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Dissolution Cavities of Karren type in the Algal Limestone Member of Al Bayda Formation, Sector (3), Wadi Az Zad, Al Jabal Al Akhdar, NE Libya

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Abstract

The study area of Wadi Az Zad is characterized by landforms of relatively stepped terraced escarpment and karst isolated hills.At least three distinct karst features are recognized in the selected measured traverses in the surface exposure of the Algal Limestone Member at Wadi Az Zad which are: Groove karren, Circular karren, and Kluft karren.

Histograms of the Algal Limestone Member at the studied traverses (T1-T3) have revealed some relationships of the recognized karren types with their elevation, lithology, topography and number of karrens or density variations. For instance, the observed densities of these surface cavities vary widely from high density of about (5.2-15.8) karren/m^2 for circular type which is found to be associated with flat area and grainstone facies, to an intermediate density of about (1.6-3.2) karren/m^2 for groove type which is found to exist mostly in relatively slope areas and in mudstone facies, and eventually to low density of about (0.5-1.5) karren/m^2 for kluft type which is found to be associated with relatively fractured (heavily jointed) and of wackstone – packstone facies.

These surface dissolution cavities are evident to be associated with lithologic and structural characters of the Algal Limestone facies in the study area.

Keywords: Al Jabal Al Akhdar, Algal Limestone, Karren, Wadi Az Zad

1. Introduction

Karst features are the foremost examples of surface water erosion on this planet. The sculpturing and removal of limestone rocks is predominantly by solution, aided in some cases by soil transmission or piping, eventually causing collapse. Surface karst features are small landforms created by solution of the surface of the rock (Selby, 1985). In general, also karst landforms (minor and major) are best developed in limestone and dolomites. Karst surface morphologies exist at a variety of scales. Inevitably then, a wide variety of geomorphological techniques and methods are employed in karst morphometric analysis (McIlroy de la Rosa, 2012; McIlroy de la Rosa et al., 2012).

Carbonate rocks of Algal limestone member in sector (3) (Fig.1) crop-out over approximately (75%) of the study area, and are characterized by surface features which are formed mainly through surface runoff and aided by integrated conduit flow systems through surface joints and even porous, leached grainstones.

We observed and measured karst features in Wadi Az Zad; we were constrained by conditions of the exposures to measuring features of the limestone surface rather than of land surface. In general, we found that the solution features on the surface of the limestone are smaller than dolines or caves of meso-karren type (Eren et al., 2010) and too small to create permanent depressions in the overlying sediment cover because the rate of dissolution is certainly much slower than the rates of surface phenomena like intensive bioturbation. The high density (number/unit area) of small solution features (karren types) on the surface of the Algal Limestone Member and sparse land-surface depressions or sinkholes are, in part, a consequence of the differences in lithology, structure, runoff, and the mechanism of dissolution of the various facies types of this limestone.

The objective of this study is to outline some of the diagnostic surface karst features in the Algal Limestone Member of sector (3), and to reveal their relationship to lithological changes and minor structural features.

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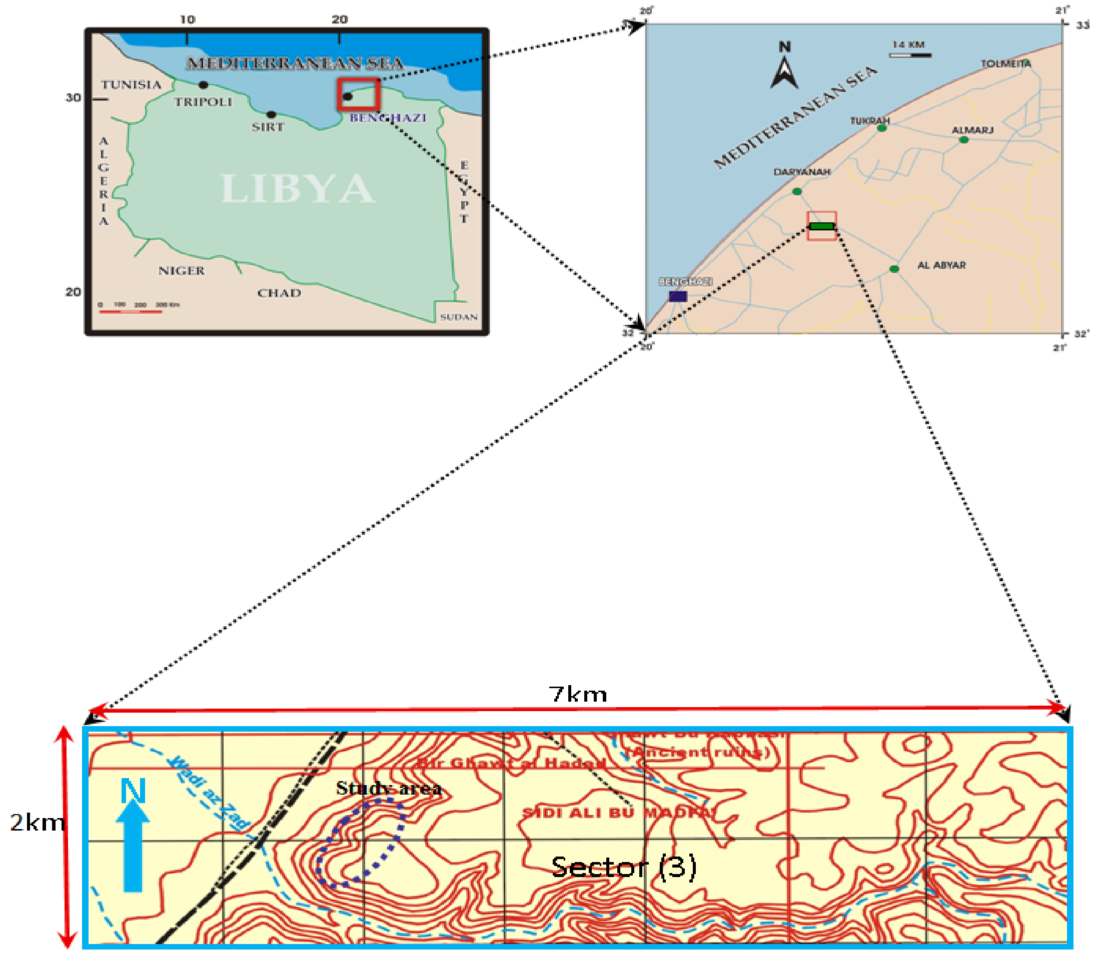

Figure 1 .Location map of sector (3) area, showing studied escarpment (dashed circle), Wadi Az Zad, Al Jabal Al Akhdar, NE Libya.

2. Geologic Setting

2.1. Geologic Units

Karst formation is an active and on-going process in the Algal Limestones of Wadi Az Zad in Tansoloukh area. Horizontal solution cavities that cut across evident bedding surfaces are present at several elevations.

Shahhat Marl Member and Algal Limestone Member (Early Oligocene) are exposed in the study area (Fig.2) and are potentially active in karst processes. The Shahhat Marl is the oldest rock unit exposed in the study area and represent the basal sedimentation unit corresponds to major transgression in the area (Rohlich, 1974). It is mainly yellow to whitish yellow marl and marly bioclastic limestone (mudstone to wackstone texture), and soft. It contains two to three marly beds, a few meters thick, wedges-out east of Wadi Az Zad. Fossils include benthonic foraminifera, echinoids, bryozoans, and mollusks. Remnants of marine organisms, as shell fragments that formed this unit, were composed originally of aragonite.

The primary biogenic aragonite has been dissolved, leaving behind molds of the organisms and creating a well-connected secondary porosity. The Algal Limestone sediments, overlying the Shahhat Marl in the field area, consists of thick-bedded to massive, white to creamy, white fossiliferous microcrystalline, chalky to medium grained Algal limestone (mudstone-grainstone texture). It is characterized by the presence of flat-like to ball-like shapes of algae (corralline red algae) of the genus Lithothamnium (Pietesz, 1968; Barr and Weeger, 1972; Muftah and Erhoma, 2002) , mollusk, nummulites and some bryozoan fragments are also present, usually embedded in sparite, but micritic matrix is occasionally very well developed at some places, which may suggest deposition in an inner-neritic conditions of shallow marine environment (Rohlich, 1974).

2.2. Depositional History

Several studies describe the geologic history of the study area, and summarize the depositional history of Al Jabal Al Al Akhdar and Cyrenica platform of northeast Libya (Klitzsch, 1970; Rohlich, 1980; El Arnauti and Shelmani, 1985; Abulsamad and Barbieri, 1999; El Hawat and Abdulsamad, 2004; El Arnauti *et al*., 2008; Yanilmaz *et al*., 2008). Carbonate and evaporite sediments were deposited on Al Jabal Al Akhdar and Cyrenica platform from the Early Cretaceous to the Late Paleogene when the deposition of transgressive carbonate rocks were followed by progressed Neogene sedimentation of regressive, highly agitated glauconitic to Oolitic limestones (grainstones) of Early to Late Miocene to local erosion and local reworking in the Late Miocene. Significant deposition may have been absent during the Pliocene and was certainly absent during the Pleistocene. Quaternary sedimentation may have been limited to reworking of Miocene deposits, local fluvial deposition as debris flow, and the deposition of terrace deposits were also topping the sequence.

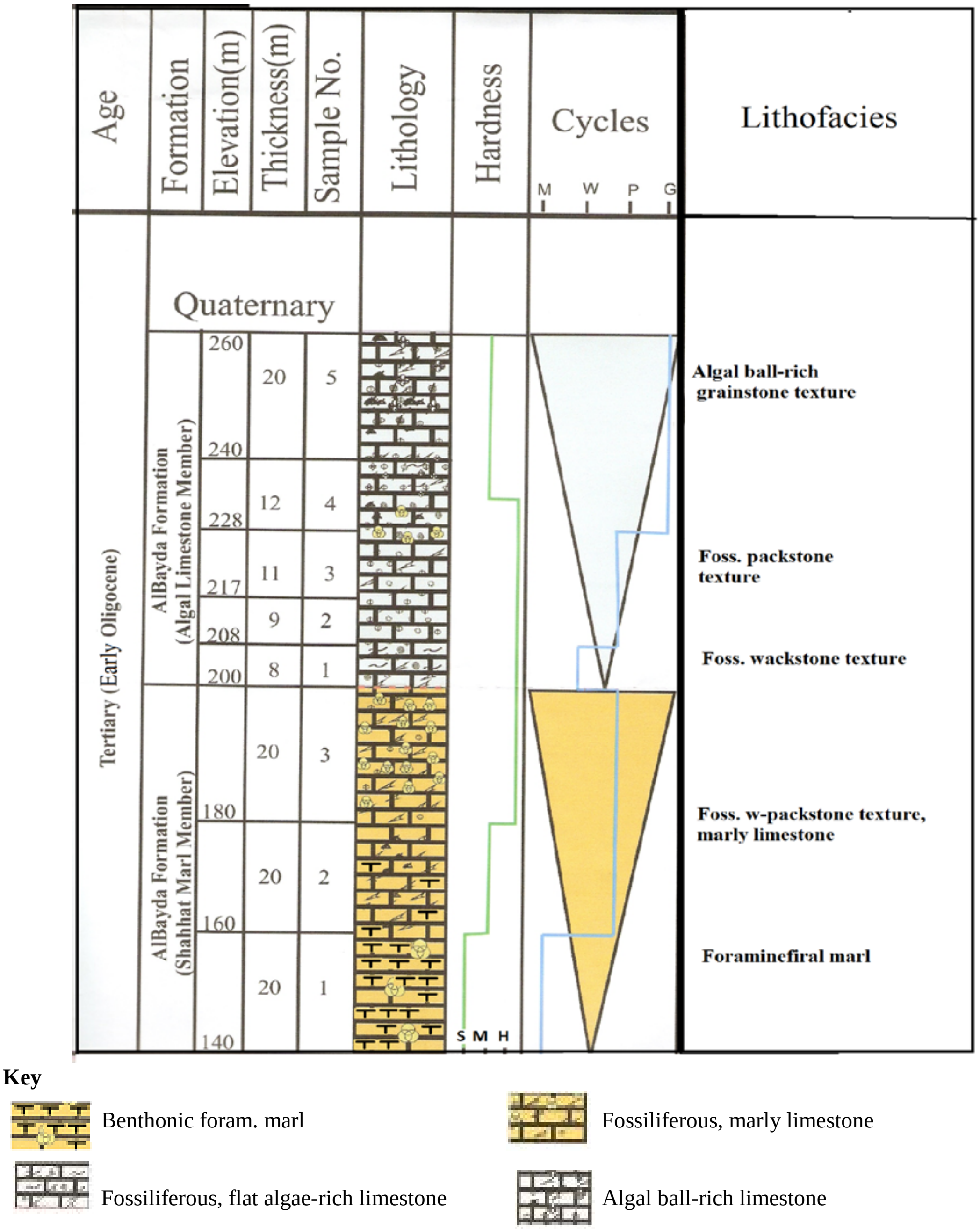

Figure 2, Generalized lithostratigraphic column of exposed pre-Quaternary deposits in Wadi Az Zad, sector (3), Al Jabal Al Akhdar, NE Libya

3. Structural Attitudes of Algal Limestone

The exposed Algal Limestone rocks are of horizontal to semi-horizontal bedding characterized by regional low dip of about 2º -5º SW. These beds are well jointed at some places and characterized by two major regional joint-trends oriented NW-SE and NE-SW. These regional fracture trends may be attributed to tensional stresses associated with the formation of Al Jabal Al Akhdar. According to Rholich (1974; 1980), two different episodes of uplift occurred during (Late Cretaceous to Late Miocene). Other possible minor trend of joints oriented E-W was also recognized, which might have contributed partially to the formation of the existent escarpment as a result of some compression and inversion tectonics in parts of Al Jabal Al Akhdar (Guiraud and Bosworth, 1999; Guiraud et al., 2005). A direct surface measurement of the joint patterns in the Algal Limestone is in general possible. Moreover, the linear features are observable on a regional scale on topographic maps and aerial photographs representing wadies parallelism and orientation, as the water flows northwest in the direction of the regional dip and discharges along the present-day coast. The joints and some minor fractures in the wackestone-packstone facies are responsible for the development of linear solution features (Kluft type) that form from the downward percolation of surface water along the joints and fractures.

4. Database

Several traverses have been taken through the outcrop of Algal Limestone Member in the study area (Fig.3) where lithology and mainly structural features have been detected and noted in a geological column. We examined, photographed, described, and counted surficial karst features exposed in three traverses (T1-T3), but safety and access limitations prevented in situ measurements of spacing and distance; so we counted these karst features across known distances. The sampling area is relatively reasonable; it is of about 480m^2 (6m x 80m), so the distribution and characteristics of the recorded solution features may be representative, in general, of small-scale karst features on the surface of the studied Algal Limestone. This Karren study involves the comparison of different parameters of the same form, allowing the researcher to deduce how the topographic and stratigraphic position of the karst terrain may influence the development of mesoscale forms. According to Tóth (2009), for any given karren form, characteristic parameters such as width, depth, and length should be chosen and compared with measurements of the same karren form under different conditions.

This study took into consideration main literatures on karstification, Jenings (1971), Sweeting (1973), White (1988, 1990), Abdulalim and Sobhi (2002), Waltham (2005), Lundberg and Ginés, (2009), Cucchi (2009), Tóth, (2009), Ford and Williams (2007) and Ginés et al. (2009) and inspection of karst features in the field and some discussions with an experienced consultant.

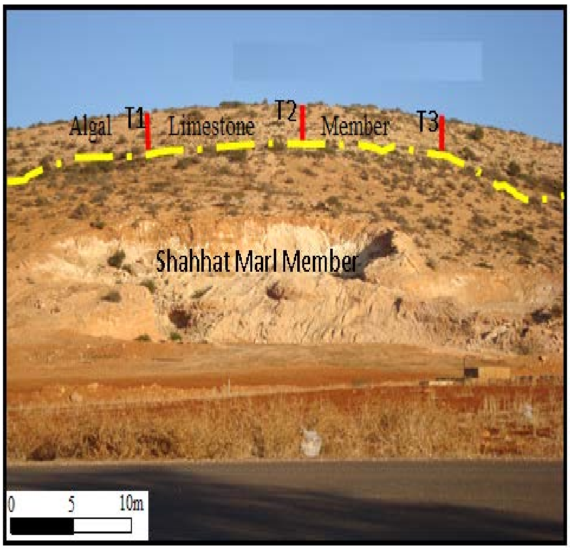

Figure 3. Studied escarpment composed of Shahhat Marl Member at the base which is used as quarry and Algal Limestone Member at the top in which studied traverses (T1,T2 and T3) can be seen, sector (3), Wadi Az Zad (Looking SE).

5. Observations

The evidence for regional karstification in the study area is extensive and there is no reason to preclude karst conditions in the Algal Limestone Member.

The following observations indicate that dissolution cavities of karst features do exist:

1. Extensive caliche in the exposed rock.
2. Solution-controlled vugular porosity.
3. Irregular surface features and of strong surface runoff.

On field observations, karren types were observed at the studied facies of the Algal Limestone Member.

Based on field observations, there are three main types of karrens, namely Groove karren, Circular karren and Kluft karren (Table 1).

5.1. Karren Processes

Falling droplets, sheet and channeled runoff, film flow, and pounded water may create small-scale dissolution forms (Karren), where rain falls onto limestone and break onto it (Ford *et al*., 1988; Bogli, 1980) gave detailed classification and discussion on surface dissolution features and their processes in limestone.

5.2. Groove karren

Longitudinal linear, groove like channels are few, (0.5cm-3.6cm) deep, (1cm-4cm) wide, but they are of (13cm-50cm) long, found at various elevations at (190m, 220m, 240m, 250m and 260m) in hard, fine- grained (mudstone to wackestone) facies they form because of strong runoff on steep slopes. (Figs.4 a,b), in cross-section AB (Fig. 5) they are of angular sharp base.

5.3. Circular karren

Circular in plane like features of localized dissolution action, these karst forms are found in flat areas because water stands (stagnates) for a longer time, thus giving the dissolution enough time to act vertically down in a pan shape, other than the mentioned grooves which form on the steep slopes due to running water.

They are few, (1cm-45cm) wide to few (1cm-40cm) deep and (0.5cm-25cm) long. They are found at various elevations (180m, 190m, 200m, 225m, 230m and 240m), usually associated with packstone to grainstone facies (Figs.6a,b), in cross-section (Fig.7), and they are rounded features.

5.4. Kluft karren

Straight or sinuous channels or film flow features are few, (0.3cm-0.5cm) deep, (0.5cm-1cm) wide, and about (36cm-180cm) long. They are found at various elevations (190m, 200m, 243m, 257m and 260m), usually associated with wackstone to packstone facies of relatively flat, parallel to bedding plane to highly jointed areas. (Figs.8a, b).

Table 1. Field observations and types of karrens in Algal Limestone Member, sector (3).

Elevation (M)	Facies			- Groove karren					+ Circular karren					* Kluft karren				
				No.	Area(M²)	L (cm)	W (cm)	D (cm)	No.	Area (M²)	L (cm)	W (cm)	D (cm)	No.	Area(M²)	L (cm)	W (cm)	D (cm)
260	- Mudstone		* W-P	18	9.5	13-20	2-4	0.5-1						5	4	90-180	0.5-1	0.5
257			* W-P											8	15	50-63	1	0.5
250	- Mudstone			8	2.5	20-50	1-4	1										
243			* W-P											6	10	36-60	0.5	0.5
240	- Mudstone	+ Grainstone		12	7	25-40	2-3	0.5-1	163	24	1-8	1-2	1.5-3					
230		+ Grainstone							73	14	2.4	3-4	1.5-3					
225		+ Grainstone							350	48	1-3	1.7-4	2-4					
220	- Mudstone			9	4.5	15-40	2-4.5	1-3.6										
200		+ Grainstone	* W-P						335	28	2-25	3.6-45	5-40	5	10	1,20	1	0.5
190		+ Grainstone	* W-P	10	6	13-35	2-3	1-3	400	25.3	2.6-7	5.5-7	2-4	12	8	73-90	0.5-1	0.3-0.5
180		+ Grainstone							200	26	0.5-1.2	1.5-3.8	1-3					

Key:
- \- Groove karren associated with mudstone facies.
- \+ Circular karren associated with grainstone facies.
- * Kluft karren associated with wackestone to packstone facies.
- L= Length of karren features.
- W= Width of karren features.
- D= Depth of karren features.

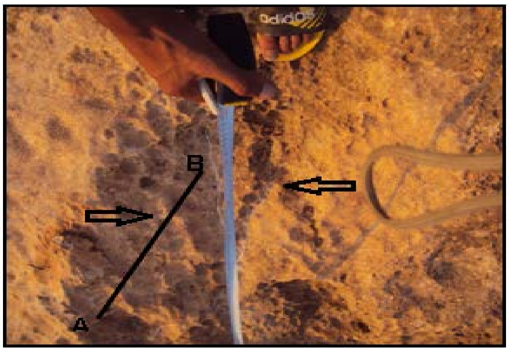

Figure 4a, Groove karren (arrows) in mudstone facies of Algal Limestone Member at elevation 220m

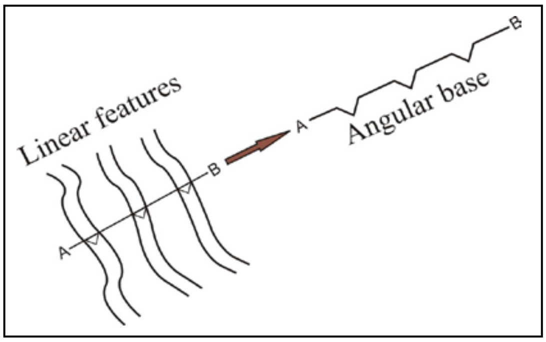

Figure 5, Cross section through groove karrens, showing linear features (grooves) of angular base on steep slopes due to running water.

Figure 4b.Groove karren in mudstone facies of Algal Limestone Member at elevation 290m.

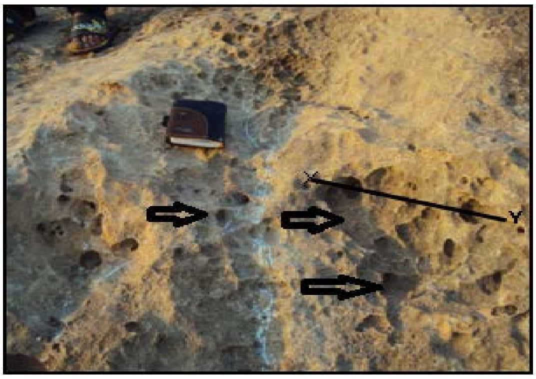

Figure 6a, Deep (2-4 cm) circular karren (arrows) in grainstone facies of Algal Limestone Member at elevation 190m.

Figure 6b, Oversized (25cm) long circular karren in grainstone facies of Algal Limestone Member at elevation 200m.

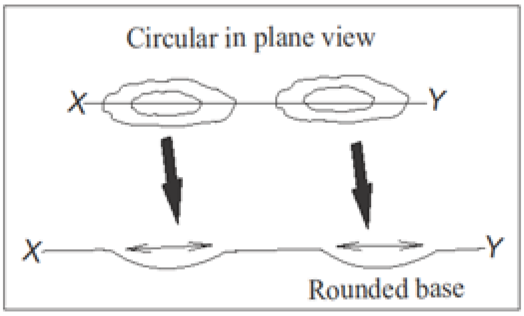

Figure 7. Cross-section through circular karrens found in flat areas, as water standing longer time, dissolution acts vertically down in a pan shape of rounded base**.**

Figure 8a. Kluft karren (arrow) in wackestone to packstone facies,parallel to bedding plane of Algal Limestone Member.

Figure 8b, Kluft karren (arrows) in wackestone to packstone faciesof Algal Limestone Member associated with joint >150cm long at elevation 190m.

6. Histograms Construction

Various histograms (Fig.9) have been constructed to show a relationship of observed karren types with some parameters such as:

1. Relationship between karren types with elevation:
   a. Elevation of groove karren at 190m, 220m, 240m, 250m and 260m.
   b. Elevation of circular karren at 180m, 190m, 200m, 225m, 230m and 240m.
   c. Elevation of kluft karren at 190m, 200m, 243m, 257m and 260m.

So, the elevation of groove (gr.) and kluft karrens (kl.) are relatively observed in higher elevation and characterized by mud-supported steep slope and of relatively extensive jointed areas relatively. However, circular karren (cir.) as evidenced in the studied section (Fig. 2) to occupy lower elevation (240m and below) represented by porous grainstone facies which is getting tighter of crystalline nature at higher elevation (260m). Actually, short distances (in vertical and lateral directions) within and between studied, traverses have revealed sudden facies changes effecting the spatial changes of karren types in an unpredictable fashion.

2. Relationship between karren types with lithology:
   a. The groove karren present only in mudstone.
   b. The circular karren present only in grainstone.
   c. The kluft karren present only in wackestone to packstone, which formed of enlarging of pre-existing joints by the dissolution action of acidic water.

Lithology of the Algal Limestone Member has a profound effect on karstification, and the formation of different karren types, as calcite dissolves more readily than other carbonates due to its higher solubility (Martinez and White 1999). Karstification can also take place where the Algal Limestone Member changes in facies (Fig.2) from benthonic foraminiferal marl, to fossiliferois marly limestone, to fossiliferous algal limestone. As mud to grains ratio decreases, a circular karren type dominates the outcrop surface, as in this facies, water standing for a period of time, percolates down with the help of the relatively porous texture of this unit. On the other hand, if mud to grains ratio increases, groove karren dominates the exposed surface because of strong runoff on steep slopes and the relative decease in porosity of this facies; thus this facie is usually characterized by mudstone-wackestone texture. As the exposed Algal Limestone is characterized by joints and fractures, formed during periods of uplift (Rohlich, 1980), governs the orientation of the kluft karren type in mudstone-packstone facies, increasing their secondary permeability, rainwater, during humid periods, begins to dissolve the carbonate along these structural weakness planes.

3. Relationship between karren types with topography:
   a. The groove karren exist only in slope areas.
   b. The circular and kluft karrens exist only in flat areas.

4. Relationship between karren types with density (number of karren per unit area):

Karren types in the study area are different in density, and show tendency of high to low density from circular to groove to kluft type.

According to White (1988), the karst feature density (Dd for doline and kd for karren in our case) could be defined as: the number of karren (Nk) in the karst area with the dimension of inverse area or per unit area (Ak), (Kd =Nk/Ak).

The studied area which is suitable for sampling is about 240m^2 , so the distribution and characteristics of the surface dissolution features recorded in the photographs (Figs.4-8) are mostly representative in general of the karren features and their in-situ measured spacing and distance on the exposed surface of the Algal Limestone Member of Wadi Az Zad.

The observed densities of these surface cavities (Table 2) vary widely as following:

Measured high density of about (5.2-15.8) karren/m2 for circular type, which is found to be associated with flat area and grainstone facies.

An intermediate density of about (1.6-3.2) karren/m^2 for groove type which is found to be mostly in relatively slope areas and of mudstone facies.

Low density of about (0.5-1.5) karren/m^2 for kluft type which is found to be associated with relatively fractured (heavily jointed) and wackestone–packstone facies.

Table 2. Karren density measurement in Algal Limestone Member, sector (3). (Kd= Nk/Ak after White 1988).

Elevation (M)	K.type	No.	Area (M^2)	$K_d = \frac{N_k}{A_k}$
260	Groove	18	9.5	1.8
	Kluft	5	4	1.2
257	Kluft	8	15	0.5
250	Groove	8	2.5	3.2
243	Kluft	6	10	0.6
240	Groove	12	7	1.7
	Circular	163	24	6.8
230	Circular	73	14	5.2
225	Circular	350	48	7.2
220	Groove	9	4.5	2
200	Kluft	5	10	0.5
	Circular	335	28	12
190	Groove	10	6	1.6
	Kluft	12	8	1.5
	Circular	400	25.3	15.8
180	Circular	200	26	7.6

Key: K.type= karren type.

K_d: karren density.

N_k: Number of karren.

A_k: Area of karren.

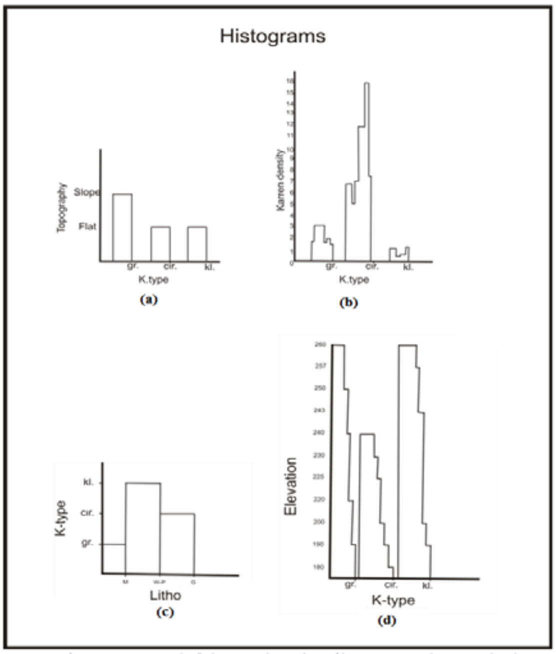

Figure 9. Histograms (a-d) showing relationships of karren types with topography, density, lithology and elevation, in Algal Limestone Member, sector (3).

7. Conclusion

Based on field observations and literature review, the Algal Limestone facies in sector (3) area, Tansulukh region are dominated by minor surface dissolution karstic features like cavities. Histograms have shown some relationships of these karstic features (karren types) with some parameters such as lithology, topography and density. The observed dissolution karstic features are found to be mainly controlled by lithologic change; as mud to grains ratio decreases, circular karren type dominates the outcrop surface where water standing for a period of time, percolates down with the help of the relatively porous packstone-grainstone texture. On the other hand, if mud to grains ratio increases, groove karren will dominate the exposed surface because of the strong runoff on steep slopes and the relative decease in porosity of this mudstone-wackestone facies. Structural attitudes and characters of the exposed Algal Limestone Member in the study area have an impact on the type of karren; as joints and fractures, formed during periods of uplift, govern the orientation of the kluft karren type in mudstone-packstone facies and increasing their secondary permeability through extensive joints to dissolve the carbonate along these structural weakness planes.

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