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First report of palynomorph assemblages from the beachrocks of the southeastern Gulf of Sirte (Mediterranean Sea), coast of Brega, Libya

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ABSTRACT

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A diverse assemblage of palynomorphs is being reported for the first time from the beachrocks. The studied samples are from southeastern Gulf of Sirte (Mediterranean Sea), coast of Brega, Libya. A survey of palynological literature indicates that there is no record of palynomorph assemblages from beachrocks from anywhere. The objective of this study was to explore the possibility of presence of palynomorphs in beachrocks, and if present, demonstrate their paleoenvironmental significance. Five beachrock surface samples yielded palynomorph assemblages which are divided into five groups based on their biological affinities: (1) angiosperm palynomorphs; (2) algal palynomorphs; (3) fungal palynomorphs; (4) marine invertebrate palynomorphs; and (5) miscellaneous palynomorphs. Microscopic remains of solid hydrocarbons are present as well. The recovered palynomorph assemblages are sourced from the shallow marine environments and the nearby coastal plants. Presence of very few angiosperm pollen reflect a low floral diversity of the coastal desert environment. Algal and invertebrate palynomorphs also suggest a low biological diversity in the intertidal zone of this coast. This study demonstrates that rocks that seemingly are not suitable for pollen analysis can provide palaeoenvironmental information. Such a study with larger number of samples resulting in numerically and taxonomically diverse assemblages would be useful for understanding the source and environments of palynomorphs in beachrocks.

Keywords: Beachrock palynology, Non-pollen palynomorphs (NPP), Microscopic remains of solid hydrocarbons, Micropalaeontology, Floral diversity of the coastal desert.

INTRODUCTION

Brega (30°26’06"N, 19°40’01"E), a small town, is situated on the southeastern corner of the Gulf of Sirte south of the Mediterranean Sea (Figure 1). This town is also known as Marsâ al Burayqah meaning the Brega Seaport. Presence of beachrocks, their geographic locations and stratigraphic positions was described by Kumar (2015, 2016).

There are a few paleontological studies on the beachrocks that include studies on invertebrates and trace fossils. Palynological studies on beachrocks have not yet been published except for a short report on this study (Kumar 2021a). The objective of this study was to record palynomorphs from these rocks and demonstrate their paleoenvironmental significance. The present study indicates that palynologically beachrocks

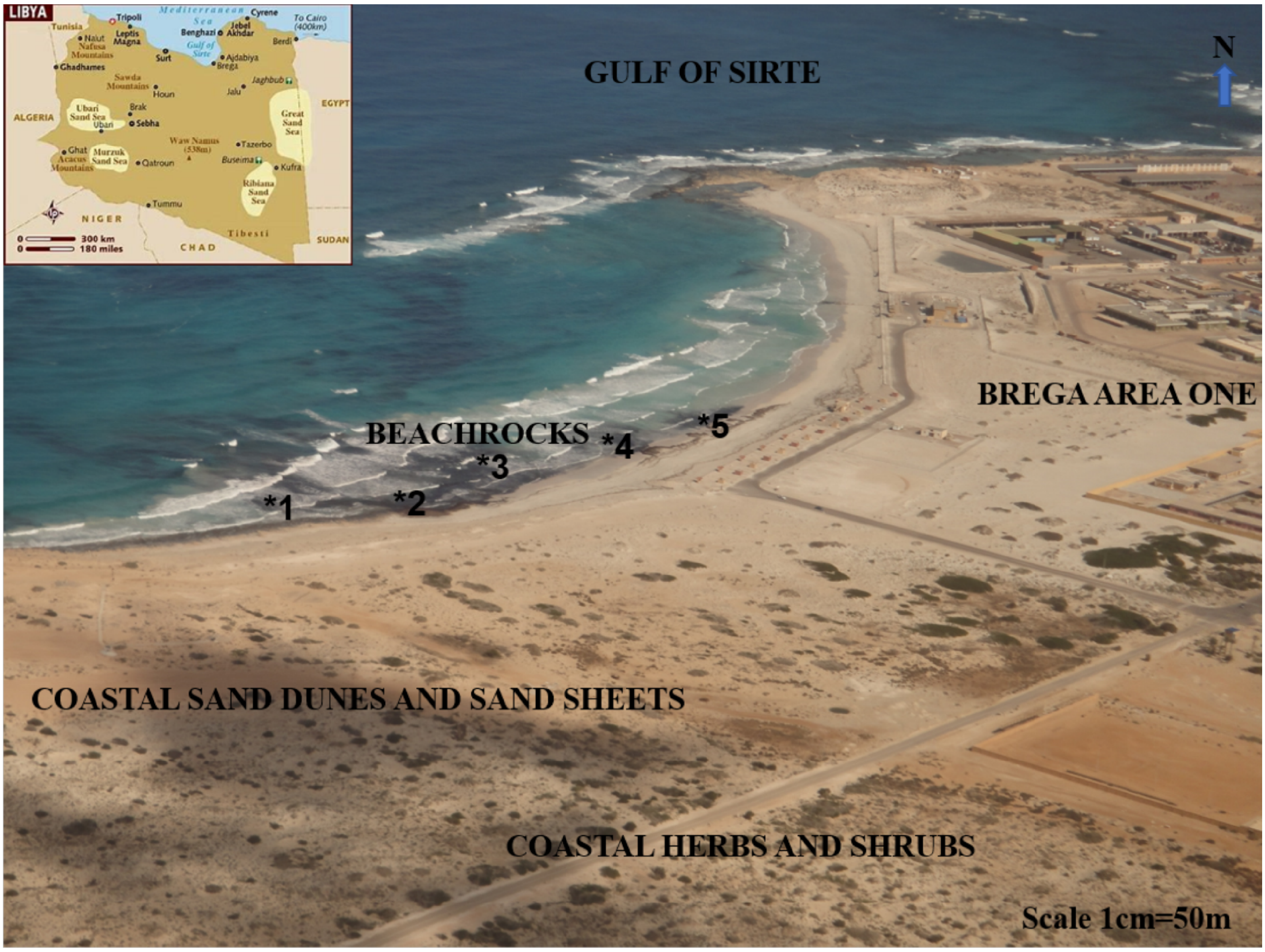

Figure 1. An aerial view of the southwestern end of the Brega Area One beach showing outcrops of the beachrocks, sand dunes and sand sheets along with sparse coastal vegetation. Location of samples studied are indicated by numbers 1 through 5. Map of Libya showing the location of Brega in the southeastern corner of the Gulf of Sirte in Mediterranean Sea (inset).

are archives of diverse groups of palynomorphs belonging to various coastal marine environments primarily from the intertidal zones, and from the coastal terrestrial vegetation. Palynomorph assemblages derived from beachrocks may be used as proxies for Quaternary paleoclimate and marine and terrestrial environments.

A BRIEF OVERVIEW OF BEACHROCK STUDIES

The study by Ginsberg (1953) on the beachrocks of South Florida was one of the early works on the beachrock geology. Beachrocks were defined by Friedman and Sanders (1978) as, "Rock that forms by cementation of the sediments in the intertidal parts of beaches." These rocks usually are well-sorted beach sands consisting mostly of carbonate skeletal particles, and the size frequency distribution of grains in most beachrocks is usually similar to that of nearby non-cemented beach sand (Friedman & Sanders 1978). They are the consolidated deposits resulting from lithification by calcium carbonate of sediments in the intertidal and spray zones (Scoffin & Stoddart 1987). Beachrocks are formed in the tropical to subtropical climate belts between latitudes 35º N and 35º S, but they are also known from higher latitudes such as the Mediterranean Sea (Arrieta et al. 2011). An extensive review on various aspects of beachrock studies was provided by Vousdoukas et al. (2007). They reported on the occurrences, characteristics, and formation mechanisms of beachrocks and discussed their impacts on the coastal zones. Further they concluded that beachrock formation is a global and diachronic phenomenon and a majority of beachrocks are found in tropical/subtropical and low temperate latitude microtidal coasts. Generally, beachrocks are exposed, and act like a natural breakwater decelerating shoreline and backshore retreat but they also tend to retard beach buildup. Despite many petrographic investigations of beachrock cements, the processes responsible for formation of beachrocks are still poorly understood (Turner 2005). The precise mechanism of the origin of beachrock has been debated for over 50 years (Gischler 2007).

Beachrocks are formed under a thin cover of sediment that overlies the unconsolidated sand. The sea water supersaturated with calcium carbonate and high temperature beach sediments are necessary conditions for cementation; thus, for the formation of beachrocks. Beachrocks typically consist of multiple layers resulting from multiple episodes of cementation and exposure and dip seaward (4–10°). They are laterally discontinuous and are exposed for short distances before disappearing under loose sand or ending entirely. Thickness of beachrocks ranges from a few cm up to 5 m with approximately 2 m being the most common (Turner 2005). Ghandour et al. (2014) described the petrographic and petrophysical characteristics of three stratigraphically asynchronous beachrocks along the Red Sea coast of Al-Shoaiba area, Saudi Arabia. They identified the compositional, depositional, and diagenetic controls on beachrock formation and their petrophysical properties.

Rates of beachrock formation vary quite rapidly ranging between months to a few hundred years (Frankel 1968, Cooper 2013), thus providing a good potential indicator of sea-level position. Hopley (1986) summarized shortcomings of beachrocks as a potential sea-level indicator. Several Pleistocene and older beachrock formations are known; however, the active nature of the sandy coasts and changing sea-levels require that most beachrocks are less than 2,000 years old. Dating of beachrocks is difficult since they are poorly suited for radiocarbon dating (Turner 2005). Vacchi et al. (2016) reviewed 917 relative sea-level (RSL) data-points that resulted in the first database constraining the Holocene sea-level histories of the western Mediterranean Sea. They standardized the geological RSL data-points using a new multi-proxy methodology based on: (1) modern taxa assemblages in Mediterranean lagoons and marshes; (2) beachrock characteristics (cement fabric and chemistry, sedimentary structures); and (3) the modern distribution of Mediterranean fixed biological indicators. Beachrocks are also known to be an indicator of Quaternary paleo-coastlines. However, their use as a sea-level indicator becomes problematic in the determination of the exact elevation of beachrock formation with respect to paleo sea-level. A study of beachrock as sea-level indicator from the coastline of Oman by Falkenroth et al. (2019) shows a set of twelve marine terraces reaching a height of 500 m above the mean sea-level. Psomiadis et al. (2014) studied clastic sedimentary features of beachrocks and unconsolidated deposits of parent beaches along the Aegian coastline, to assess their suitability in paleo-environmental reconstruction. Their results indicated that, during the time of beachrock formation, depositional conditions differed significantly from those of the modern parent beaches.

There are a few significant paleontological studies of beachrocks. Moissette et al. (2013) reported abundant and diverse skeletal organisms from the beachrock beds associated with the siliciclastic shallow-water lower Pleistocene deposits of Rhodes, Greece. These fossil communities indicate repeated drowning episodes; thus, they are valuable indicators of relative sea-level changes. Edwards and Mitchell (2018) described trace fossils preserved in the clastic beachrocks from the southern section of the Yallahs Salt Ponds on the southeastern coast of Jamaica. These beachrocks are cemented sandstones and conglomerates and their landward facies consists of cemented sandstones packed with the trace fossil

Psilonichnus produced by the ghost crab *Ocypode quadrata* (Fabricius). The bioturbated *Psilonichnus*-bearing units demonstrate that beachrock cementation occurred within the intertidal zone and the lower supratidal zone, where modern burrows of Ocypode are found. The high density of *Psilonichnus* burrows indicate multiple generations of Ocypode burrowing activity, demonstrating that the beach system was stable and not affected by any tropical storms or hurricanes for an extended period before cementation.

Coastal environments, climate, and vegetation around Brega

Mediterranean coastal Quaternary deposits of NE Libya are represented by large numbers of sabkhas, aeolian deposits, beach and coastal sand dunes and alluvium deposits, along with outcrops of the Ajdabiya Formation (Tawadros 2012). Sabkha is a surface of deflation, in an arid environment, formed by removal of dry, loose particles down to the level of the ground water or the zone of capillary concentration (Friedman & Sanders 1978). These are flat areas in desert environments, characterized by a crusty surface consisting of evaporite deposits (including salt, gypsum, and calcium carbonate), windblown sediments, and tidal deposits. Sabkhas form primarily through the evaporation of sea water that seeps upward from a shallow water table and through the drying of windblown sea sprays.

According to Fowler (2021) “Libya’s climate is dominated by the hot, arid Sahara, but it is moderated along the coastal areas by the Mediterranean Sea. The Saharan influence is stronger in summer. From October to March, prevailing westerly winds bring cyclonic storms and rains across northern Libya”. Libya has 2,103 species of tropical and Mediterranean plants that belong to 856 genera and 155 families; and herbs (annual to perennial) dominate over woody (tree and shrub) species (Feng et al. 2013). The Mediterranean coastal ecosystems of Libya cover an area 25–100 km wide where the annual rainfall is about 200–250 mm (Feng et al. 2013). Over 75% of vascular plants are distributed in the coastal areas, such as *Acacia* spp., *Borassus*, and *Phoenix* etc. In the Brega area xeric juniper trees were planted along the roadside when this industrial town was built during 1950–1960 (Kumar 2015).

Geology and beachrocks of Brega

Geology of Brega and the surrounding regions are represented by Holocene aeolian deposits, beach and coastal sand dunes and sand sheets, along with outcrops of the Ajdabiya Formation (Tawadros 2012). Outcrops of Pleistocene cemented marine dunes belonging to the Ajdabiya Formation are seen as patches of various lengths and heights that run parallel to the modern-day Mediterranean Sea coastline. The Holocene sediments around Brega include coastal and inland sand dunes and sand sheets mixed with millions of beach balls (Egagropili). The beach balls are felt textured, agglomerates, oval to spherical masses composed of the fibrous remains of seagrass *Posidonia oceanica*. Over time, dead fibrous tissue of this plant is tossed by waves, and constant rolling action of the sea eventually forms this material into balls which wash up on the beach (Kumar 2014a).

Kumar (2014b) established Brega Sandstone Bed of Pliocene age as a new stratigraphic unit and considered it as equivalent to the Lower part of the Sahabi Formation (Member V). Later, Kumar (2016) modified the stratigraphy of the area to include the stratigraphic placement of the newly described beachrock unit (Table 1, Figure 2).

About 200 m long, discontinuous outcrops of the beachrocks are present on the southwestern end of the Brega Area One beach (Figure 1). They are almost horizontal or gently dipping towards the sea; their maximum thickness is close to one m. These rocks are hard, of grey to dark grey colour, and are exposed along the seacoast. The surface of these rocks is characterized by numerous circular to sub-circular shallow depressions or holes of various diameters and depths (Figure 2.A). Although most of these holes are isolated, occasionally they may be joined into multiple holes of various diameters. The cause of their origin is unknown; however, they may have been formed by surface waves-driven erosion. Often these holes are

Table 1. Stratigraphy of Brega area, Libya (modified after Kumar 2016).

Stratigraphic Unit and age		Lithology and Fossils	Paleoenvironment
Sand sheets and sand dunes (Holocene)		Sand mixed with beach balls; Occasional molluscs	Aeolian
Beach rock (Holocene)		Hard, massive, calcareous sandstone; Corals, Gastropods	Intertidal
Ajdabiya Formation (Pleistocene)		Marine sand dunes, compact, and at places cross bedded; Occasionally bioturbated	Shallow Marine
Sahabi Formation (Member V) (Early Pliocene)	Upper part	Medium to coarse, greyish-greenish, thinly bedded sandstone with pebbles; Fossils not observed.	Intratidal to supratidal
	Lower part	White, grey and yellowish sandstone, massive, medium to coarse grained (Brega Sandstone Bed); Burrows and trails, bioturbated	Intertidal to shallow subtidal

filled by floating crude oil that gets eventually solidified (Figure 2.B). The source of this crude oil is from leakages and spills while crude oil is being pumped into larger ships for export. Although crude oil pollution in the Mediterranean Sea off Brega is not common, however, minor leakages and spills cannot be ruled out. Thus, scattered small patches of dried crude oil can often be seen around the coast of Brega (Kumar 2015, 2016).

Mostly these rocks are unfossiliferous; however, few specimens of unidentified fossil corals (Figure 2.C D), gastropods (Figure 2.E F), and rare trace fossils such as annelid trail (Figure 2.C-t) which could be free winding simple trails without ornamentation e.g., ichnogenus *Gordia* Emmons 1844 (Collinson & Thomson 1989), burrows (Figure 2.D-b) and unbranched worm tubes (Figure 2.G-w) of variable lengths and uniform diameter (3 4 mm) were observed which could be tunnels and shafts of uniform diameter, horizontal and winding e.g., ichnogenus *Planolites* Nicholson 1873.

Presence of corals in the beachrocks of Brega is intriguing and needs to be investigated because there are no coral reefs offshore Brega or in the nearby waters of the Mediterranean Sea (Aguilar 2004).There are fossil records of corals in Libya and elsewhere in the Mediterranean region. Upper Miocene corals are reported from the western Mediterranean (Esteban 1980) and Paleocene-Early Eocene of the Sirte Basin of Libya (Scheibner & Speijer 2008). Nothing conclusive can be said about the source of these corals; however, it is postulated that fossil corals might have been transported from inland Libya by annual storms and flooding events to the beaches of Brega that were eventually lithified by calcium carbonate forming present day beachrocks. The gastropods found in these beachrocks are local shallow marine inhabitants and can be observed in the recent sediments (Kumar 2016).

MATERIAL AND METHODS

Five surface samples of beachrocks were collected at different places for this study (Figure 1). These samples are hard and compact and were macerated following the techniques described by Traverse (2007). About 50 gm of each sample was washed with distilled water and crushed into coarse sand size. Crushed samples were treated with 35% hydrochloric acid (HCl) and left for 24 hours to remove carbonates, followed by a treatment with 40% hydrofluoric acid (HF) for another 24 hours to remove silica, and 50% nitric acid (HNO_3) and 5% potassium hydroxide (KOH) for oxidation and the removal of humic matter. Residues were sieved through 10 µm sieves and were mixed with a polyvinyl alcohol solution and smeared over a coverslip for drying. Later, coverslips were mounted on slides with canada balsam solution. Two slides of each sample were prepared for palynological study. The slides were studied under an OMAX Optical Microscope (MD827S30L Series) using transmitted light. Each slide was scanned under x400 magnification and palynomorphs were photographed at x400 using an inbuilt camera system in the microscope. Few large palynomorphs were photographed at x100 as well. Since palynomorph numbers are low (Table 2), all palynomorphs in each slide were counted.

RESULTS

The palynomorph assemblages of the beachrock samples are numerically poor. They are dominated by non-pollen palynomorphs (NPP) such as algal and fungal remains, marine invertebrates, and trichomes. The assemblages are divided into five groups based on their biological affinities: (1) angiosperm palynomorphs (2) algal palynomorphs (3) fungal palynomorphs (4) marine invertebrate palynomorphs, and (5) miscellaneous palynomorphs. Microscopic remains of solid hydrocarbons were observed as well. The recovered palynomorphs are illustrated in figures 3 and 4 and their numerical abundances are shown in Table 2.

The presence of diatoms in these assemblages appear to be problematic because with 40% hydrofluoric acid (HF) treatment they should have been destroyed. However, it seems that not all the siliceous matter in the beachrock samples was destroyed. Looking at the assemblages it is evident that few specimens of diatoms completely survived the chemical treatment (Figure 3.B C) while few others partially survived and became chemically altered (Figure 3.D, G). The possibility of diatom contamination in these assemblages with water during palynological preparation is ruled out since these are mainly marine diatoms.

1. Angiosperm palynomorphs

Chenopodiaceae pollen

Figure 3.X

Size: 13 µm in diameter.

Comments: Spherical, periporate pollen, generally small but of variable size. Such pollen are produced by the plants belonging to the angiosperm family *Chenopodiaceae*. This family is widely distributed in Libya and has 23 genera and 49 species (Feng et al. 2013). Similar pollen are also produced by another angiosperm family *Amaranthaceae*, which has four genera and 11 families in Libya (Feng et al. 2013). Plants belonging to these families commonly inhabit hot and arid environments. Two specimens were observed.

Tricolpate, psilate pollen

Figure 4.P

Size: 16.7 × 12.4 µm.

Comments: Ovoid, tricolpate, psilate pollen, colpi almost reaching the poles. This is an angiosperm pollen; however, it is difficult to relate it to any plant taxa. One specimen was observed.

Juniper pollen

Figure 3.A

Size: 33 µm in diameter.

Comments: Subspherical, inaperturate pollen with verrucate and gemmate exine. Verrucae and gemmae are sparsely scattered all over the exine. The morphology of this species is closely similar to the Juniper pollen (Family *Cupressaceae*). In Brega area xeric Juniper (*Juniperus phoenicea* var. *turbinata*) trees were planted along the roadside when this industrial town was built during 1950–1960 (Kumar 2015). This pollen, most likely, is sourced from the *Juniperus phoenicea* var. *turbinata* planted along the roads of Brega. Three specimens were observed.

Arecaceae pollen type 1

Figure 4.A

Size: 34.5 × 22.3 µm.

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Figure 2. Outcrops showing fossil remains of the beach rock on the southwestern end of the Brega Area One beach. **A.** Hard, gray to dark gray beachrocks exposed along the seacoast showing several circular to subcircular depressions of various diameter and depth. **B.** Depressions filled by the floating crude oil (length of pen is 14 cm). **C.** Beachrock with unidentified fossil corals (length of pen 14 is cm); an annelid trail (19 cm long; 4 mm wide) is indicated by t. **D.** Beach rock with unidentified fossil corals (length of pen is 14 cm); a burrow opening (10 mm diameter) is indicated by b. **E, F.** Beach rock with unidentified fossil gastropods (marker length is 10 cm). **G.** Unbranched worm tubes (w) of variable lengths and uniform diameter (3–4 mm) probably related to ichnogenus *Planolites* (length of pen 14 is cm). H. Herbs and shrubs along the coastal sand dunes and sand sheets. I. Fragmented remains of seagrass *Posidonia oceanica* on the beach of Brega Area One (length of pen is 14 cm).

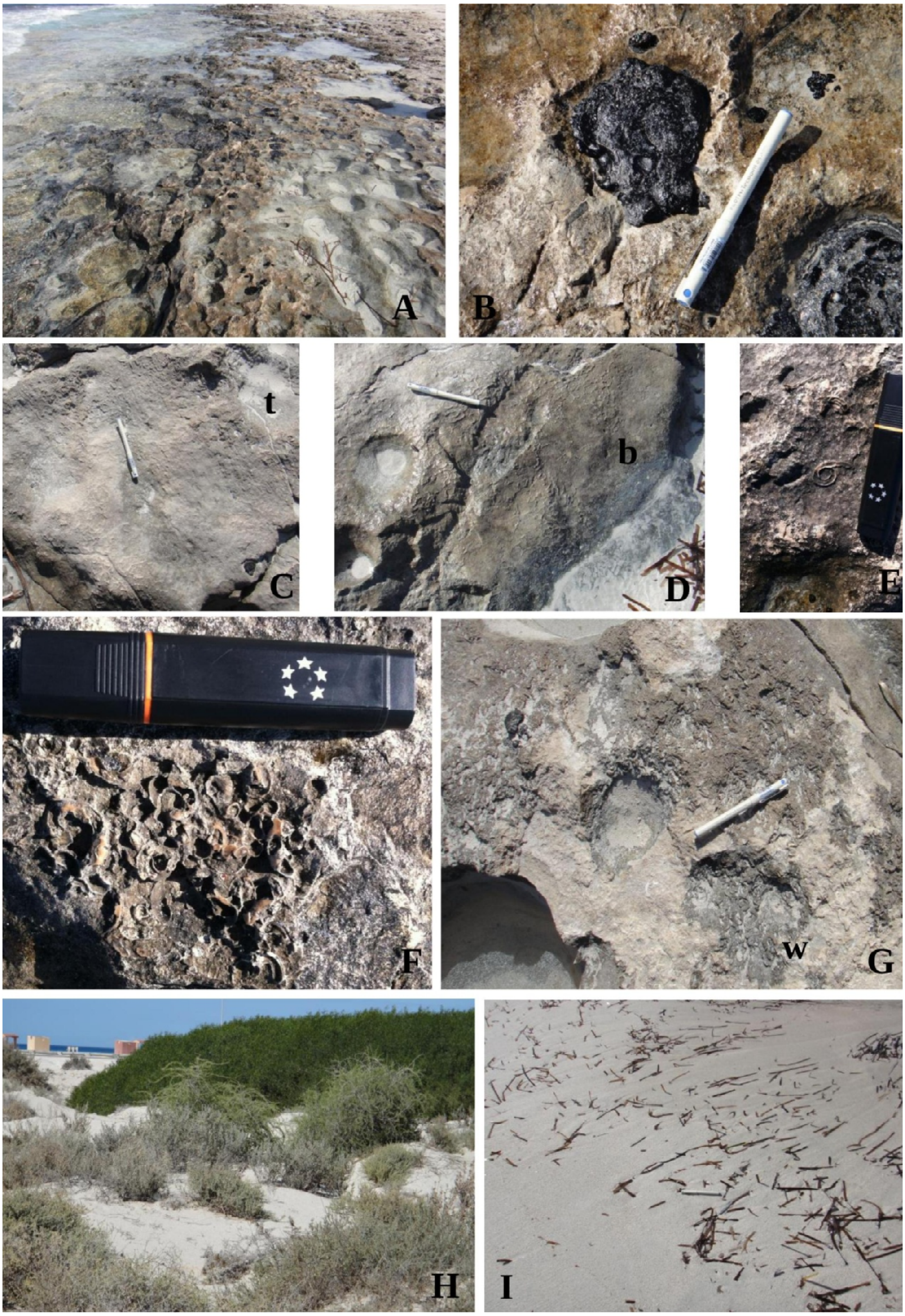

Figure 2

Table 2. Distribution of palynomorphs and palynomorph groups in the beach rock samples.

Taxa	Samples					Total
	1	2	3	4	5	
Pollen Grains						
Chenopodiaceae pollen				1	1	2
Tricolpate psilate pollen				1		1
Juniper pollen	1			2		3
Arecaceae pollen type 1	1					1
Arecaceae pollen type 2				1		1
Arecaceae pollen type 3					1	1
Algal Palynomorphs						
Cyanobacterial trichome					1	1
Algal cell type A		3				3
Algal cell type B	common in all samples					
Algal cell type C					1	1
Algal filaments	common in all samples					
Diatoms						
Amphora sp.	10					10
Licmophora sp. cf. *L. debilis*					1	1
Nitzschia sp. cf. *N. frustulum*	1				1	2
Nitzschia sp. cf. *N. perspicua*	2			3		5
Chemically altered diatoms				2	2	4
Dinoflagellate cyst						
cf. Dinoflagellate cyst					1	1
Fungal Palynomorphs						
cf. *Dictyosporites moruloides*				1		1
Fungites sp.				1		1
Glomus spore				2	1	3
Inapertisporites typicus	1	1	1			3
Inapertisporites type 1			1			1
Inapertisporites type 2				1		1
Inapertisporites type 3					1	1
Laevitubulus laxus	4					4
Polyadosporites suescae	2					2
Reduviasporonites ramosus	2		2	1		5
Xylohyphites sp.				2	3	5
Marine invertebrate remains						
Scolecodont				2		2
Resting egg capsule				3		3
Marine ostracod carapace				1		1
Miscellaneous						
Trichomes (wind-blown)	Common in all samples					
Cuticles	Common in all samples					
Woody fragments	Common in all samples					
Charcoal	Common in all samples					
Total						70

Comments: Ovoidal-elongate, monosulcate, scabrate pollen. Colpus long and narrow but become wider at ends. One specimen was observed.

Arecaceae pollen type 2

Figure 4.B

Size: 25 × 11 µm.

Comments: Ellipsoidal, monosulcate, granulate pollen, colpus long and narrow of uniform width. One specimen was observed.

Arecaceae pollen type 3

Figure 4.C

Size: 24 × 18.5 µm.

Comments: Subspherical, monosulcate, psilate pollen grain, sulcus broad, and long almost as long as the length of the pollen. One specimen was observed. The family *Arecaceae* (*Palmae*) has tropical to subtropical distribution and primarily inhabits coastal environments. In Libya, this family is represented by three genera and four species (Feng et al. 2013).

2. Algal palynomorphs

Cyanobacterial trichome

Figure 3.AC

Size: 18.5–29.6 µm.

Comments: Cyanobacteria or blue-green algae have a low state of cell differentiation. Cells are 2–4 µm in size, may occur singly or as chains of cells (trichomes), or as a sheet of cells (thallus). The colonies of cells and filaments may be free floating or attached to a substrate. Cell division occurs by binary fission resulting in filaments, sheets, or packets of cells. Some cells develop thickened walls and become resting spores (Tappan 1980). Cyanobacteria make a significant contribution to the global primary production of the oceans and become locally dominant primary producers in many extreme environments, such as hot and cold deserts, hot springs, and hypersaline environments (Garcia-Pichel 2009). The present specimen appears to be a Cyanobacterial trichome with a resting spore (RS) from which vegetative cells (V) and a terminal heterocyst (H) are emerging (Tappan

1980). One specimen was observed.

Algal cell type A

Figure 3.N

Size: 18.5 × 16 µm.

Comments: Unicellular, subspherical-elongated, green cell with a thin scabrate wall. Three specimens were observed.

Algal cell type B

Figure 3.M

Size: 26.5 µm.

Comments: Unicellular, spherical to subspherical green cell with a thick reticulate wall. Several specimens were observed.

Algal cell type C

Figure 3.AD

Size: 50 × 20 µm.

Comments: Unicellular, elongated, spindle-shaped green cell with a thin psilate wall. One specimen was observed.

Algal filaments

Figures 3.J-b, K-b

Size: 225 × 3 µm (Figure 3.J-b); length over 300 µm, width 1.5–2 µm (Figure 3.K-b)

Comments: Long, slender, pale grey, non-septate, unbranched, thin-walled algal filaments. Such filaments may be Cyanobacterial (blue-green algae) filaments common in the Mediterranean Sea. Several specimens were observed.

Diatoms

Genus: *Amphora* Ehrenb. ex Kütz. 1844

Type Species: *Amphora ovalis* (Kütz.) Kütz. 1844

***Amphora* sp.**

Figure 3.E

Size Range: 16–20 × 6.5–9 µm

Comments: This genus occurs in marine habitats as well as in freshwater environments. Ten specimens were observed.

Genus: *Licmophora* C. Agardh 1827

Type Species: *Licmophora argentescens* Agardh (typus conservandus)

Licmophora* sp. cf. *L. debilis (Kütz.) Grunowex Van Heurck 1881

Figure 3.H

Size: 31.6 × 3.5 µm

Comments: Girdle view, it's length and narrow wedge shape corresponds with the description of this species. However, it is difficult to see any ornamentation on the valve.

This is a benthic diatom that inhabits coastal marine environments around the world and is known to thrive in different substrates such as sediments, rocks, and macro-algae. One specimen was observed.

Genus: *Nitzschia* Hassall 1845

Type Species: *Nitzschia elongata* Hassal 1845

Nitzschia* sp. cf. *N. frustulum (Kütz.) Grunow in Cleve & Grunow 1880

Figure 3.C

Size: 15 × 11.5 µm.

Comments: This is a cosmopolitan marine and brackish water species. Two specimens were observed.

Nitzschia* sp. cf. *N. perspicua Cholnoky 1960 non Sovereign 1963

Figure 3.B

Size: 26.5–30 × 5.2–5.7 µm (based on five specimens).

Comments: The known length and width ranges of this species are 17–36 µm and 3–4 µm respectively. The present specimens are within the same length range but are slightly broader. The costae of this species are finer (15–17 in 10 µm) than the present specimens. Five specimens were observed. The distribution of *N. perspicua* is described by Witkowski et al. (2000) as "brackish water species inhabiting marine coasts, known from South Africa, the Mediterranean, and inland saline waters in Austria."

Chemically altered diatoms

Figure 3.D, G

Size: 38.6 × 8.3 μm (Figure 3.D); 25.3 × 8.5 μm (Figure 3.G).

Comments: These specimens have suffered moderate to advanced silica dissolution, probably during HF treatment of the samples, resulting in chemical alteration. Four specimens were observed.

Empty girdle band of a diatom with indistinguishable valve face

Figure 3.F

Size: 29 × 6.5 μm.

Comments: One specimen was observed.

? Dinoflagellate cyst

Figure 3.AB

Size: 59 × 56 μm.

Comments: Subspherical proximate dinoflagellate cyst with an apical archeopyle. Archeopyle suture and apical paraplates are not distinct. Autophragm is thin and reticulate. This form is morphologically similar to *Kallosphaeridium* sp. described from the Pliocene carbonate platform of Bahamas (Head & Westphal 1999) which are smaller (31 37 μm) in size than the present specimen. *Kallosphaeridium* sp. was also recorded from Pliocene of Florida, making these two occurrences as the only post-Miocene occurrences of this genus (Head & Westphal 1999). One specimen was observed.

3. Fungal palynomorphs

The identifications are based on comprehensive treatises on fossil fungi by Kalgutkar and Jansonius (2000) and Saxena and Tripathi (2011).

Genus: *Dictyosporites* (Felix) Kalgutkar & Janson. 2000

Type Species: *Dictyosporites loculatus* Felix 1894

cf. *Dictyosporites moruloides* (Sal.-Cheb. & Locq.) Kalgutkar & Janson. 2000

Figure 3.S

Size: 24 × 19 μm.

Comments: Kalgutkar and Jansonius (2000) emended this genus as "inaperturate, multicellate (internal septation of irregular pattern) muriform fungal spores, cells rounded to rounded polygonal. Overall shape rounded, oval/ovoid to elongate; indentions may occur where septa intersect the amb." The present specimen is morphologically similar to *Dictyosporites*

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Figure 3. All photos ×400 unless otherwise mentioned. **A.** Juniper pollen, slide 1Ka; 136×7; size 33 μm in diameter. **B.** *Nitzschia* sp. cf. *N. perspicua* Cholnoky 1960 non Sovereign 1963, slide 1Ka; 142 × 8; size 30 × 5.2 μm (×1000). **C**. *Nitzschia* sp. cf. *N. frustulum* (Kütz.) Grunow in Cleve & Grunow 1880, slide 5Kb; 133.2× 11; size 17.5 × 5 μm (×1000). **D**. Chemically altered diatom, slide 4Ka; 143.2 × 13.5; size 38.6 × 8.3 μm. **E**. *Amphora* sp., slide 1Kb; 132 × 11.5; size range 16–20 × 6–9 μm. **F**. Empty girdle band of a diatom, slide 3Kb; 147.5 × 4; size 29 × 6.5 μm. **G**. Chemically altered diatom, slide 5Ka; 131 × 10.2; size 25.3 × 8.5 μm. **H**. *Licmophora* sp. cf. *L. debilis* (Kütz.) Grunow ex van Heurck 1881, slide 5Ka; 131.5 × 9; size 31.6 × 3.5 μm. **I**. Trichomes, slide 4Kb; 140 × 8.2; size 210 × 3 μm. **J**. a *Laevitubulus laxus* Burgess & Edwards 1991, slide 1Kb; 138 × 19.6; size: length 118 μm, diameter 3.5–4.5 μm. J. b Algal filament, slide 1Kb; 138 × 19.6; size 225 × 3 μm. **K**. a *Xylohyphites* sp., slide 4Kb; 131 × 3.8; conidia size 5–8 × 2.5–3.5 μm. K. b Algal filament, slide 4Kb; 131 × 3.8; length over 300 μm, width 1.5–2 μm. **L**. *Reduviasporonites ramosus* Kalgutkar 1993, slide 3Kb; 132.8 × 14; size length 104.5 μm; cells 4.5–5.5 × 1.5–2.5 μm. **M**. Algal cell type B, slide 4Kb; 145 × 19; size 26.5 μm. **N**. Algal cell type A, slide 2Ka; 137.8 × 13; size 18.5 × 16 μm. **O**. *Glomus* spore, slide 4Kb; 139 × 10; size 65 × 54 μm. **P**. *Polyadosporites suescae* Hammen 1954, slide 1Ka; 146.5 × 12.3; size (cluster diameter) 30 μm. **Q**. Resting egg capsule, slide 4Kb; 146 × 5.5; size 28 × 17.5 μm. **R**. Marine ostracod carapace, slide 4Ka; 141.3 × 3.2; size 95 × 75 μm. **S**. cf. *Dictyosporites moruloides* (Sal.-Cheb. & Locq.) Kalgutkar & Janson. 2000 (degraded), slide 4 Ka; 135 × 14; size 24 × 19 μm. **T**. Scolecodont, slide 4Kb; 147 × 17; size 53 × 39 μm. **U**. *Inapertisporites* type 1, slide 3Kb; 139.5 × 17; size 41 μm (diameter); appendage 10 × 4.5 μm; wall thickness 3–3.5 μm. **V**. *Inapertisporites* type 2, slide 4Ka; 140 × 11; size 45 μm (diameter); appendage 13.5 × 9.5 μm; wall thickness 2.5 μm. **W**. *Xylohyphites* sp., slide 5Kb; 133 × 22.2; size 151 × 1.8 μm. **X.** *Chenopodiaceae* pollen, slide 4Ka; 144 × 20; size 13 in μm diameter. **Y.** Oil droplet, slide 4Kb; 137 × 13.4; size 117 × 58 μm. **Z.** Trichomes, slide 5Kb; 139 × 20; size 80–86 × 2–2.5 μm. **AA.** Trichomes, slide 5Ka; 133.6 × 17.2; size 78 × 72.6 μm. **AB.** ?Dinoflagellate cyst, slide 5Kb; 143.5 × 14; size 59 × 56 μm. **AC.** Cyanobacterial trichome with a resting spore (RS) from which vegetative cells (V) and a terminal heterocyst (H) are emerging, slide 5Ka; 146 × 5; size 18.5–29.6 μm. **AD.** Algal cell type C, slide 5Kb; 141 × 6.5; size 50 × 20 μm

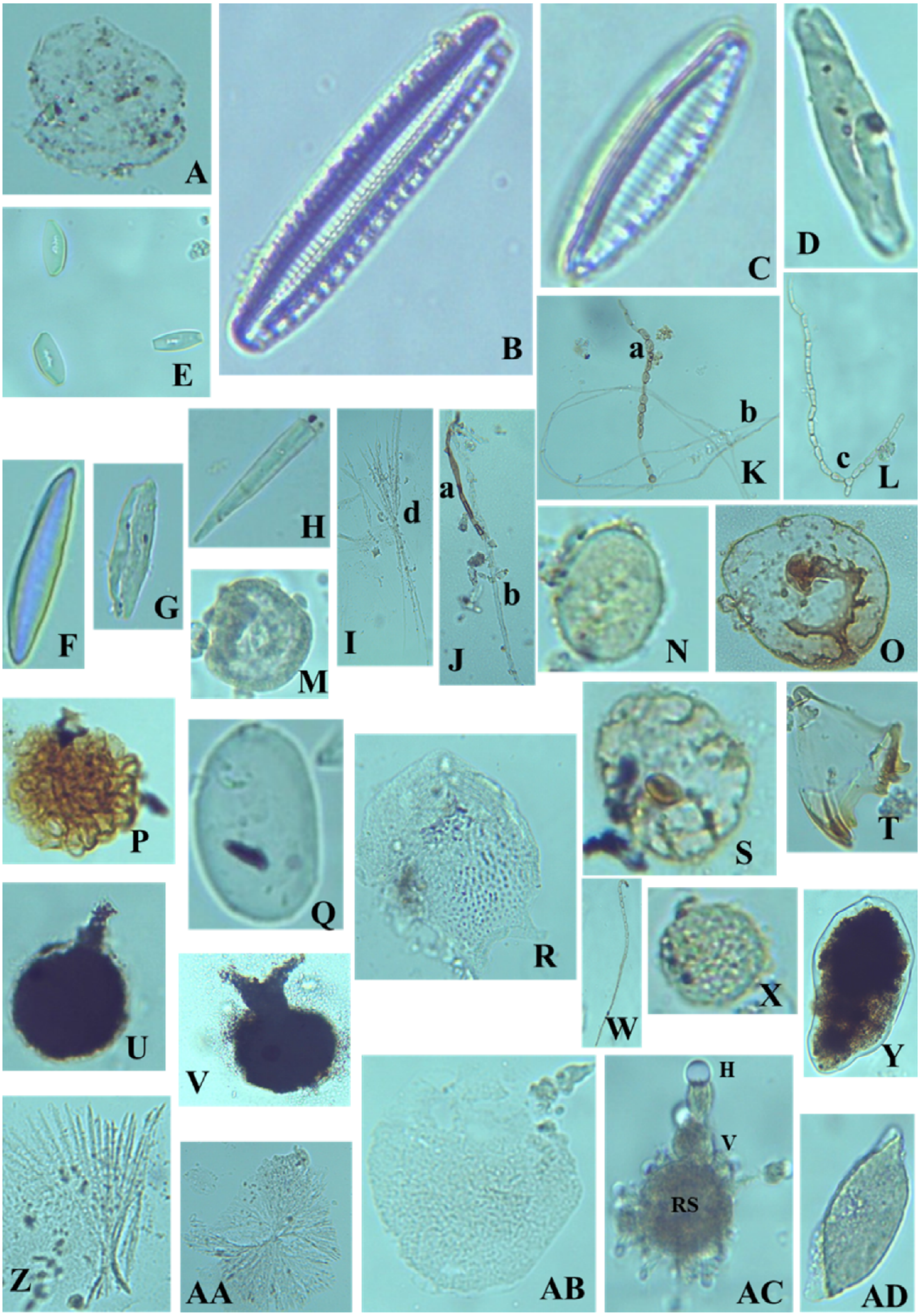

Figure 3

moruloides (Sal.-Cheb. & Locq.) Kalgutkar & Janson. 2000 (Plate 15, figure 25). One specimen was observed.

Genus: *Fungites* Casp.1907

Type Species: Not designated (Kalgutkar & Jansonius 2000)

***Fungites* sp.**

Figure 4.R

Size: Hypha length 250 µm, diameter 3–5 µm; thallus 86 × 34 µm; sporangia 8–13 µm.

Comments: Long hypha attached to an organic structure, probably a fungal thallus. The hypha is long, slender, and of variable diameter. The distal end of the hypha has two sac-like structures, probably sporangia. One specimen was observed.

Genus: *Glomus* Tul. & C. Tul. 1845

Type species: *Glomus macrocarpum* Tul. & C. Tul. 1845

***Glomus* spore**

Figure 3.O

Size: 65 × 54 µm.

Comments: *Glomus* (family *Glomeraceae*) is related to the fossil fungus *Glomites*. These are globose chlamydospores, aseptate and inaperturate, of variable size (18–138 µm). They have a symbiotic relationship with roots of higher plants, and inhabit terrestrial habitats, such as deserts, grasslands, and tropical forests. *Glomus* spores are produced at the tips of hyphae either within the host root or outside the root in the soil. Three specimens were observed.

Genus: *Inapertisporites* Hammen 1954

Type Species: *Inapertisporites variabilis* Hammen 1954.

Inapertisporites typicus Hammen 1954

Figure 4.L

Size: 13.7 µm diameter.

Comments: Inaperturate, spherical, dark brown, small fungal spores with a verrucate-baculate wall. Three specimens were observed.

***Inapertisporites* type 1**

Figure 3.U

Size: 41 µm (diameter); appendage 10 × 4.5 µm; wall thickness 3–3.5 µm.

Comments: Inaperturate, spherical, black spore, wall thick, brown and perinate with a short appendage that is distally digitate. One specimen was observed.

***Inapertisporites* type 2**

Figure 3.V

Size: 45 µm (diameter); appendage 13.5 × 9.5 µm; wall thickness 2.5 µm.

Comments: Inaperturate, spherical, black spore, wall thin brown and perinate with an appendage that is distally bifurcate. One specimen was observed.

***Inapertisporites* type 3**

Figure 4.O

Size: 33.5 µm diameter, wall thickness 3–4 µm.

Comments: Inaperturate, spherical, black spore, wall thick, brown and perinate with a short perinal extension. One specimen was observed.

Genus: *Laevitubulus* Burgess & D. Edwards 1991

Type Species: *Laevitubulus tenuis* Burgess & D. Edwards 1991

Laevitubulus laxus Burgess & D. Edwards1991

Figure 3.J-a

Size: Length 118 µm; Diameter 3.5–4.5 µm.

Comments: Light brown, psilate tubes of generally uniform diameter, occasionally branched. The diameter of the tubes ranges between 5–7.5 µm (Burgess & Edwards 1991) and 2–6 µm (Kalgutkar & Jansonius 2000). Present specimen is unbranched and compares well with *Laevitubulus laxus* Burgess and D. Edwards 1991. Four specimens were observed.

Genus: *Polyadosporites* Hammen 1954 emend. Kalgutkar & Janson. 2000

Type Species: *Polyadosporites suescae* Hammen 1954

Polyadosporites suescae Hammen 1954

Figure 3.P

Size: Cluster diameter 30 µm.

Comments: Loosely aggregated cells in clusters in which individual cells are not connected by shared walls. These clusters are spherical to subspherical in shape (Kalgutkar & Jansonius 2000). Two specimens were observed.

Genus: *Reduviasporonites* L.R. Wilson 1962

Type Species :*Reduviasporonites catenulatus* L.R. Wilson 1962

Reduviasporonites ramosus Kalgutkar1993

Figure 3.L

Size: Length 104.5 µm; cells 4.5–5.5 × 1.5–2.5 µm.

Comments: Uniseriate chains of cells, often branched, comprising of many cells. Cells have psilate walls, ovoid to barrel-shaped to elongate. Five specimens were observed.

Genus: *Xylohyphites* Kalgutkar & Sigler 1995

Type Species: *Xylohyphites verrucosus* Kalgutkar & Sigler 1995

***Xylohyphites* sp.**

Figures 3.K-a, W

Size: Conidia size 5–8 × 2.5–3.5 µm (Figure 3.K-a); 151 × 1.8 µm (Figure 3.W).

Comments: Chains of conidia tapering at each end sometimes with a slight protuberant hilum as visible in Figure 3.K-a. Conidia are pale brown, aseptate, ellipsoidal or cylindrical. Five specimens were observed.

cf. Fungal spore

Figure 4.K

Size: 12 × 10 µm.

Comments: Small, dark brown, inaperturate, aseptate spore with short processes. Processes are of varying width and length, distally blunt or bulbous and closed. One specimen was observed.

4. Marine invertebrate palynomorphs

Scolecodont

Figure 3.T

Size: 53 × 39 µm.

Comments: Scolecodonts are any jaw piece of a polychaete annelid worm (Traverse 2007). A wide variety of annelids commonly inhabit coastal areas worldwide. Two specimens were observed.

Resting egg capsule

Figure 3.Q

Size: 28 × 17.5 µm.

Comments: Probably an egg of a marine copepod. One specimen was observed. Copepods commonly inhabit the coastal waters of the Mediterranean Sea (Molinero et al. 2009). Copepod eggs have been reported from the coastal marine sediments (Mudie et al. 2010, 2011, Kumar 2020, 2021b). Three specimens were observed.

Marine ostracod carapace

Figure 3.R

Size: 95 × 75 µm.

Comments: One specimen was observed.

5. Miscellaneous palynomorphs

Trichomes (wind-blown)

Figures 3.I, Z,AA, 4.J

Size: 210 × 3 µm (Figure 3.I); 78 × 72.6 µm (Figure 3.AA); 80–86 × 2–2.5 µm (Figure 3.Z);135 × 102 µm (Figure 4.J).

Comments: Trichomes are fine outgrowths on plants, algae, lichens, and certain protists, for example, hair, glandular hair, scales, and papillae. Commonly trichome is a hair; unicellular or multicellular, branched, or unbranched (Figure 3.I). Branched hair can be dendritic (Figures 3.Z, AA). Several remains of trichomes were observed.

Cuticles

Figure 4.H, M, Q

Comments: These cuticles are the remains of wind-blown leaves of grasses or higher plants from the coastal vegetation of Libya (Figure 2.H). Some cuticles show distinct cellular structure (Figure 4.H) while others are in the form of amorphous organic remains (Figure 4.M, Q) which could be biodegraded remains of seagrass (*Posidonia oceanica*) that commonly grows in the shallow water coastal regions of the Mediterranean Sea, and their fragmented remains can be seen on the Brega Area One beach (Figure 2.I).Several specimens of these cuticles were observed.

Woody fragments

Figure 4.E–G, I

Comments: These are microscopic remains of wind-blown pieces of wood fragments from the coastal plants of Libya. Few of them show features of tracheid (Figure 4.I). Several specimens of woody fragments were observed as well.

Charcoal

Figure 4.D, N

Comments: These are microscopic burnt pieces of woody fragments; some are completely burnt to black (Figure 4.D), and others are partially burnt brown to brownish black (Figure 4.N). The presence of charcoal indicates natural forest fires or possibly wood burning due to human activity. Several specimens of charcoal fragments were observed.

Forma A

Figure 4.S

Size: 86 × 65 µm.

Comments: Unknown form probably related to some algal body. One specimen was observed.

Remains of oil (oil droplet)

Figure 3.Y

Size: 117 × 58 µm.

Comments: Brega is a major Libyan port for the export of crude oil. Leakages and spills of crude oil may take place causing pollution in the coastal region. Scattered patches of crude oil can be seen lying over the beachrocks (Figure 2.B). Presence of oil droplets in these rocks suggests that either these rocks are of recent age, or the oil might have seeped inside the rocks through cracks or fissures. Several remains of oil droplets of various sizes were observed in the palynomorph assemblages in all the five samples.

DISCUSSION

Only few angiosperm pollen are part of these assemblages. Rare specimens of polyporate pollen having affinity with families *Chenopodiaceae* and/or *Amaranthaceae* were observed. These families commonly inhabit hot and arid environments in Libya (Feng et al. 2013). Rare specimens of *Arecaceae* pollen types 1, 2 and 3 are monosulcate pollen having affinity with family *Arecaceae* (*Palmae*) were observed as well. In Libya, this family is represented by three genera and four species. Pollen taxa having affinity with the family *Arecaceae* may be related to tropical palm taxa *Borassus*, and *Phoenix* which occur along the coastal areas in Libya (Feng et al. 2013). Few specimens of Juniper pollen were also observed. This pollen, most

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Figure 4. All photos ×400. **A**. *Arecaceae* pollen type 1, slide 1Ka; 146 × 14; size 34.5 × 22.3 µm. **B**. *Arecaceae* pollen type 2, slide 4Ka; 129 × 13.5; size 25 × 11 µm. **C**. *Arecaceae* pollen type 3, slide 5Kb; 131 × 15; size 24 × 18.5 µm. **D**. Black oxidized debris (Charcoal), slide 1Ka; 133.5 × 6.8; size 60.5 × 49 µm. **E**. Woody fragment, slide 1Ka; 134.2 × 3.2; size 98 × 11µm. **F**. Woody fragment, slide 2Kb; 147.5 × 22; size 107 × 49 µm. **G**. Woody fragment, slide 3Kb; 131 × 11; size 118.4 × 44 µm. **H**. Cuticle, slide 1Ka; 142 × 12; size 75 × 56 µm. **I**. Woody fragment (tracheid), slide 4Ka; 135 × 3; size 123 × 86 µm. **J**. Trichomes, slide 4Ka; 133 × 8; size 135 × 102 µm. **K**. cf. Fungal spore, slide 1Kb; 140.5 × 20.2; size 12 × 10 µm. **L**. *Inapertisporites typicus* Hammen 1954, slide 3Kb; 147 × 6; size 13.7 µm in diameter. **M**. Amorphous organic matter (degraded cuticle), slide 1Ka; 141.8 × 18.6; size 103 × 67 µm. **N**. Brown degraded debris (Charcoal; partially burnt wood fragment), slide 2Ka; 141.2 × 18.8; size 53 × 37 µm. **O**. *Inapertisporites* type 3, slide 5Kb; 135 × 17; size 33.5 µm in diameter, wall thickness 3–4 µm. **P**. Tricolpate, psilate pollen, slide 4Ka; 146.5 × 16.5; size 16.7 × 12.4 µm. **Q**. Amorphous organic matter (degraded cuticle), slide 4Kb; 138 × 8; size 169 × 74 µm. **R**. *Fungites* sp., slide 4Kb; 139 × 17; size: hypha length 250 µm, width 2–5 µm; thallus 86 × 34 µm. **S**. Forma A, slide 5Kb; 144 × 16; size 86 × 65 µm.

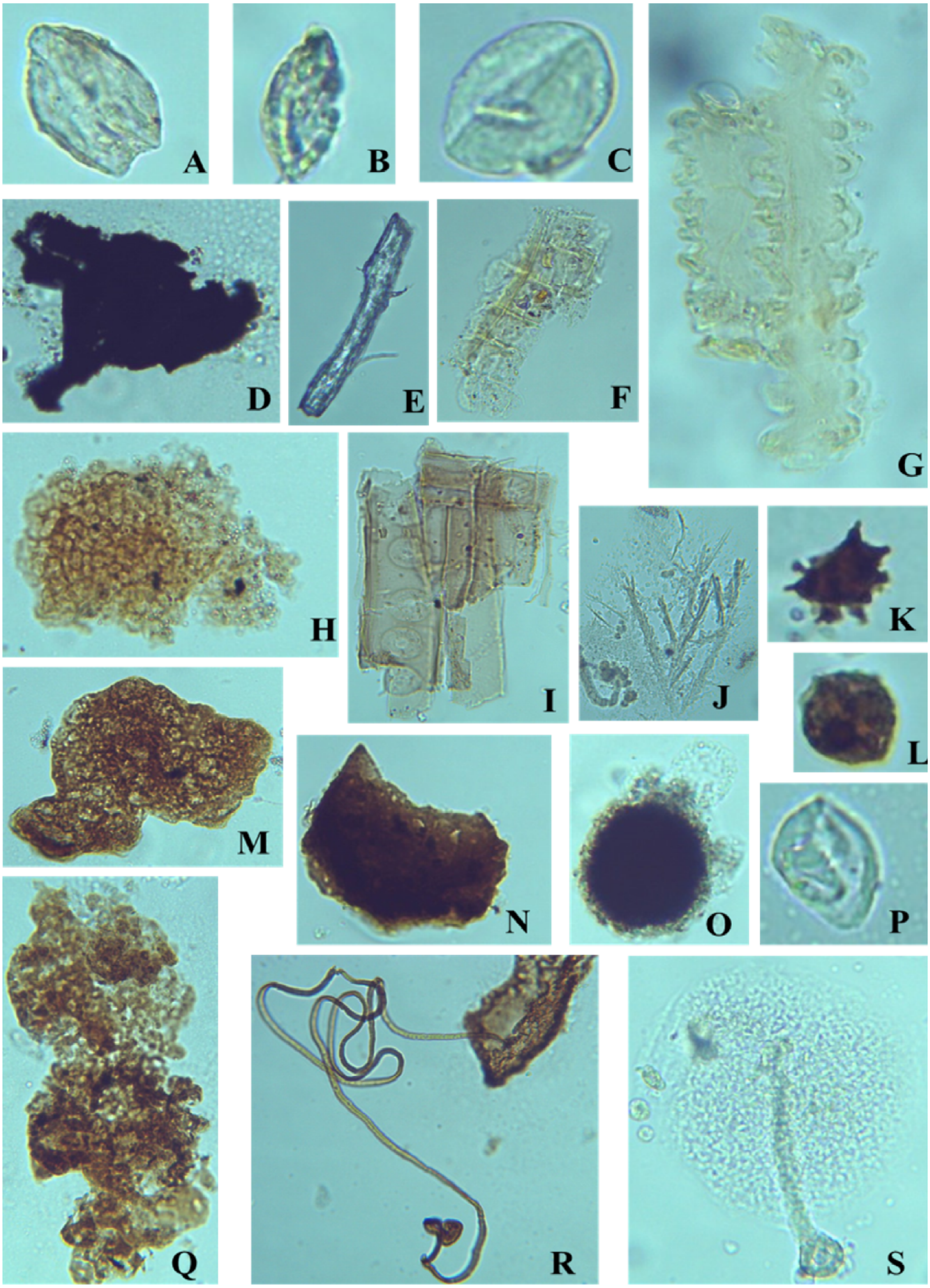

Figure 4

likely, is sourced from the *Juniperus phoenicea* var. *turbinata* planted along the roadside when this town was built during 1950–1960 (Kumar 2015). Thus, the angiosperm pollen flora indicates the coastal flora of Libya suggesting a sparse coastal vegetation with a very low floral diversity characteristic of desert environments. Surprisingly grass pollen and pollen of *Acacia* spp. were not observed in this study; however, they occur along the coastal regions. It is possible that maceration of larger numbers of beachrock samples may yield such pollen.

Among the algal palynomorphs several types of algal cells and filaments along with few diatom taxa were observed. A single specimen of Cyanobacterial trichome was observed as well. These are chains of cells and filaments found floating or attached to a substrate in marine environments (Tappan 1980). Cyanobacteria are significant contributors to the global primary production of the oceans and become dominant primary producers in extreme environments, such as hot and cold deserts, hot springs, and hypersaline environments (Garcia-Pichel 2009). Thus, the specimen of Cyanobacterial trichome is a significant part of the assemblage. Different types of algal cells and filaments may be related to Cyanobacteria or green algae common in the Mediterranean Sea.

Few specimens of various diatom taxa were observed as well. *Amphora* occurs in marine habitats as well as in freshwater environments. *Licmophora* is a benthic diatom that inhabits coastal marine environments around the world and is known to thrive in different substrates such as sediments, rocks, and macro-algae. *Licmophora* sp. cf. *L. debilis* occurs along the European coasts. *Nitzschia* sp. cf. *N. frustulum* is a cosmopolitan marine and brackish water species. *N. perspicua* is a brackish water species that inhabits marine coasts of South Africa, the Mediterranean, and inland saline waters in Austria (Witowski et al. 2000).

One specimen of questionable Dinoflagellate cyst was also observed. The form is morphologically similar to the dinoflagellate cyst genus *Kallosphaeridium* de Coninck 1969 emend. Jan du Chêne et al.1985. Similar specimens of *Kallosphaeridium* sp. were recorded from Pliocene of Bahamas and Florida (Head & Westphal 1999).

Taxonomic diversity of fungal palynomorphs is relatively higher in these assemblages than other groups. They include various types of fungal hyphae, spores, and a fruit body. Some of these forms were identified from sediments representing various environments of the southern Red Sea coast of Saudi Arabia (Kumar 2020, 2021b). Fossil fungi may provide useful information about the paleoecology, past habitats, and their hosts (Kalgutkar & Jansonius 2000). Saxena and Tripathi (2011) suggested that it is advisable to take into consideration the complete palynological assemblage for palaeoenvironmental interpretations rather than just based on fungal remains.

This fungal assemblage is indicative of dry, hot, and marine coastal environments that becomes wet and humid because of cyclonic storms' led rainfall between the months of October and March. Coastal regions of Libya have Mediterranean climate characterized by a cool rainy winter season and a hot dry summer. Genus *Glomus* is an endomycorrhizal fungus that has a symbiotic relationship with roots of higher plants, and inhabits terrestrial habitats, such as, deserts, grasslands, and tropical forests. These are not normally transported; their presence is an indicator of soil erosion (Cook et al. 2011). Presence of *Glomus* is an indicator of soil erosion along the coastal region. The fungal assemblage represents dry, hot coastal environments having wet and humid rainfall months.

There are very few marine invertebrate palynomorphs that include scolecodonts, resting egg capsule of copepods and marine ostracod carapace. Scolecodonts are any jaw piece of a polychaete annelid worm (Traverse 2007). A wide variety of annelids commonly inhabit the coastal areas worldwide including the coastal regions of Brega. The resting egg capsule is an egg of a marine copepod that commonly inhabits the coastal waters of the Mediterranean Sea (Molinero et al. 2009). The specimen of marine ostracod carapace is superficially like *Cistacythereis pokornyi hellenica* Uliczny found in Pliocene-Recent sediments from Eastern Mediterranean (web reference: Ostracods – UCL).

A variety of cuticles were observed in these assemblages. Some of them are from wind-blown leaves from the coastal plants with distinct cellular structures while others are amorphous organic remains of seagrass *Posidonia oceanica* that commonly inhabit the shallow coastal regions of the Mediterranean Sea. Like the cuticles, the microscopic remains of wood fragments are wind-blown pieces of wood fragments from the coastal plants of Libya. Presence of charcoal indicates natural fires or fires due to human activity. Several specimens of charcoal fragments were observed.

The palynomorph assemblages from the beachrock samples of the Brega coast demonstrate that shallow marine environments and nearby coastal region plants contribute to the assemblage. Presence of few angiosperm pollen reflects a low floral diversity of the coastal desert environment. Algal and invertebrate palynomorphs reflect their low diversity in the intertidal zone of this coast. The low numbers of palynomorphs may be attributed to the coarse-grained sands that eventually form beachrocks are known to yield low numbers of palynomorphs. Palynomorph preservation may also be adversely impacted due to a high energy intertidal environment in which beachrocks are formed. The results of this study demonstrate that the beachrock forming environment which is not suitable for pollen analysis may provide palaeoenvironmental information and offer new insight on the source and preservation potential of palynomorphs in beachrocks. It is possible that a larger number of samples may result in numerically and taxonomically diverse assemblages which could provide useful information for understanding the source and environments of palynomorphs in beachrocks.

Several remains of oil droplets of various sizes were observed in the palynomorph assemblages in all the five samples. Their presence is a very interesting finding. As discussed earlier, beachrocks are formed by cementation of the sediments in the intertidal zones of beaches, that contain well-sorted beach sands consisting mostly of carbonate skeletal particles. Present study demonstrates that beach sands get cemented (due to high saturation of Calcium Carbonate in the water) along with all the microscopic organic debris sourced from the shallow marine environments as well as from the coastal regions. The oil droplets found in the palynological slides indicate presence of fragments of solid hydrocarbons in the intertidal environments that got cemented along with the sands. The most plausible source of this oil is from leakages and spills of crude oil from the oil tankers that transport crude oil from the Brega Port. Scattered patches of crude oil can be seen lying over the beachrocks (Figure 2.B). This suggests that either these beachrocks are of very recent age, or the oil might have seeped from surface inside the older beachrocks through cracks or fissures. Another possible source of solid hydrocarbons could be oil seepages from subsurface hydrocarbon reservoirs that gets solidified once on the surface. Several such deposits are known from various parts of the world (Kumar 1981, Selley & Sonnenberg 2015).

CONCLUSIONS

1. A diverse assemblage of palynomorphs is reported for the first time from the beachrocks of southeastern Mediterranean coast of Brega, Libya. This is the first report of occurrence of palynomorphs in beachrocks.
2. The recorded palynomorphs were divided into five groups based on their biological affinities: (1) angiosperm palynomorphs (2) algal palynomorphs (3) fungal palynomorphs (4) marine invertebrate palynomorphs, and (5) miscellaneous palynomorphs. Microscopic remains of solid hydrocarbons are present as well.
3. These assemblages demonstrate that microscopic biological entities present in the intertidal environments get simultaneously cemented along with sand that form beachrocks. Such biological entities are sourced from shallow marine environments and the coastal region plants.

4. Presence of few angiosperm pollen reflect a low floral diversity of the coastal desert environment.
5. Algal and marine invertebrate palynomorphs suggest a low diversity in the intertidal zones of this coast.
6. Low palynomorph numbers are also attributed to beachrocks being formed from cementation of coarse-grained sands and a high energy intertidal environment.
7. This study offers new insight on the source and preservation potential of palynomorphs in beachrocks and suggests that a more extensive palynological study of beachrocks is needed.
8. It also demonstrates that an environment which is not considered suitable for pollen analysis may provide useful palaeoenvironmental information.

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REFERENCES

Agardh C.A. 1827. Aufzählung einiger in den ostereichischen Ländern gefundenen neuen Gattungen und Arten von Algen nebst ihrer Diagnostik und beigefugten Bemerkungen. Flora oder Botanische Zeitung, Regensburg 2: 625–640.

Aguilar R. 2004. The corals of the Mediterranean. Annual Report Oceana. https://oceana.org/sites/default/files/reports/CoralsMediterraneaneng.pdf. Accessed on July 27, 2021.

Arrieta N.N., Goienaga I., Martínez-Arkarazo X., Murelaga J.I., Sarmiento B.A. & Madariaga J.M. 2011. Beach rock formation in temperate coastlines: examples in sand-gravel beaches adjacent to the Nerbioi-Ibaizabal Estuary (Bilbao, Bay of Biscay, North of Spain). Spectrochim Acta A Mol Biomol Spectrosc. https://doi:10.1016/j.saa.2011.01.031.

Burgess N.D. & Edwards D. 1991. Classification of uppermost Ordovician to Lower Devonian tubular and filamentous macerals from the Anglo-Welsh Basin. Botanical Journal of the Linnean Society 106: 41–66.

Caspary R. 1907. Atlas von dreissig Tafeln zu der Abhandlung: Die Flora des Bernsteins und anderer fossiler Harze des ostpreussischen Tertiärs. Königlich Preußische Geologische Landesanstalt, Berlin 1–33.

Cholnoky B.J. 1960. Beiträgezur Kenntnis der Diatomeenflora von Natal (Südafrika). Nova Hedwigia 2(1/2): 1–128.

Cleve P.T. & Grunow A. 1880. Beiträgezur Kenntniss der Arctischen Diatomeen. Kongliga Svenska-Vetenskaps Akademiens Handlingar 17(2): 1–121.

Collinson J.D. & Thompson D.B.1989. Sedimentary Structures. Chapman & Hall.

Cooper J.A.G. 2013. Sea Level Studies: Sedimentary indicators of relative sea-level changes-high energy. Earth Systems and Environmental Sciences, Encyclopedia of Quaternary Science (Second Edition). https://doi.org/10.1016/B978-0-444-53643-3.00134-5.

Cook E.J., van Geel B., van der Kaars S. & van Arkel J. 2011. A review of the use of non-pollen palynomorphs in palaeoecology with examples from Australia. Palynology. https://doi.org%2F10.1080%2F01916122.2010.545515.

de Coninck J. 1969: *Dinophyceae* et Acritarcha de l'Yprésien du sondage de Kallo. Mémoires de l'Institut royal des sciences naturelles de Belgique161: 1–67.

Edwards T.C.P. & Mitchell S.F. 2018. Trace Fossils in Clastic Beachrocks at the Yallahs Salt Ponds, Jamaica: Implications for Beach rock Cementation. Journal of Coastal Research. https://doi.org/10.2112/JCOASTRES-D-16-00176.1.

Esteban M. 1980. Significance of the upper Miocene coral reefs of the western Mediterranean. Palaeogeography, Palaeoclimatology, Palaeoecology. https://doi:10.1016/0031-0182(79)90080-4.

Falkenroth M., Schneider B. & Hoffmann G.2019.Beach rock as sea-level indicator A case study at the coastline of Oman (Indian Ocean). Quaternary Science Review. https://doi:10.1016/j.quascirev.2019.01.003.

Felix J. 1894. Studienüber fossile Pilze; Zeitschrift der DeutschenGeologischen Gesellschaft 46: 269–280.

Feng Y., Lie J.-Q., Xu X.-W & Pan B.-R.2013. Composition and characteristics of Libyan flora. Archives of Biological Sciences 65: 651–657.

Fowler G.L. 2021. Libya. Encyclopedia Britannica. https://www.britannica.com/place/LibyaAccessed on August 16, 2021.

Frankel E. 1968. Rate of formation of beach rock. Earth & Planetary Science Letters4: 429–440.

Friedman G.M. & Sanders J.E.1978. Principles of Sedimentology. John Wiley & Sons.

Garcia-Pichel F. 2009. Cyanobacteria. In Encyclopedia of Microbiology. Elsevier Inc. https://doi.org/10.1016/B978-012373944-5.00250-9.

Ghandour I.M., Al-Washmi H.A. & Bantan R.A. 2014. Petrographical and petrophysical characteristics of asynchronous beachrocks along Al-Shoaiba Coast, Red Sea, Saudi Arabia. Arabian Journal of Geoscience. https://doi.org/10.1007/s12517-012-0826-9.

Ginsberg R.N. 1953. Beach rock in South Florida. Journal of Sedimentary Petrology 23: 85–92.

Gischler E. 2007.Beach rock in intertidal precipitates, in Nash D.J & Mclaren S.J. (Editors.). Geochemical Sediments and Landscapes, Chapter 11. https://doi/10.1002/9780470712917.ch11.

Hassall A.H. (1845). A history of the British freshwater algae, including descriptions of the *Desmideae* and *Diatomaceae*. Sunderland & Knox, London I: 1–462.

Head M.J. & Westphal W. 1999. Palynology and paleoenvironments of a Pliocene carbonate platform: The clino core, Bahamas. Journal of Palaeontology 73:1–25.

Hopley D. 1986.Beach rock as sea-level indicator. In van de Plassche (Editor). Sea-Level Research: A manual for the collection and evaluation of data. Geo Books.

Jan du Chêne R., Stover L.E. & de Coninck J. 1985. New observations on the dinoflagellate cyst genus *Kallosphaeridium* de Coninck 1969. Cahiers de Micropaléontologie 4: 1–18.

Kalgutkar R.M. 1993. Paleogene fungal palynomorphs from Bonnet Plume Formation, Yukon Territory. Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 444: 51–105.

Kalgutkar R.M. & Jansonius J. 2000. Synopsis of fossil fungal spores, mycelia and fructifications. Ser. No. 39, American Association of Stratigraphic Palynology Foundation.

Kalgutkar R.M. & Sigler L. 1995. Some fossil fungal form-taxa from the Maastrichtian and Palaeogene ages. Mycological Research 99: 513–522.

Kumar A. 1981. Palynology of the Pitch Lake, Trinidad, West Indies. Pollen et Spores 23(2): 259–272.

Kumar A. 2014a. Origin and distribution of "Beach Balls" (Egagropili) of Brega, Libya, "Kedron Balls" of New Brunswick, Canada, and Carboniferous "Coal Balls". Earth Sci India (Popular Section), VII (III): 1–12.

Kumar A. 2014b. Geology of the Brega area and the ichnofauna of the 'Brega Sandstone Bed' (Pliocene), Libya. Arabian Journal of Geoscience. https://doi 10.1007/s12517-014-1656-8.

Kumar A.2015. Geological and environmental features around Brega region, Libya. Earth Science India (Popular Section), VIII (II): 1–14.

Kumar A.2016. Coastal geology and revised stratigraphy of the Brega area, Libya. Arabian Journal of Geoscience. https://doi 10.1007/s 12517-016-2359-0.

Kumar A.2020. Palynology of the recent intertidal sediments of the Southern Red Sea Coast of Saudi Arabia. Palynology. https://doi.org/10.1080/01916122.2020.1 767708.

Kumar A. (2021a). First report of occurrence of palynomorphs in the beachrocks and their paleoecological implications. Academia Letters, Article 3884. https://doi.org/10.20935/AL3884.

Kumar A. (2021b). Palynomorph assemblages and mineral microfossils from various Southern Red Sea coastal environments of Saudi Arabia. Earth Science India14(2): 41 97. https://doi.org/10.31870/ESI.14.2.2021.4.

Kützing F.T. 1844. Die Kieselschaligen. Bacillarien oder Diatomeen. Nordhausen: 1 152. https://doi.org/10.5962/bhl.title.64360.

Moissette P., Koskeridou E., Cornéec J-J. & Andréd J-P. 2013. Fossil assemblages associated with submerged beach rock beds as indicators of environmental changes. Palaeogeography Palaeoclimatology Palaeoecology. https://doi.org/10.1016/j.palaeo.2012.09.007.

Molinero J.C., Vukanic V., Lucic D., Ibanez F., Nival P., Licandro P., Calbet A., Christou E.D., Daly-Yahia N., Fernandez de Puelles M.L., Mazzocchi M.G. & Siokou-Frangou I. 2009. Mediterranean marine copepods: basin-scale trends of the calanoid. *Centropages typicus*. Hydrobiologia. https://doi 10.1007/s10750-008-9524-8.

Mudie P.J., Marret F., Rochon A. & Aksu A.E. 2010. Nonpollen palynomorphs in the Black Sea corridor. Vegetation History and Archaeobotany 19: 531–544.

Mudie P.J., Leroy S.A.G., Marret F., Gerasimenko N., Kholeif S.E.A., Sapelko T. & Filipova-Marinova M. 2011. Nonpollen palynomorphs: Indicators of salinity and environmental change in the Caspian-Black Sea-Mediterranean corridor, in Buynevich, I., Yanko-Hombah, V., Gilbert, A. S., and Martin, R. E. (Eds). Geology and Geochronology of the Black Sea Region: Beyond the Flood Hypothesis. Geological Society of America Special Paper 473: 1–27.

Psomiadis D., Albakanis K., Zisi N., Ghilardi M. & Dotsikam E.2014. Clastic sedimentary features of beachrocks and their paleoenvironmental significance: comparison of past modern coastal regimes. International Journal of Sedimentary Research 29: 26–268.

Salard-Cheboldaeff M. & Locquin M.V. 1980. Champignons présents au Tertiaire le long du littoral de l'Afrique équatoriale.105e Congrès National des Sociétéesavantes, Caen 1980, Sciences 1: 183–195.

Saxena R.K. & Tripathi S.K.M. 2011. Indian Fossil Fungi. The Palaeobotanist 60(1): 1–208.

Scheibner C. & Speijer R.P. 2008. Late Paleocene–early Eocene Tethyan carbonate platform evolution - A response to long- and short-term paleoclimatic change. Earth Science Reviews. https://doi.org/10.1016/j.earscirev.2008.07.002.

Scoffin T.P. & Stoddart D.R. 1987. Beach rock and intertidal cements. In: Scoffin, T. P. (Editor), An Introduction to Carbonate Sediments and Rocks. Blackie Publishing Co.

Selley R.C. & Sonnenberg A.S. 2015. Elements of Petroleum Geology. 3rd ed. Elsevier.

Tappan H. 1980. The paleobiology of plant protists. W. H. Freeman & Co.

Tawadros E. 2012. The Geology of North Africa. Balkema.

Traverse A. 2007. Paleopalynology. 2nd ed Springer.

Tulasne L.-R. & Tulasne C. 1845. Fungi nonullihypogaei, novi v. minus cogniti. Giornale Botanico Italiano 12(7-8): 55–63.

Turner R.J. 2005. Beachrock, in Schwartz M.L.(Editor.) Encyclopedia of Coastal Science. Kluwer Academic Publ.

Vacchi M., Marriner N., Morhange C., Spada G., Fontana A. & Rovere A. 2016. Multiproxy assessment of Holocene relative sea-level changes in the western Mediterranean: Sea-level variability and improvements in the definition of the isostatic signal. Earth Science Reviews. https://doi.org/10.1016/j.earscirev.2016.02.002.

van der Hammen T. 1954. El desarrollo de la flora Colombianaenlosperiodosgeologicos–1. Maestrichtiano hasta Terciaro mas inferior (Una investigacion Palinologica de la formacion de Guaduas y equivalentes). Boletin Geologico (Bogota) 2(1): 49–106.

van Heurck H. 1881. Synopsis des Diatomées de Belgique Atlas. plates XXXI-LXXVII.

Vousdoukas M.I., Velegrakis A.F. & Plomaritis T.A. 2007. Beach rock occurrence, characteristics, formation mechanisms and impacts. Earth Science Reviews. https://doi.org/10.1016/j.earscirev.2007.07.002.

Wilson L.R.1962. A Permian fungus spore type from the Flowerpot Formation of Oklahoma. Oklahoma Geology Notes 22: 91–96.

Witkowski A., Lange-Bertalot H. & Metzeltin D. 2000. Diatom Flora of Marine Coasts I. Lange-Bertalot, H. (Editor) Iconographia Diatomologica. Annotated Diatom Monographs 7. Koeltz Scientific Books.

Web Reference: Ostracods – UCL. https://www.ucl.ac.uk/GeolSci/micropal/ostracod.html.