in abundance in carbonate rocks that have been eroded and dissolved. Lithology, joint pattern, fractures, faults, cave breakdown, and evaporate weathering all influence cave morphology [16]. Caves are karstic

topography that appear in the study area as horizontal holes in sediment of various sizes. Faults assist in the construction of caves by acting as a fluid channel for solution and karst formation. Massive, permeable and jointed limestone beds dominate Darnah formation. Darnah formation overlies the low permeability Apollonia formation. These characteristics were principally responsible for cave formation in these rock units (Figure 9).

Figure 9. Caves with different sizes in the study area

4. Quaternary deposits: These deposits (gravel and boulder), which are often loosened by weathering, are composed of rocks derived from Late Cretaceous the Tertiary and Early Cretaceous limestone. The pebbles are unsorted, half to well rounded, and range in size from 5 to 20 cm. The size of these boulders is primarily determined by distance traveled along stream routes (Fig 10).

Figure 10. Quaternary deposits in the study area.

CONCLUSION

The most significant factors regulating the drainage pattern and topography in the study area are structural features. The structural elements have been supported in the assembly and distribution of water, resulting in the formation of several types of Karst features in the studied area. This effect was paired with the current Mediterranean climate and the characteristics of rock formations. Wadi Al-Battum is trapped between two sinistral strike slip faults that control the drainage pattern in the valley. The systematic joint sets have supplied the most efficient initial routes for surface water infiltration into the Darnah formation. Along the main wadi and the main planes of the strike-slip faults that trapped the valley, the density of joints and brecciation increases.

The Dernah Formation is mainly composed of fine to medium-grained limestone that ranges in color from white to yellowish-white and yellowish gray. In micrite cement, bioclastic grains such as Nummulites of various sizes, gastropods, bivalves, corals, shell fragments, and echinoids were embedded. In terms of grain size, the limestone is mostly wackstone, floatstone, packstone, grainstone, and mudstone. A caliche crust commonly covers the limestone's exterior surface. Dernah formation has been divided into three units in the study area based on fossils content, color, and Dunham classification.

Different types of Karren have been identified, and their distribution was generally aligned with lithology and structural line directions. These karren were Rillen, Rinnen and spongy karren. Solution basins were common on Dernah formation; some of them were positioned parallel to tectonic lineaments. Caves formed in the phreatic zone, first followed by bedding and structural planes, then deepened and modified by free-flowing streams. This valley's drainage system is sub-parallel to dendritic drainage, indicating that the area has been affected by strike-slip movement, joints, and steep slopes. The geomorphic study of the drainage basin reveals that the area has strong groundwater prospects.

Disclaimer
The article has not been previously presented or published, and is not part of a thesis project.

Conflict of Interest
There are no financial, personal, or professional conflicts of interest to declare.

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