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Egagropili Sand Dunes (Holocene) along the southeastern Gulf of Sirte (Mediterranean Sea) coast of Brega, Libya: their genesis and palaeoenvironmental implications

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ABSTRACT

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The beaches around the coastal town Brega, Libya, are covered with *Posidonia oceanica* banquettes and millions of scattered predominantly spherical Egagropili of various sizes. Isolated areas of Egagropili sand sheets and sand dunes are the characteristic geomorphological feature of the Brega coast. Formation of Egagropili sand sheets and sand dunes goes through the following five stages: 1. Formation of Egagropili under shallow marine environment, 2. Deposition of *Posidonia oceanica* banquettes on the beaches, 3. Desiccation of dead leaves and concentration of Egagropili, 4. Formation of Egagropili sand sheets, and 5. Formation of Egagropili sand dunes. Predominant westerly winds between October and March play a major role in transporting dead leaves of *Posidonia oceanica* and associated Egagropili from shallow marine environments over the adjacent beaches. Another wind pattern, Ghibli, is a hot and arid wind that blows from south towards north all over Libya several times a year which is responsible for carrying large quantities of sand from the Sahara region to the Mediterranean coast. A combination of these two wind patterns is responsible for the formation of Egagropili sand dunes. These sand dunes are suggested to be of Holocene age, and they are palaeoenvironmentally significant. Egagropili sand dunes of the Brega coast are distinctive Holocene deposits, where all the biological, environmental, and atmospheric factors responsible for their formation can be concurrently observed in modern times.

Keywords: *Posidonia oceanica* 'banquettes', Egagropili sand dunes, Mediterranean Sea, Brega coast, Libya

INTRODUCTION

The coastal town of Brega (30°26'06" N, 19°40'01" E) is located on the southeastern corner of the Gulf of Sirte (Mediterranean Sea). Geographically, the town is divided into three regions, named as Brega Area One, Brega Area Two and the New Brega (Figure 1). The beaches around this town are covered with enormous amounts of dead leaves of uprooted seagrass *Posidonia oceanica*, (Figure 2.B–E) known as banquette (Astier et al. 2020). These banquettes are sometimes fresh green, but generally wet brown and dried and desiccated brown (Figure 3.A, C). Additionally, millions of scattered Egagropili of various sizes (diameter 1.5–10 cm) and shapes (spherical, subspherical, and elongated), and isolated areas of sand sheets and sand dunes composed of Egagropili are found here as well.

The sea grass *Posidonia oceanica* balls are known as Egagropili (Mirpoor et al. 2021). Egagropili, also spelled as Egagropoli, or Aegagropiles are known

Figure 1. Map of the Brega region showing various localities and the coastal areas where sand dunes and sand sheets composed of Egagropili, and dead seagrass (*Posidonia oceanica*) occur. Inset: Map of Libya showing location of Brega on the southeastern corner of the Mediterranean Sea. (http://1.bp.blogspot.com-HCeIPGn1aY8/TWt8FNcXDWI/AAAAAAAAAFE/9lyNbV60xIQ/s1600/map_of_libya.jpg) Accessed on September 20, 2021.

as 'Sea Balls', 'Beach Balls', 'Neptune Balls' or 'Kedron Balls'. Usually they are spherical or subspherical, and occasionally elongated (fibrous) masses of organic matter. They occur primarily on the sea beaches but are also found on the lake shores. They are light brown spheroids formed by the leaf fiber of dead *Posidonia oceanica* aggregates following the wave motion and transported to the beaches.

Occurrence of Egagropili is widespread on the Mediterranean Sea beaches. The dead fibrous tissues of this species are tossed around by waves resulting in the constant rolling action of the sea which turns the fibrous material into balls that ultimately wash up on the beaches. Similar brown spheroids are known from the Lunenberg coast of Nova Scotia, Canada, that are rolled up remains of brown algae but also incorporate red seaweeds, sea sponges, and small seashells. On the shores of Kedron Lake in New Brunswick, Canada, similar balls are formed by needles of fir, pine and spruce from the forest surrounding the lake by rolling together with twigs, sandy silt, and other vegetable matter on the lake bottom. They are formed by the churning of waves that are ultimately transported to the lake shore. Such balls have also been reported from the lake shores from various regions of the U.S.A. (Kumar 2014a).

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Figure 2. Formation of Egagropili sand sheets and sand dunes**. A.** Growth of seagrass (*Posidonia oceanica*) under shallow marine condition. **B.** Uprooted *Posidonia oceanica* leaves and rhizome washed on beach sand. **C.** Presence of seagrass *Posidonia oceanica* 'banquette' on the beaches of Brega. **D.** Presence of dry *Posidonia oceanica* leaves along with Egagropili. **E.** Abundance of dry *Posidonia oceanica* leaves along with Egagropili. **F.** Abundance of Egagropili of various sizes and shapes on the beaches of Brega. **G.** Egagropili sand sheets. **H.** Egagropili sand dunes in the coastal regions of Brega. Figures 2.A and 2.B accessed on September 20, 2021 from (https://www.bing.com/images/search?q=Posidonia+oceanica&id=473CA231B46F86B3542C9 FBA2FAAF4F85652A75B&form=IARRTH&first=1&disoverlay=1)

Figure 2

Isolated hills of Egagropili sand dunes are longitudinal dunes (seif),1 to 3 m high, and about 70 m long; they occur along the beaches of Brega (Figures 2.H, 3.G). The coastal areas are covered by widespread sand sheets, also composed of millions of Egagropili (Figures 2.F, G). These Egagropili are predominantly spherical and of different diameters (1.5 cm –10 cm) are being reported for the first time from the beaches of Brega. These sand dunes primarily are made of sand size particles but there is occasional presence of pebble and cobble fragments as well. These coarser fragments get transported probably during winter storms from the dry riverbeds nearby. There is very little vegetation cover over the sand dunes except for scattered grasses and few small shrubs; however, vegetation cover on sand sheets is more pronounced that includes grasses, herbs, and shrubs (Figure 3.H). The objective of this study was to describe the genesis of Egagropili sand dunes and sand sheets and discuss their palaeoenvironmental implications.

A quantitative study of the contribution of biogenic sediments produced in *Posidonia oceanica* meadows and photophilic algal communities to the sediment budget of a Mediterranean beach–dune system of an Italian beach found that 83% of sediments were in the coastal wedge, 16% in the dune fields and only 1% in the subaerial beach (De Falco et al. 2017). These sediments were composed of bioclastic and non-bioclastic grains from various sources, particularly from *Posidonia oceanica* meadows that were transported to the beach–dune system. It is quite interesting to note that there was no mention of presence of Egagropili in these sediments. There is a possibility that the presence of Egagropili in these sediments were ignored by De Falco et al. (2017).

GEOLOGY OF BREGA

Mediterranean coastal Quaternary deposits of NE Libya include the fossil marine sand dunes of the Ajdabiya Formation, sabkhas, aeolian deposits, beach and coastal sand dunes and alluvium deposits (Tawadros 2012). The geological map of Libya (Vesely 1985) shows presence of two stratigraphic units around Brega: Q2e is Holocene aeolian deposits and Q1c is Pleistocene cemented littoral deposits and sand dunes with calcarenites of the Ajdabiya Formation. Kumar (2014b) described geology of the Brega area and established local Neogene Stratigraphy. A new stratigraphic unit 'The Brega Sandstone Bed' of Pliocene age was proposed and several types of trace fossils were described from this formation. Based on new geological information from the wider regions of Brega, the Neogene Stratigraphy of the Brega region was modified (Kumar 2016). Table 1 shows Neogene stratigraphy of the Brega region.

The Holocene sediments around Brega include coastal and inland sand dunes, and sand sheets. There are many sand dunes of various sizes that occur all over this region. Sand dunes occur on top of the Ajdabiya Formation along the coast, and over the plains of the Brega Area (Figure 3.G). One very striking feature of the Mediterranean Sea beaches around Brega is the presence of millions of brown coloured Egagropili that occur mixed with sand in the sand sheets and sand dunes (Figures 2.F–H, 3.E–G). They are spread all along the beach and at times marking the limits of the waves reaching on land (Figures 2.C–F, 3.E).

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Figure 3. A. Presence of enormous amounts of dead leaves of uprooted seagrass *Posidonia oceanica* 'banquette' on the beach of Brega Area One. **B.** A single Egagropili. **C.** Dead leaves of uprooted seagrass *Posidonia oceanica* and two small Egagropili (one spherical and the other elongated) on the beach of Brega Area One. **D.** These are xeric pine trees planted along the road at the time of construction of Brega Area Two. They are all bent south to southeastward indicating the direction of prevailing westerly winds when they move over to the land areas, the wind direction changes more towards north-south direction. **E.** Millions of Egagropili of various shapes and sizes are seen scattered along the beaches of Brega. They are mixed with dead leaves of uprooted seagrass *Posidonia oceanica*. **F.** Ripple-marked sand sheet with concentration of several Egagropili. **G.** Egagropili sand dunes overlying the Ajdabiya Formation (Pleistocene), there is very little vegetation growth; mainly grasses and few small shrubs on the sand dune. **H.** Vegetation growth on sand sheet includes grasses, herbs, and shrubs.

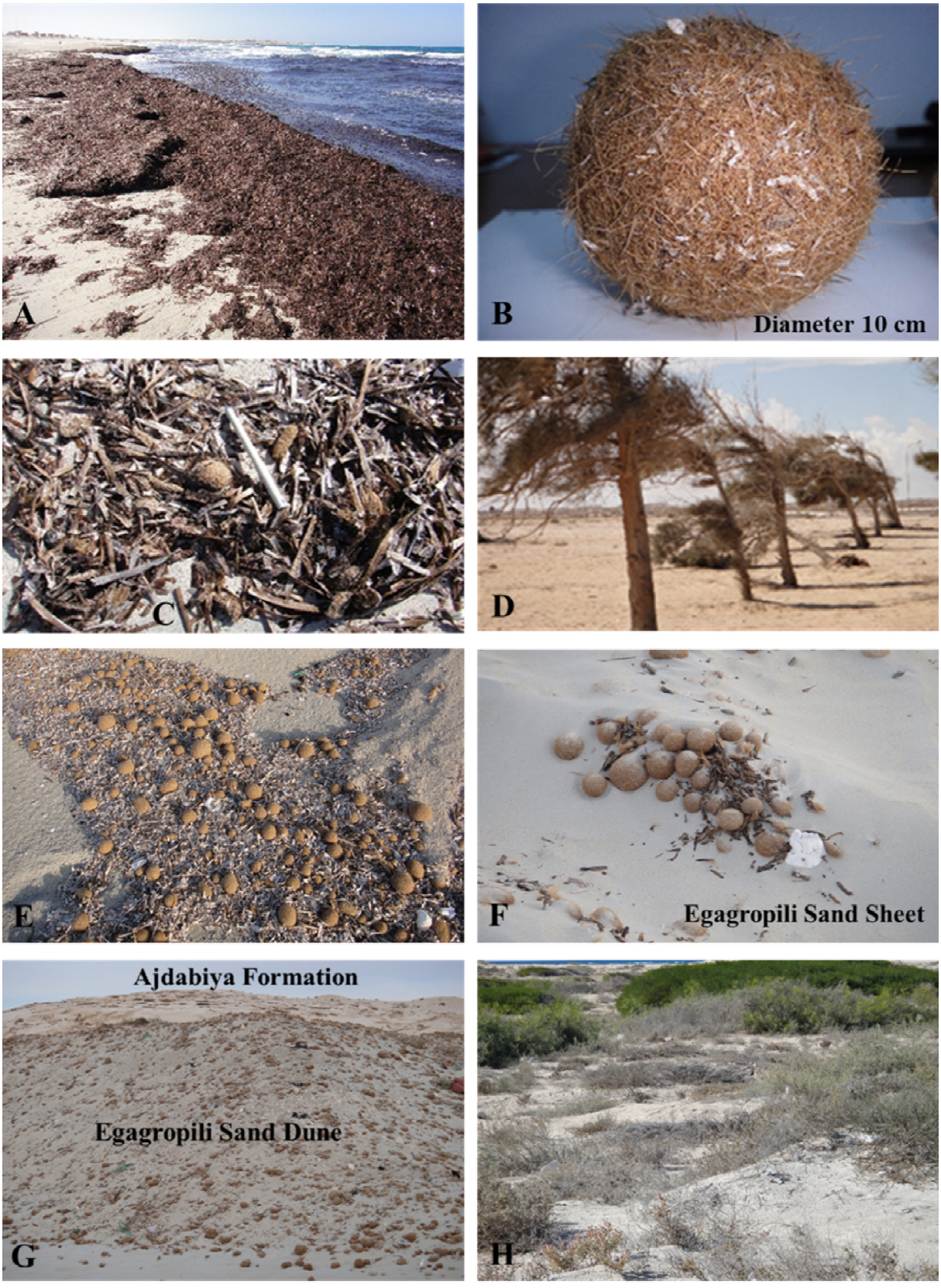
A
B
Diameter 10 cm
C
D
E
F
Egagropili Sand Sheet
Ajdabiya Formation
Egagropili Sand Dune
G
H

Figure 3

Table 1. Sequence of stratigraphic units, their lithology, fossil contents, age, and depositional environments (Kumar 2016). Egagropili sand sheets and sand dunes are part of Holocene sediments of the Brega region.

Stratigraphic Units		Lithology	Fossils	Paleoenvironments	Age
Sand sheets and sand dunes		Sand mixed with Egagropili	Occasional molluscs	Aeolian	Holocene
Beachrock		Hard, massive, calcareous sandstone	Corals, Gastropods	Intertidal	Holocene
Ajdabiya Formation		Marine sand dunes, compact, and at places cross bedded	Occasionally bioturbated	Shallow Marine	Pleistocene
Sahabi Formation (Member V)	Upper part	Medium to coarse, greyish-greenish, thinly bedded sandstone with pebbles	None observed	Intratidal to supratidal	Early Pliocene
	Lower part	White, grey and yellowish sandstone, massive, medium to coarse grained (Brega Sandstone Bed)	Burrows and trails, bioturbated	Intertidal to shallow subtidal	

ECOLOGY AND DISTRIBUTION OF *POSIDONIA OCEANICA*

Posidonia oceanica, a sea grass, is an aquatic angiosperm endemic to the Mediterranean Sea (Telesca et al. 2015). This species forms large underwater meadows (Figure 2.A) in the photic zone of sheltered coastal waters with sandy or rocky substrates (Pirog 2011); that creates the habitat for many other marine organisms (Gobert et al. 2006). It is known to be one of the largest, slowest growing and longest living plants; based on the plant's known growth rate, they are likely to be thousands or possibly tens of thousands of years old (Arnaud-Haond et al. 2012). They are an important sink of carbon dioxide and an important source of oxygen; and are a habitat for numerous species of fish and other invertebrate animals (Boudouresque et al. 2017).

Presence of *Posidonia oceanica* depends on temperature, salinity, depth, and turbidity (Telesca et al. 2015). This species grows best in clean waters; its presence marks a pollution free environment; thus, it becomes sensitive to climate change (ocean warming and acidification) where meadows are being threatened by rising sea temperatures, which slows down its growth. The Mediterranean Sea region is warming faster; thus, it is adversely impacting the *Posidonia oceanica* meadows (Telesca et al. 2015). Efforts to mitigate climate change are urgently needed to preserve this key ecosystem (Jordà et al. 2012). Human activities such as coastal urban development, fishing, aquaculture, various types of pollution such as chemicals from agricultural run-off, sewage, and desalination plants are putting these plants at risk. These plants have survived Quaternary glaciation (Telesca et al. 2015).

Posidonia meadows occur in large parts of the Mediterranean Sea but during the past few decades they have disappeared from certain areas. Length of Mediterranean Sea coastline is 46,000 km, of which *Posidonia oceanica* covers about 11,907 km (Telesca et al. 2015). Only 11% of the Libyan coast has been surveyed, and total area covered by *Posidonia oceanica* is only 1,235 ha (Màrba et al. 2014).

Old leaves of this plant, shed annually, get transported to the adjacent seashore forming dense masses called banquettes (Figure 3.A). Widespread presence of banquettes of decomposing leaves of

Posidonia oceanica along with millions of Egagropili on the beaches of the Brega coast indicate presence of this species in the shallow waters off Brega (Figures 2.C–F, 3.A–C). Presence of Egagropili sand dunes and Egagropili sand sheets along the Brega coast indicate that *Posidonia oceanica* has been present in this area for a considerably long time, probably for thousands of years. Figure 1 in Telesca et al. (2015) shows the distribution of *Posidonia oceanica* in the Mediterranean Sea; however, it does not show presence of this species along the coast of Brega because this coast has not been surveyed as shown in Figure 3 of Telesca et al. (2015). Kumar (2014a) had shown the widespread presence of Egagropili (Beach Balls) along the Brega coast, Libya.

Presence of enormous volumes of *Posidonia oceanica* banquettes on the sandy beaches of the Mediterranean Sea pose problems for their management. They are often mechanically removed to make the beaches attractive for tourism. However, this leads to massive loss of sediments trapped in banquettes from the sandy beaches leading to coastal erosion, changing beach morphology, and depletion of nutrient and biomass for the coastal ecosystem (Simeone and De Falco 2013). Astier et al. (2020) and Cantasano (2021) suggest keeping the banquettes intact on the sandy beaches for the defense against coastal erosion. This is improving tourism by making the beach a popular destination, for example in Tunisia (Astier et al. 2020).

GENESIS OF EGAGROPILI SAND SHEETS AND SAND DUNES

Egagropili sand sheets and sand dunes are distinct geomorphological features of the Brega coast. Their formation goes through the following five stages.

1. Formation of Egagropili under shallow marine environment: Leaves of *Posidonia oceanica* are shed annually and these dead leaves are the primary source of Egagropili. The dead leaves are tossed under water and moved around by waves in the shallow marine environments where this species grows. The constant rolling action of the sea waves turns the fibrous material of the dead leaves into spherical or subspherical balls of various sizes (Kumar 2014a). Initially they are smaller in size, around one cm in diameter, but may grow gradually.

2. Deposition of *Posidonia oceanica* banquettes on the beaches: Waves that impact the coastal areas are generated by offshore storms expanding their energy in the coastal zone and shallow waters (Keller 1999). This process leads to the formation of a beach, a landform consisting of loose sand or gravel that is accumulated by wave action at the shoreline. Dead leaves of *Posidonia oceanica* are transported by the constant wave action from shallow marine environments and get deposited over the adjacent seashore forming banquettes associated with large numbers of Egagropili. In the Brega area transportation of dead *Posidonia oceanica* leaves from shallow depths to the adjacent beaches is due to high southward wind that results from the dominant westerlies. According to Fowler (2021), "Libya's climate is dominated by hot, arid Sahara, but along the coastal region it is moderated by the Mediterranean Sea. The Saharan influence is stronger during summer months. From October to March, prevailing westerly winds bring cyclonic storms and rains across northern Libya." The westerly winds begin to blow southwards as they come over the Mediterranean Sea. This wind pattern is responsible for the formation of banquettes on the beaches and transporting dried Egagropili from beaches to other coastal environments and further inland areas becoming part of the sand sheets and sand dunes.

3. Desiccation of dead leaves and concentration of Egagropili: Once the banquettes are deposited over the beaches, the desiccation of dead leaves of *Posidonia oceanica* begins under the intense heat due to the hot and arid climate in Brega. The dry green leaves gradually turn brown; they begin to fragment under the wind action leaving large masses of fragmented pieces of leaves and Egagropili on the beaches (Figures 2.D–E, 3.C, E). Desiccation is a slow process that destroys the softer tissues of *Posidonia oceanica* leaves leaving fibrous matter on the beaches. Constant wind action causes fibers to roll into balls which

in due course of time become larger as more fibers become part of the ball. Thus, Egagropili form under water as well as on land, however, they mainly grow on land.

4. Formation of Egagropili sand sheet: Constant wind action has a winnowing effect on the masses of dead leaves and Egagropili. In due course of time fragmented leaves are blown away leaving mainly concentrated masses of Egagropili on the beaches (Figure 2.F). High winds transport Egagropili from beaches to other coastal environments and to further inland areas becoming part of the sand sheets (Figures 2.G, 3.F). Sand sheets along the beaches of Brega have enormous numbers of spherical to subspherical Egagropili of various diameters.

5. Formation of Egagropili sand dunes: Sand on beaches is not static; constant movement of sand under the influence of wind leads to the formation of sand dunes. When the wind blows, sand grains move up the gentle slope and then down the slip face, causing the sand dune to move in the direction of the wind (Keller 1999). Dunes have a variety of sizes and shapes and develop under various conditions. Constant wind action keeps the sand grains moving forming the sand sheets and eventually forming sand dunes. Constant wind action transports Egagropili along with sand forming Egagropili sand sheets and the Egagropili sand dunes. The Egagropili sand dunes of the Brega coast are Longitudinal Dunes (Seif) whose average height is 3 m and length ranges between 50–80 m. Such dunes are formed in areas with high, somewhat variable winds and a small amount of sand available (Keller 1999), and sometimes with two wind directions (Friedman & Sanders 1978). Seifs are long ridges of sand that form more or less parallel to the prevailing winds and where sand supplies are limited. These are 3–4 m high and several dozen meters long. In large deserts such dunes can reach a great size, for example, in North Africa and Arabia (Tarbuck & Lutgens 1999, Kumar & Abdullah 2011). In Libya westerly winds blow toward south over the Mediterranean Sea (Pariona 2018). In the Brega area, this wind direction is demonstrated by southwardly bending trees along the roads (Figure 3.D). Another significant wind pattern is Ghibli which is a hot and arid wind that blows from south towards north all over Libya several times a year. The Ghibli is responsible for carrying large quantities of sand from the Sahara region to the Mediterranean coast. A combination of these two wind patterns is responsible for the formation of Egagropili sand dunes.

AGE OF THE EGAGROPILI SAND DUNES

There is no age control on these Egagropili sand dunes; however, they overlie the Ajdabiya Formation of Pleistocene age (Figure 3.G). Thus, they are considered to be of Holocene age. *Posidonia oceanica* is a slow growing and long living species, and based on their growth rate, they are likely to be thousands of years old (Arnaud-Hanod et al. 2012). No Egagropili were observed in the Ajdabiya Formation; thus, the age of the Egagropili sand dunes in the Brega area is suggested to range between few thousand years to Recent. The process of formation of such sand dunes continues in the modern days as can be observed by the presence of abundant *Posidonia oceanica* banquettes mixed with Egagropili on the beaches of Brega (Figure 3.A), and widespread concentrations of mostly Egagropili (Figure 3.B–C). A Holocene age is suggested to these sand dunes since they contain enormous numbers of Egagropili.

PALAEOENVIRONMENTAL IMPLICATIONS

This work explains the process of formation of Egagropili sand sheets and sand dunes. Formation of Egagropili is controlled by shallow marine environments, ecology of *Posidonia oceanica* and Mediterranean Sea climatic conditions. Thus, their presence in Holocene sand dune deposits have palaeoenvironmental and palaeoclimatic implications. Strong winds generated by westerlies transport dead leaves of *Posidonia oceanica* and Egagropili from shallow marine environments over the adjacent beaches depositing banquettes. Heat and strong aridity cause desiccation and rolling action of the wind makes Egagropili larger in size and they

accumulate in millions over the beaches. Egagropili sand dunes demonstrate how wind patterns control transportation processes of dead leaves of *Posidonia oceanica* and Egagropili in the beach and dune systems throughout the Holocene. Egagropili sand dunes of the Brega coast are distinctive Holocene deposits where all the biological, environmental, and atmospheric factors responsible for their formation can be concurrently observed in the modern times.

CONCLUSIONS

The beaches of Brega are covered with enormous amounts of sea grass *Posidonia oceanica* banquettes and millions of Egagropili of various sizes. Along the coastal areas Egagropili sand sheets and sand dunes are present as isolated deposits. Formation of Egagropili sand dunes go through five stages: 1. Formation of Egagropili under shallow marine environment, 2. Deposition of *Posidonia oceanica* banquettes on the beaches, 3. Desiccation of dead leaves and concentration of Egagropili, 4. Formation of Egagropili sand sheet, and 5. Formation of Egagropili sand dunes. Predominant westerly winds associated with storms and rains impact the region between October and March. Ghiblis are hot and arid winds that blow from south towards north all over Libya several times a year. A combination of these two wind patterns is responsible for formation of Egagropili sand dunes. These sand dunes are suggested to be of Holocene age. Egagropili sand dunes of the Brega coast are characteristic deposits where all the biological, environmental, and atmospheric factors responsible for their formation can be simultaneously observed in modern times.

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