Ichnology of the carbonate aeolianites of the Quaternary Gargaresh Formation, western Libyan coast.

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Abstract

Quaternary carbonate aeolianites are well exposed in sea cliffs along the western coast of Libya. These deposits form the major part of the Gargaresh Formation; also include paleosols and shallow marine facies. The aeolianites and paleosols contain abundant calcified root structures; rhizolithes. The presence of abundant rhizoliths at several horizons of the aeolianites indicates that the carbonate dunes were stabilized at least episodically by vegetation during relatively wet period. Animal trace fossils recorded in the aeolianites include several specimens of *Skolithos linearis* burrows; vertical or nearly vertical to bedding planes. Also irregularly meandering burrows parallel to stratification have been recorded in the aeolianites.

Key words:
Rhizoliths, *Skolithos linearis*, Quaternary carbonate aeolianites, Gargaresh Formation, western Libyan coast.

Introduction

Ichnofossils are little studied and poorly known in the Quaternary sediments exposed along the Libyan coast. These include traces made by plants (considered to be ichnofossils by some workers, e.g., Curran and White, 1991 and Gregory *et al.*, 2004) and trace fossils made by animals.

Traces made by plants are dominated by mineralized root structures. Several different names have been used to describe cemented root structures, including rhizoliths (Klappa, 1980, Loope, 1985), rhizocretions (Steinen, 1974; Esteban, 1976), dikaka (Glennie and Evamy, 1968) and rhizoids (James and Choquette,1984). The term rhizolith has been increasingly used in recent years to describe various forms of root structures that occur in calcretes, aeolianites and subaerially exposed marine carbonates. According to Klappa, (1980), rhizoliths are organo-sedimentary structures resulting in the preservation of roots of higher plants in mineral matter. Although superficially similar to some burrows, rhizoliths can be recognized by the criteria given by Klappa (1980) and Curran (1984). Root casts, like animal burrows are commonly circular in cross-section and cylindrical in shape. However, root casts can be distinguished from animal burrows in that they have downward bifurcations with decreasing diameters as branching order increases. Mineralized root structures are abundant in Quaternary terrestrial carbonates including aeolianites and calcretes (Cramer and Hawleins, 2009). Examples of spectacular development of rhizolithes have been recorded in the Quaternary calcareous dunes of Australia (Read, 1974), Florida (Ball, 1967), San Salvador (Curran, 1984), Spain (Mallorca; Klappa, 1980 & Gran Canaria: Alonso-Zarza *et al.*, 2008) and Tunisia (Plazait and Mahmoudi, 1990).

Burrows and burrowing animals are common in the modern siliciclastic inland dune fields (Ahlbrandt *et al.*, 1978). On the other hand, trace fossils in carbonate aeolianits were rarely documented. However, recent descriptions of trace fossils from Pleistocene-Holocene carbonate dunes demonstrate that they can hold a moderately diverse assemblage of traces (Curran, 1984; White and Curran,1988, Curran and White, 1991 and Genise, *et al.*, 2010). Some organisms are especially adapted to life in dune fields and many of them made several different types of burrows. Some dune animals burrow in sand to obtain food and moisture (Seeley and Hamiton, 1976) or for protection from heat, cold or predators.

In the present paper we document the distribution of rhizoliths and and animal trace fossils in the sediments of the Gargaresh Formation, particularly in the aeoliantes. Also a composite

section representing the Gargaresh Formation is suggested; based on field study of fifteen coastal exposures.
The study area extends over three hundred kilometers of western Libyan coast. Fifteen coastal exposures were investigated, situated between Misratah and Sabratah (Fig. 1) At each site stratigraphic sections were logged and photographed. Several examples of faunal bioturbations related to plant roots have been reported in the aeolianites and paleosols of the different profiles. More attention was given to the main morphological features of rhizoliths in the aeolianites. Rhizolith geometries, (length and diameter) were measured in the coastal exposures of An Naggazah, Karot Zliten and Misratah (Table 1).

The Gargaresh Formation

The Gargaresh Formation represents a characteristic geological and geomorphologic feature of the western coastal plain of Libya. The formation occurs as a ridges along the Mediterranean coast; rising 4-60m above sea level (Mann, 1975 a & b and Ilich and Smykatz-Kloss, 1980). The type section (14m thick) has been described along the shore west of Tripoli (El Hinnawi and Cheshitev, 1975). The Gargaresh Formation may be underlain by Cenomanian dolostone (Sidi As Sid Formation) and/or Middle Miocene limestone (Al Khums Formation)
A composite section representing the Gargaresh Formation and overlying surficial sediments is suggested; based on field study of

fifteen coastal exposures. The composite section comprises several informal units (Fig. 2). The basal unit (unit A) of the Gargaresh Formation is represented by a bioclastic highly calcareous sandstone which grades upward to fossiliferous sandy limestone (shallow marine facies); followed by paleosols and aeolianites units B and C (Fig. 2 and Fig. 3 a & b). At some coastal exposures, the paleosols are missing and the aeolianites rest directly on the shallow marine facies (Fig. 3 c). The transition from shallow marine facies to paleosols or aeolianites indicates a drop in the sea level. The shallow marine units is characterized by tabular cross-bedding and abundant disarticulated bivalve particularly *Anadara* (Fig. 2 d). Other recorded fossils include benthic foraminifera (dominated by miliolids) in addition to echinoderm fragments, ostracods, sponge spicules and serpulids.

The paleosol unit consists mainly of brownish red sediments dominated by fine to very fine quartz sand with variable amount of clays and carbonates. Rhizoliths, carbonate nodules and land snails are common features in the paleosols. Drifted marine fossils (benthic foraminifera, coralline red algae, echinoderm fragments, etc) are encountered; may be related to aeolian input from exposed shallow marine sediments during periods of low sea-level stands. Also, the marine elements in the paleosols may have been derived from the overlying carbonate aeolianites as a consequence of burrowing activity.

Aeolianites constitute the major part of the Gargaresh Formation. Aeolianites represent coastal limestones that record the reworking of vast quantities of shallow marine bioclastic carbonate sediment into coastal dunes (Brooke, 2001 and Loope, and Abegg, 2001). Dune morphology (Fig. 3 e), large scale cross-bedding (Figs. 3 b, c & f) and rhizoliths are common features. Dissolution pipes; distinctive features of syngenetic karst on the aeolianites, are commonly observed in several coastal exposure. The orientation of these pipes is commonly vertical or steeply oblique to dune development. The aeolianites contain high concentrations of biogenic marine carbonate and have been interpreted as being emplaced during periods of intense aeolian activity. The appearance of thin discontinuous paleosols within the aeolianite sequence probably represents a relatively brief and localized pause in aeolian sedimentation during wetter climate.

The Holocene soils (unit D in Fig. 2) which cap the aeolianite succession of the Gargaresh Formation display a pronounced undulating character and can be traced along the entire aeolianites belt. The soils may be overlain by brown aeolian quartz sand and/or quartz-rich carbonate sand (unit E in Fig. 2).

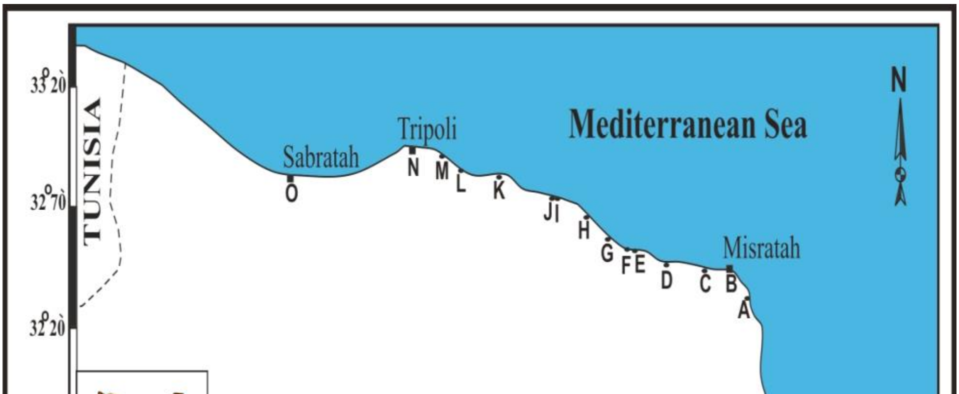


Fig. 1. Site locations of the examined sediments of the Gargaresh Formation exposed along the western Libyan coast.

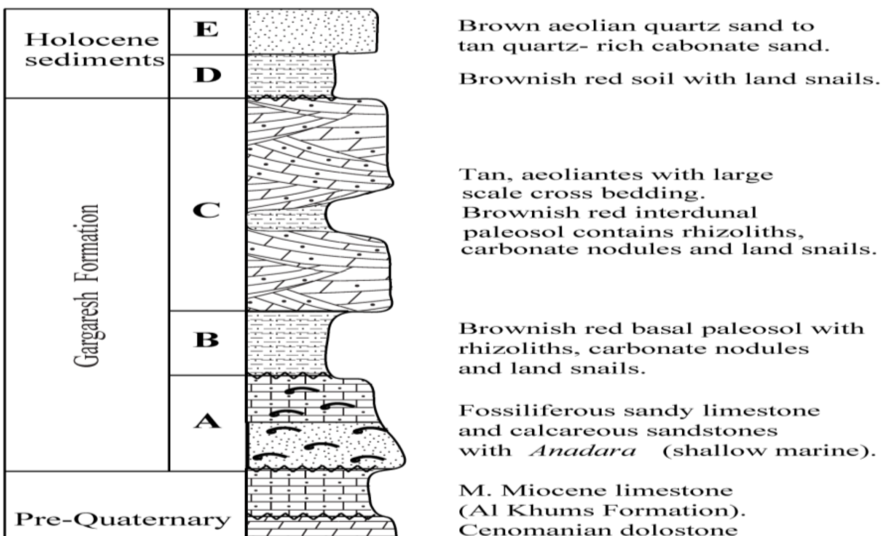


Fig. 2. Schematic diagram showing a generalized composite sequence of the Gargaresh Formation and the Quaternary informal lithostratigraphic units (A - E); based on 15 profiles along the western Libyan coast.

Fig. 3 Lithostratigraphic units of the Gargaresh Formation exposed along the western Libyan coast.

Fig. **a**. A coastal exposure at Zawyet Al Mahjoub showing the sequence of the Gargaresh Formation; aeolianite underlain by a brownish red, friable sandy paleosol and shallow marine facies. The white tent for scale is 2.2m high.

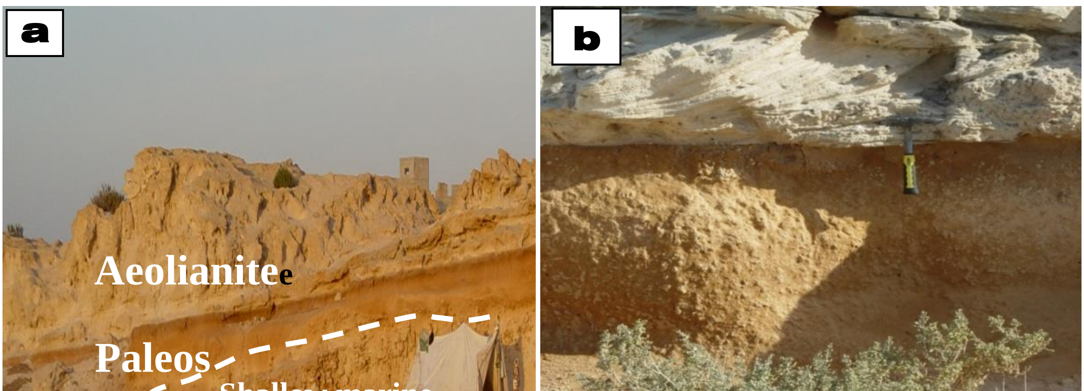
Fig. **b**. A close-up view of the paleosol illustrated in Fig. a. The paleosol contains abundant rhizoliths, carbonate nodules and drifted marine fossils. Note the wedge planner cross-bedding in the aeolianite which truncates the paleosol. Geologic hammer for scale is 28cm long.

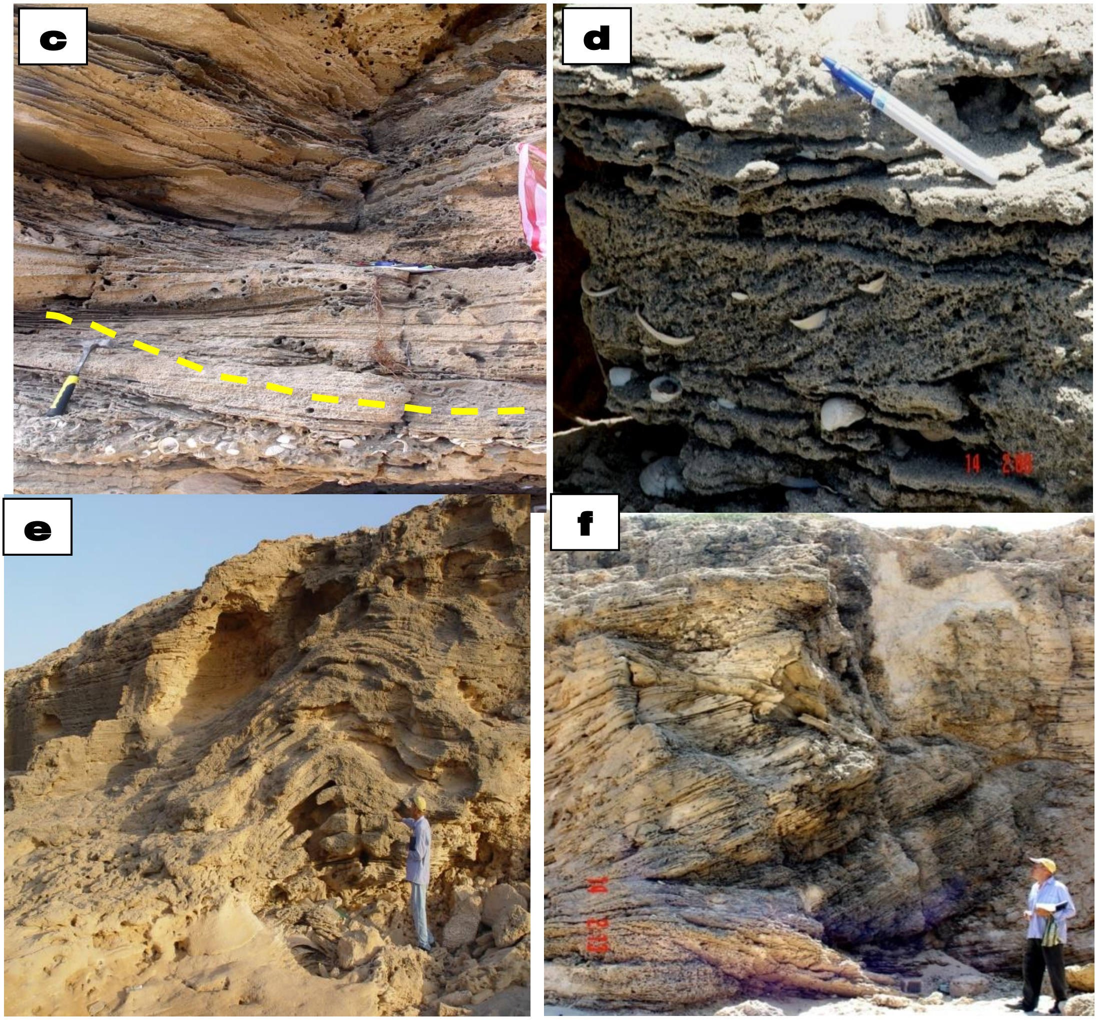
Fig. **c**. Large scale cross-bedded Pleistocene aeolianites of the Gargaresh Formation at Karot coast. Note the truncation surface (marked by broken line) between the shallow marine facies (shell banks of *Anadara*) and the overlying aeolianite. Geologic hammer for scale is 28cm long.

Fig. **d**. A close-up view of the shallow marine facies of the Gargaresh Formation at Karot coast showing planner cross-bedded calcarenite with disarticulated shell of *Anadara*. Pen for scale is 15cm.

Fig. **e**. Dune morphology in the Pleistocene aeolianites of the Gargaresh Formation at Ghanima coast. Wind direction (right-left) is indicated by lateral displacement of aeolian ridges. Geologist for scale is 1.8m tall.

Fig. **f**. A coastal exposure at Karot showing a thick aeolianite sequence of the Gargaresh Formation with large scale tabular cross-bedding and variation in the direction of the cross-bed sets. Frequent change in paleo-wind direction is apparent from the orientation of the foresets of successive sets. Geologist for scale is approximately 1.8m tall.

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Plant ichnofossils (rhizoliths)

Bioturbation related to plant roots is common features of the Quaternary sediments exposed along the western Libyan coast. Rhizoliths have been observed in different units of the Gargaresh Formation; aeolianites and paleosols recorded in the different profiles. Sediments in direct contact with the rhizoliths are more cemented by carbonates. This may be related to micro-environmental conditions around the roots which can result in local carbonate cementation. Differential weathering like that seen in the aeolianites (Figs. 4 a-d) and paleosols (Fig. 4 e), mean that the rhizoliths are commonly left standing in relief against the host softer sediment. The contrast in the amount of cement between the rhizoliths and the encasing sediment points to the significant role that plants can have in diagenesis of carbonates in a vadose environment (Jones and Ng, 1988 and McLaren, 1995). However, further detailed studies of the external form and internal fabrics of rhizoliths should be rewarding. Rhizoliths are worthy of attention because they bear evidences concerning plant / sediment interactions.

More attention is given to the rhizoliths of the aeolianites. Their main morphological characteristics in the aeolianites of four coastal exposures are given in Table 1. Two main types of rhizoliths have been distinguished. The criteria used for the classification of rhizoliths include density or degree of bioturbation ranging from isolated traces to dense, and rhizolith geometries (Table 1). The first type is represented by networks of small rhizoliths, few centimeters in length. About 50% of the rhizoliths are less than 10 cm in length. The rhizoliths occur in many shapes and orientations. The density of rhizoliths is moderate to high. Several networks of rhizoliths have been recognized in the same bed as result of successive stages of plant colonization. Some aeolianite units are almost wholly occupied by root casts in growth position. The best developed small rhizoliths field seen in the aeolianites was exposed at Ghanima and Qasr Hamad (Fig. 4 a&b). At both localities, thousands of rhizolith specimens are exposed in growth position. Due to their high density, the rhizoliths may completely destroy the sedimentary structures. The cross-bedding in the aeolianites is highly obliterated. Both the small dimensions and the common high density of bioturbation traces suggest that they are rhizoliths associated with grass plants (Klappa, 1980),

The second type is dominated by large rhizoliths; up to 58 cm in length (Table 1). The root casts are normally vertical with downward-tapering diameter (Fig. 4 e). The density of rhizolith is moderate to low. In some cases the external walls of the rhizoliths show small millimetric protuberances (Fig. 4 d), representing secondary roots. The rhizoliths are commonly truncated by internal stratification (Fig. 4 e). This relation demonstrates their contemporaneity with sedimentation.

Another type of plant preservation in mineral matter is represented by columnar structures. Most of the analysed structures appear as free large standing, vertical, cylindrical columns scattered over a wide area at Ghanima aeolianites (Fig. 4 f). These structures are considered as tree trunks, preserved in situ casts in the aeolianites. The trunk casts exhibit outer surface features characterized by a pattern of poorly preserved pits and raised rims. Most of the tree trunk casts are characterized by large size, up to 30 cm in diameter. It is very probable that the tree trunks, with their large diameters, formed during relatively wetter periods. Preservation of such large tree trunks is favored by conditions of rapid sediment accumulation by an advancing sand dunes. The tree trunk casts recorded in the present study bear some similarities to the megarhizoliths in the Pleistocene aeolianites from Gran Canaria (Alonso-Zarza, *et al.*, 2008). These megarhizoliths are characterized by central pores corresponding to the cavities originally occupied by the roots. This was not observed in the tree trunk casts described in the Libyan aeolianites.

Recognition of paleo-rhizoliths is useful in distinguishing phases of dune activity versus dune stabilization, delineation of paleo-dune morphology; and in the determination of the vadose zone (McLaren, 1995). The relationship between the Libyan aeolianites and associated plants has pale-climatic inferences. The presence of abundant rhizoliths at several horizons indicates that the aeolianites were stabilized at least episodically by vegetation. Also aeolianites with abundant rhizoliths or tree trunks suggest plant colonization during slightly wetter periods. Aeolianite deposits lacking plants would represent more arid times. This alternation of arid and less arid conditions has been detected in the Libyan aeolianites recognized at several exposures.

Animal burrows

Several examples of faunal bioturbations are obtained in the current study; mainly recorded in the Quaternary aeolianites. Several specimens of *Skolithos linearis* have been observed in the aeolianites of Karot, Zawyet Al Mahjoub and Kaam (Fig. 5 a, b and c).The *Skolithos* tubes, most commonly functioning as dwelling burrows (Curran and White 1991); is vertical to nearly vertical to bedding planes and most commonly few millimeters in diameter. Individual specimens can be up to 8 cm. long; most specimens are considerably shorter, but the full length of the original tube normally is not preserved. Most probably the trace makers of *Skolithos Linearis* were insects or arachinids or both (Curran, and White, 2001).

The ichnogenus *Skolithos* is known to have a much broader range of environmental occurrences; from siliciclastic inland dune fields (Ahlbrandt *et al.*, 1978) and fload plain deposits (Ratcliffe and Fagerstrom, 1980) to deep-sea fans (Crimes, 1977). Also *Skolithos* burrows have been reported in the

Quaternary carbonate aeolianites. Although these trace fossils are not diagnostic of the aeolian environment, but their presence in ancient carbonates should not be used to exclude the possibility of aeolian deposition.

Another trace fossil in the Libyan aeolianite is represented by irregularly meandering small burrows (Fig. 5 e). These are best seen on the upper surface of strata. They have a uniform diameter of few millimeters along their length which commonly exceeds 15 cm. Similar structures have been published commonly. For example, burrows with similar surface pattern have been described in the Bahamian carbonate aeolianite (White and Curran, 1988, Fig. 13 & Curran and White, 1991, Fig. 9e). Both authors suggested that larval or adult insects were the probable tracemaker organisms. Also comparable structure were recorded in the Late Pleistocene aeolianites of the south coast of Mallorca (Fornos *et al.*, 2002). The latter authors attributed these structures to insects.

Fig. **a**. A coastal exposure at Ghanima showing the aeolianites of the Gargaresh Formation; overlain by Holocene soil; 2m thick. The cross-bedding in the aeolianites is highly obliterated by dense rhizoliths.

Fig. **b**. A close-up view of network of small rhizoliths at Qasr Hamad; interpreted as grass roots that penetrated the aeolianites.

The rhizoliths occur at different shapes and orientations and they may completely destroy the primary sedimentary structures of the aeolianites. Pen for scale is 15cm long.

Fig. **c**. A close-up view of the aeolianites of the Gargaresh Formation at An Naggazah coast showing root moulds which appear as voids where the roots were formerly present. The sediment directly adjacent to the moulds are highly lithified. Pen for scale is 15cm long.

Fig. **d**. Coastal exposure of the aeolianites of the Gargaresh Formation at Tripoli coast showing a calcified root (rhizolith) cropping out in a solution pipe. Pen for scale is 15cm long.

Fig. **e**. A close-up view at Ghanima coast showing a large rhizolith with tap root, starting just above the lower surface the aeolianite and extending down to the paleosol. Geologic hammer for scale is 28cm long.

Fig. **f**. Exhumed petrified tree trunk as free standing column at Ghanima aeolianites. Bar scale = 10cm.

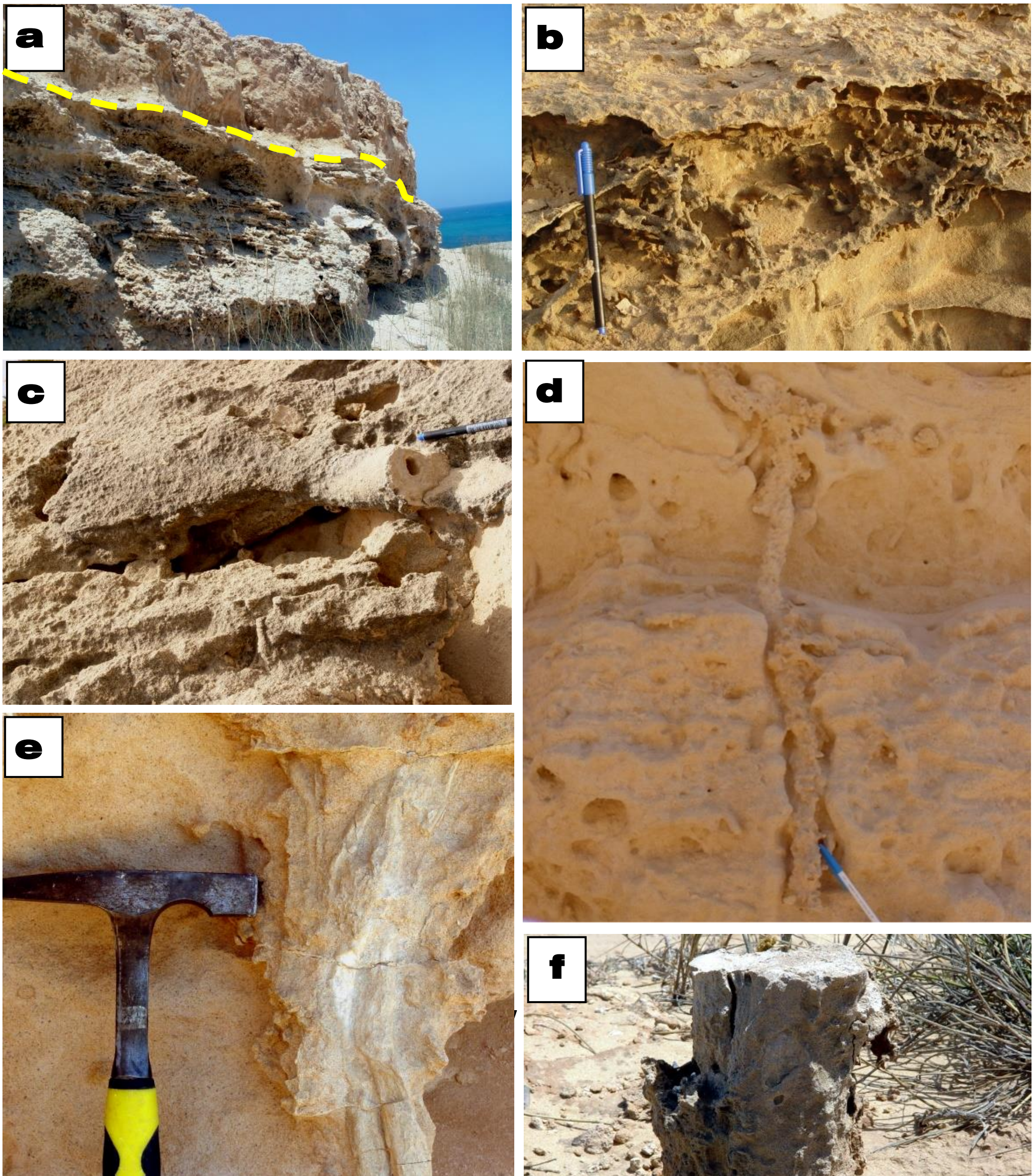
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Fig. 4. Plant trace fossils in the Pleistocene aeolianites of the Gargaresh Formation.

Table 1. Main morphological characteristics of rhizoliths recorded in the Quaternary aeolianites of the Gargaresh Formation exposed along the western Libyan coast (length: L & diameter: D in cm).

An Naggazah		Karot		Zliten		Misratah	
L	D	L	D	L	D	L	D
50	3.0	25	1.8	12	1.0	10	1.2
5	2.7	14	1.2	4	0.8	8	2.4
4.2	2.0	12	0.8	6	0.4	3	0.5
31	6.6	10	1.0	8	1.2	17	0.4
18	1.8	22	0.6	3	0.5	7	0.4
14	3.8	18.5	2.0	8	0.8	58	0.4
10	2.8	16	1.8		0.6		
3	1.0	25	2.1				

7	1.3	40	0.5				
9	1.8	35	0.6				
14	2						
12	2.8						
22	1.8						

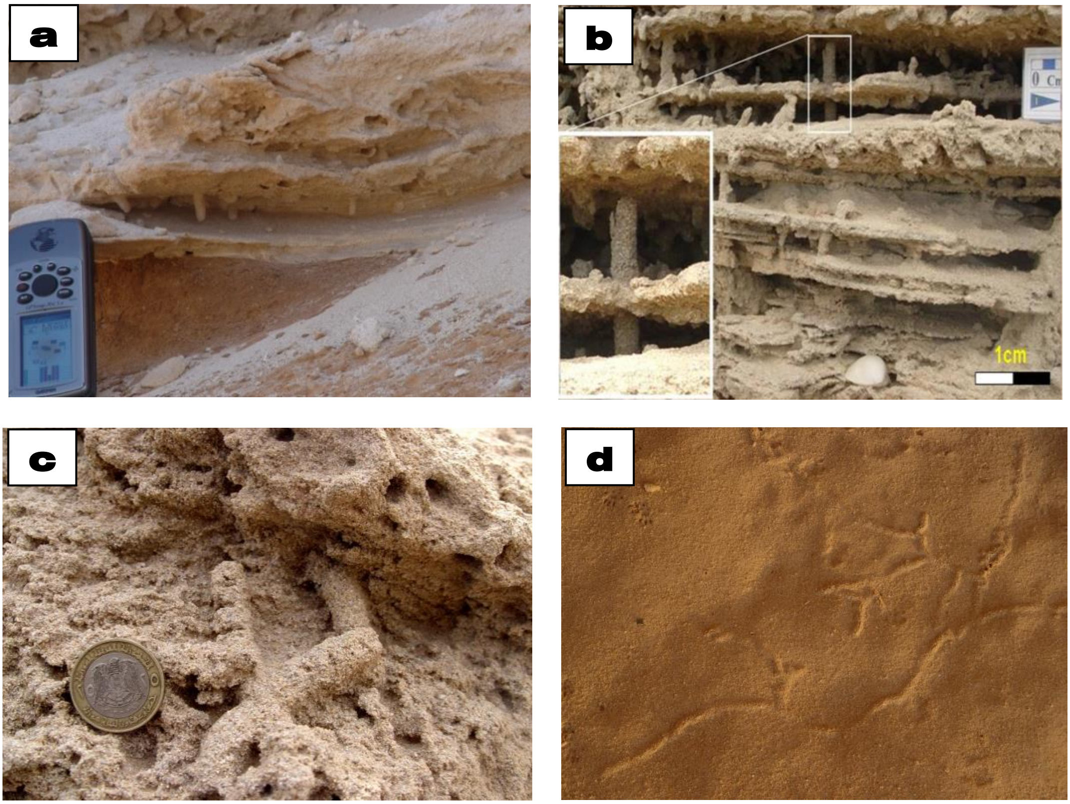

Fig. 4. Animal trace fossils recorded in the Pleistocene aeolianites of the Gargaresh Formation.

Fig. **a**. *Skolithos linearis* burrows in aeolianite beds at Zawyet Al Mahjoub. GPS for scale 12 cm long.

Fig. **b**. Aeolianite at Karot coast showing *Skolithos linearis*; possibly dwelling burrows of arachnids, insects or both.

Fig. **c**. Coastal exposure at Kaam showing *Skolithos linearis* burrows. Coin for scale is 2.5cm in diameter.

Fig. **d**. Irregular burrows on bedding planes of the Gargaresh aeolianites at Zawyet Al Mahjoub; may have been made by insects or insect larvae. Bar scale = 10cm.

Conclusions

The Quaternary Gargaresh Formation represents a characteristic geological and geomorphlogical feature of the northwestern coast of Libya. The formation comprises impressive carbonate aeolianites exposed in sea cliffs; underlain by paleosols and shallow marine facies. Trace fossils formed by both animals and plants are common components of the aeolianites. The abundant mineralized root structures (rhizoliths) at several horizons indicate that the carbonate dunes were episodically stabilized by vegetation during relatively wet periods. The animal trace fossils recorded in the aeolianites include several specimens of *Skolithos Linearis*. Although *Skolithos* burrows are not diagnostic of the aeolian environment, but their presence in ancient carbonates should not be used to exclude the possibility of aeolian deposition.

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آثار الحفريات في الكثبان الجيرية التابعة لتكوين قرقارش (الزمن الرابع) ،ساحل ليبيا الغربي

الصادق خميرة

قسم علوم الأرض والبيئة – كلية العلوم – جامعة المرقب — ليبيا

الملخص:

تتواجد الكثبان الجيرية التابعة للزمن الرابع بصورة مميزة في الجروف البحرية بغرب ليبيا، وتمثل هذه الكثبان الجزء الرئيسي من تكوين قرقارش، والذي يحتوي على سحنات أخرى، مثل: رواسب التربة القديمة، ورواسب البيئة البحرية الضحلة. وتتميز الكثبان الجيرية بتواجد ملحوظ لجذور النباتات المتكلسة في عدة مستويات، مما يدل على استقرار الكثبان خلال فترات متقطعة تتميز بمناخ رطب نسبيا، كما تحتوي الكثبان الجيرية على آثار حفريات حيوانية، أهمها جنس *Skolithos* .