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ORIGINAL ARTICLE

Biodegradation effects over different types of coastal rocks

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Abstract Modern coastal areas have natural and transported rocks (armourstone) on which various types of organisms live. Burrowing, boring and feeding by these organisms can destroy or modify the coastal rocks and hence change the coastal morphology. Two rock types and three dominant types of organisms have been studied in Mersin Bay, Eastern Mediterranean of southern Turkey. In this study area, Plio-Quaternary conglomerates and variously aged limestone armourplates have been affected by Phoronida worms, bivalve *Brachidontes pharaonis* (Fischer P. 1870) and the limpet *Patella* sp. Phoronida colonies were found covering the hard substratum as a mat and form tubular endolithes of 35.0 mm depth and 1.5 mm diameter, whilst *Brachidontes pharaonis* (Fischer P. 1870) form 44 mm deep vase-shaped gastrochaenolites. The bioerosive activity of Limpet *Patella* sp., found intertidal and within the spray zone, cannot be significantly observed on the rocks over short time periods. The soft sandy matrix of the conglomerates present were found to disintegrate by bioerosional processes, with the released gravels being transported and deposited onto the beach. Within the armourstone limestone blocks, a maximum of 44.0 mm deep holes developed after 50–60 years. However, these biological activities do not threaten the stability of the blocks due to their hard and homogeneous internal structure. Furthermore, the organism colonies that cover these rocks as a strong mat (maximum 29.0 mm) act to protect their surfaces from further biological attack and wave action.

Keywords Bioerosion · *Brachidontes pharaonis* (Fischer P. 1870) · Phoronida worms · Limestone · Conglomerates · Armourstone · Mediterranean coast

Introduction

Several different types of organisms live within the shallow marine environment under fragile environmental conditions (Ekdale and Bromley 2001). Factors that affect the biological diversity and activities of the shallow marine organism include temperature, salinity, entering of fresh water, nutrient availability, light penetration, sediment input, pH, ground type, coastal morphology, sea floor topography, wave action, tidal range, human activities, etc. (Young and Urguhart 1998; Cerrano et al. 2001; Kleeman 2001; Guidetti et al. 2003; Wilson 2006).

Ground type, which can evolve as a result of both artificial and natural processes, is one of the most important factors of biodiversity. Organisms generally prefer ground made of very hard limestone (Trudgill and Viles 1998; Cerrano et al. 2001; Taylor and Wilson 2003) and relatively soft clastic rocks such as conglomerate and

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sandstone (Young and Urguhart 1998; Babic and Zupanic 2000; Taylor and Wilson 2003).

Human constructions in maritime provinces such as breakwater, jetty, harbour, marina constructions, artificial fillings for recreational facilities, roads and other buildings use a great quantity of armourstone and other additional materials. Materials of various ages and types can be used during the construction of these buildings. They not only change the nature of the coastal morphology, but also create a new habitat for different types of shallow marine organisms. The boring, burrowing and feeding activities of shallow marine organisms can destroy both natural and artificial grounds and hence naturally change the coastal morphology (Trudgill and Viles 1998; Young and Urguhart 1998; Ekdale and Bromley 2001).

The Mersin coast of South Turkey, Eastern Mediterranean, is an example of where both natural (Plio-Quaternary conglomerates) and transported rocks (various aged limestone armourplates) exist. Here, three different types of organisms are dominant within these rocks. Therefore, they provide a good oppurtunity for studying biodegradation effects on coastal areas. The aims of this study are to determine the various biodegradational effects and quantity of biodegradation on different rocks created by the same organism, the effects of environmental conditions over the biodegradation for the same rock type as well as to investigate the rock stability as a result of the total biodegradation activities.

General geology

The basement of the Adana Basin includes Permo-Carboniferous limestone, Triassic clastic rocks (Karagedik Formation), Jurassic–Cretaceous limestone (Cehennemdere Formation), Upper Cretaceous limestone and calciturbidite (Yavca Formation), Upper Cretaceous Mersin Ophiolite and Upper Cretaceous–Paleocene Fındıkpınarı Melange (gabbro, serpentinized peridodite-pyroxenite and sedimentary blocks; Demirtaşlı et al. 1984; Yetiş and Demirkol 1986; İşler 1990; Ünlügenç et al. 1990; Parlak and Delaloye 1996; Özer et al. 2004; Figs. 1, 2).

The Cenozoic rocks consist of four mega-sequences (Ünlügenç et al. 1990; Gürbüz 1999). These include: the Karsantı (Oligocene limestone and clastics) and Gildirli Formations (Oligocene-Early Miocene clastic); the Karaisalı (Early-Middle Miocene reefal limestone) and Kaplankaya Formations (Early-Middle Miocene claystone, marl, sandy limestone); the Cingöz (Middle Miocene deep sea clastic) and Güvenç Formations (Middle Miocene deep

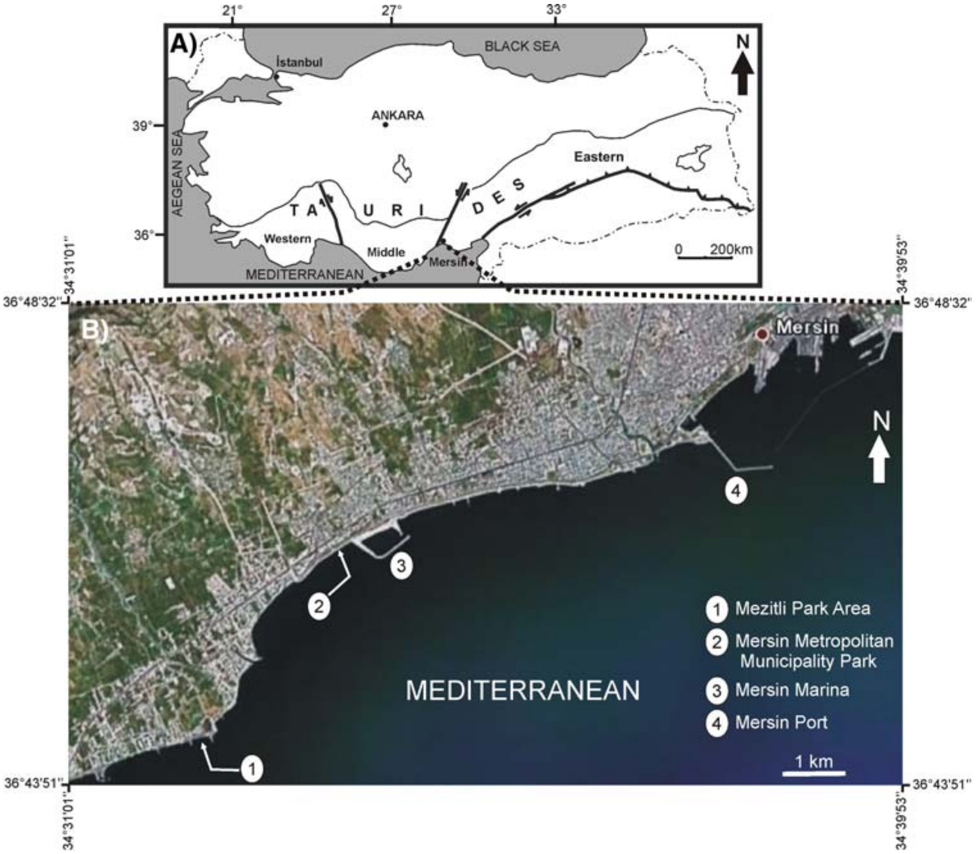

Fig. 1 **a** The study area is located in front of the Middle Taurides (Özgül 1976). **b** Satellite view of the Mersin coast from Google Earth, access date: 27 March 2007)

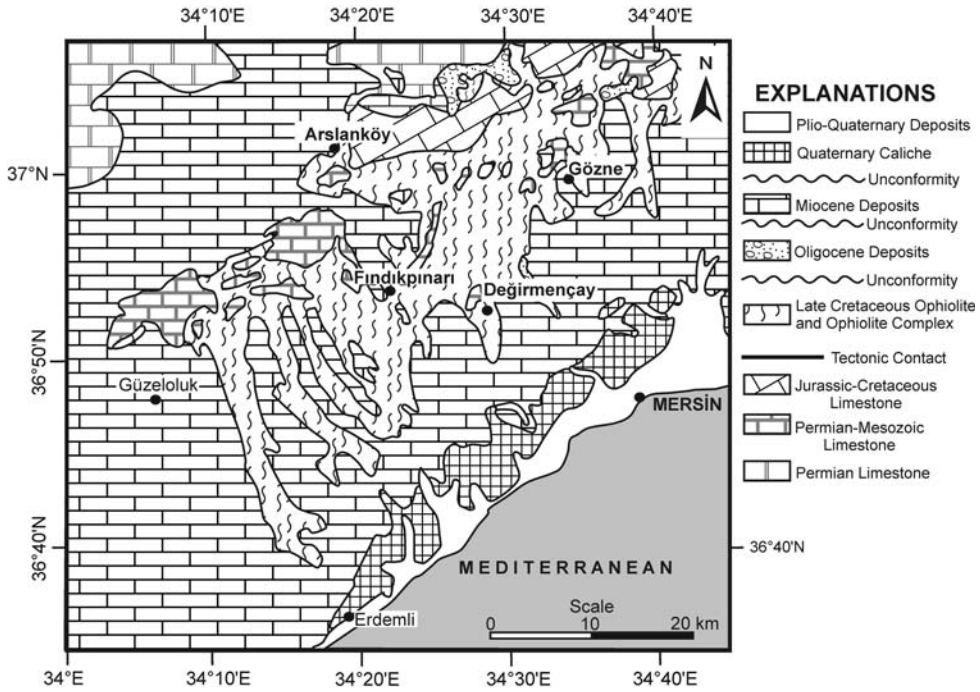

Fig. 2 General geological map of the study area (modified from Erentöz and Ternek 1962)

sea shale); and the Kuzgun (Middle–Late Miocene reefal limestone, shallow marine clastic, and fluvial clastic) and Handere Formations (Late Miocene–Pliocene limestone and evaporite; Fig. 2). In the vicinity of the study area, there are also Plio-Quaternary deposits of clayey, sandy, gravelly alluvial deposits, caliche and gravelly red-colored alluvial soil (DSİ 1978; Şenol et al. 1998; Eren et al. 2004; Şahin et al. 2003; Fig. 2).

Method

Four areas were selected in the Mersin Bay for this study of which only the westernmost area (Mezitli Park) includes Plio-Quaternary conglomerates. Since 2003, the Mersin metropolitan municipality park contains fillings, which have been constructed using blocks of the Miocene reefal limestones and to a lesser extent the Plio-Quaternary caliches. Between 1997 and 2000, the Mersin Marina was constructed using Miocene reefal limestone blocks. The Mersin port construction started in 1954 and continued at intervals beginning from 1990 using both the Miocene reefal limestone and the Jurassic–Cretaceous limestone.

Three different biodegradation zones have been delineated in these man-made structures. These include the subtidal zone (green-gray colored; Phoronida worms and bivalve *B. pharaonis* are dominant, always under water), the intertidal zone (gray-white colored; Phoronida worms and bivalve *B. pharaonis* are dominant with the lesser limpet *Patella* sp. sometimes exposed), and the spray zone (dark white-colored; sparsely attached *Patella* sp. always under atmospheric condition).

Organism diversity and their bioerosive effects were recorded during the field study. Hand samples were collected and detailed photographs were taken for researching the vertical changes of bioerosive activity. Thin sections of these samples were also examined under the microscope. Limestones were classified based upon the Folk (1962) and Dunham (1962) carbonate classification systems.

Dominant organisms of the Mersin coast

The clastic and limestone rocks of the Mersin Bay have been affected by the Phoronida worms, bivalve *Brachidontes pharaonis* (Fischer P. 1870) and limpet *Patella* sp. The suspension feeder Phoronida worms are known as horseshoe worms and have a wide geographical range between 0 and 70 m depth (Emig and de Mittelwihr 1999). The tubes of these organisms can either rest over the hard substrate surface or buried within sand and mud. They tend to live in colonies and twist over each other (forming hardground). Some species can dissolve the limestone or seashell forming holes (endolithes; Emig and de Mittelwihr 1999).

Brachidontes pharaonis (Fischer P. 1870) is a suspension feeder, macro borer and common in and on the hard substratum (Safriel et al. 1980; Kleman 2001; Karayakar 2005). The bivalve *B. pharaonis* can burrow vase shape holes called gastrochaenolites (found as ichnofossils), providing information about the initial position of the rock and palaeogeographic condition during the bioerosion time (Taylor and Wilson 2003).

The Patellacea is a herbivorous macro borer and can cause bioerosion through the physical process of scraping (Andrews and Williams 2000; Kleman 2001). Both bivalve *B. pharaonis* and Patellacea are dominant in rough and semi-rough conditions (Kleman 2001). Limpet *Patella* sp. can live in shallow marine environments and can attach itself to wet rocks subjected to water spray along the coast of Turkey within the Aegean and Eastern Mediterranean Seas (Ergen and Öztürk 1999).

Results

Biodegradation effects over the clastics

The Viranşehir coast is located 12 km SW of the Mersin City Center, South Turkey, and contains Plio-Quaternary conglomerates. These conglomerates consist mostly of Late Cretaceous ophiolite (diabase, gabbro, serpantinite, peridodite, pyroxenite) and various aged (Palaeozoic to Miocene) limestone gravels with varying textures (biomicrite to biolithite; bindstone, framestone, wackestone and packstone). Their gravel sizes range between 2 mm and 25 cm. The matrix among the gravels is a medium to coarse-grained sand that has a similar composition to the larger clasts (Fig. 3a, b). Carbonate cementation has also been determined within the matrix via thin section examination (Fig. 3a). The sandier matrix is thought to provide a relatively less resistant ground than the gravel.

The conglomerates generally form independent, small cliff sets elongated parallel to the shoreline. During the day, they are covered by 0–10 cm of seawater (Fig. 3C). During low tides, conglomeratic sets close to the shoreline are exposed (20–30 cm thick rock expose above the sea level), while during high tide periods, they are covered by 30–50 cm of seawater. Tidal range of the Viranşehir coast

Fig. 3 **a** Microphotograph of the sandier matrix of Plio-Quaternary conglomerates. *Op*, ophiolite; *L*, limestone; *Q*, quartz; *M*, micrite; *C*, calcite cement. **b** Side view of the organic cover on the conglomerates. **c** General view of the Plio-Quaternary conglomerates. **d** Detailed view of the organism over the conglomerates. *Op*, ophiolite; *D*, Phoronida worms; *P*, limpet *Patella* sp.; *B*, bivalve *B. pharaonis*. **e** Boring (*arrows*) of the loose sandier matrix below the hard gravels; *Op*, ophiolite. **f** General view of the imbricated gravelly beach (sieve deposits) in Viranşehir coast

varies between 50 and 80 cm in the study area. Thus, the Viranşehir coast can be classified as a microtidal (wave dominated) coast based upon the classification of Davies (1973).

The conglomeratic sets produce a suitable high energy, clean, clear, warm, well lit hard substratum environment for organisms. However, this hard substratum can be weakened by both the activities of waves and organisms.

Within the study area, the relatively soft matrix of the conglomerates were totally covered by mats of Phoronida worm colonies. Here, the Phonorida worms had created endolithes tubes of 0.5–8.0 mm depth and 0.4–1.2 mm diameter inside the matrix of the conglomerate (Table 1). In addition, bivalve *B. pharaonis* have also colonized over the Phoronida worm mats and loose sand matrix. These bivalves have created gastrochaenolites 4.0–7.0 mm deep and 6.0–8.0 mm wide (Table 2). Sometimes, they are found as an ichnofossil inside the gastrochaenolites of limestone gravels (Fig. 3d). Limpet *Patella* sp. attach to both the Phoronida worms colonies and gravels. Phoronida worms can also develop over the calcareous shell of the limpet *Patella* sp. and bivalve *B. pharaonis* as a tubular shape (Fig. 3d).

The boring and hollowing activities of limpet *Patella* sp., Phoronoida worms and bivalve *B. pharaonis* have caused the disintegration, fragmentation and dispersion of the sandier matrix as well as the release of conglomerate gravels. This has resulted in the released gravels being transported to the shore by waves. This process has formed an imbricated, poorly sorted gravelly beach without matrix (sieve deposits; Fig. 3e). On the conglomerate matrix, organic cover thickness that includes bivalve *B. pharaonis* and Phonorida worm colonies is reaches a maximum of 29.0 mm (Table 1; Fig. 3b).

Biodegradation effects over limestone

Cream-white colored Miocene reefal limestone blocks with various textures (biomicrite, biolithite; wackestone, packstone, bindstone, etc.) were abundantly used as armourstone in the construction of the Mersin metropolitan municipality park filling (2003), Mersin Marina (1997–2007) and Mersin port (1954–1990). Plio-Quaternary caliche blocks were rarely used, except in the Mersin metropolitan municipality park filling due to its unsuitable block size and low strength. For this reason it is not evaluated under the scope of this study. Milky-brown colored and recrystallized Jurassic–Cretaceous limestone blocks were used only in the construction of Mersin port. These three types of armourstone sources are located in the northern part of the Mersin City Center (Fig. 2). The oldest limestone rocks have rarely supplied the necessary block size due to their dense fracturing. Thus, usage of Miocene reefal limestones has steadily increased due to suitable block size and short transportation distance.

Table 1 Statistical evaluations of the depth, diameter and yearly production (depth) of the endolithes produced by Phoronida worms and maximum organic covers in different zones of the Mersin Bay (S Turkey; E Mediterranean)

Location	Phoronida worms											
	Depth (mm)						Diameter (mm)				Organic cover (mm)	Number of sample
	Minimum	Maximum	Average	SD	Minimum/year	Maximum/year	Minimum	Maximum	Average	SD	Maximum	
Plio-Quaternary conglomerates	0.5	8	4	2.8	–	–	0.4	1.2	0.78	0.26	29	10
Mersin municipality park (Miocene limestone; 2003; 4 years)												
Intertidal	1	9	4.14	2.64	0.25	2.25	0.4	1.3	0.79	0.37	10	11
Subtidal	2	12	8.62	3.58	0.5	3.0	0.6	1.3	0.88	0.25	31	8
Mersin Marina (Miocene limestone; 1997–2000; 7 years)												
Intertidal	2	5	3.5	1.29	0.29	0.71	0.8	1.3	1.08	0.22	24	4
Subtidal	4	12	8.14	2.92	0.57	1.71	0.6	1.3	1.01	0.24	25	7
Mersin port (1954–1990; 17 years)												
Miocene Limestone												
Intertidal	3	4.5	3.87	0.78	0.18	0.26	0.8	0.9	0.83	0.06	15	3
Subtidal	2.5	18	9.86	4.59	0.15	1.06	0.5	1.2	0.8	0.23	9	21
Jurassic–Cretaceous limestone												
Intertidal	3	13	7	3.29	0.18	0.76	0.4	1.1	0.76	0.22	8	11
Subtidal	3	35	10.4	7.95	0.18	2.05	0.4	1.5	0.85	0.32	15	15

Table 2 Statistical evaluations of the depth, width and yearly production (depth) of the gastrochaenolites produced by bivalve *Brachidontes pharaonis* (Fischer P. 1870)

Location	*Brachidontes pharaonis* (Fischer P. 1870)										
	Depth (mm)						Width (mm)				Number of samples
	Minimum	Maximum	Average	SD	Minimum/ year	Maximum/ year	Minimum	Maximum	Average	SD	
Plio-Quaternary conglomerates	4	7	5.7	1.37			6	8	7	0,89	6
Mersin municipality park (Miocene limestone; 2003; 4 years)											
Intertidal	0	0	0	0			0	0	0	0	0
Subtidal	8	25	16.67	7.61	2.0	6.25	8	10	9.17	0.93	4
Mersin. Marina (Miocene limestone; 1997–2000; 7 years)											
Intertidal			9			1.29			4		1
Subtidal	7	14	10	2.74	1.0	2.0	6	12	8.8	2.68	5
Mersin port (1954–1990; 17 years)											
Miocene limestone											
Intertidal	0	0	0	0			0	0	0	0	0
Subtidal	11	24	19.6	5.3	1.57	3.43	8	11	9.4	1.14	5
Jurassic–Cretaceous limestone											
Intertidal	0	0	0	0			0	0	0	0	0
Subtidal	10	44	27.5	13.8	0.59	2.59	5	22	12.09	6.01	11

Mersin metropolitan municipality park

The samples of the subtidal zone of the Mersin metropolitan municipality park (Fig. 4a) have been covered by a 10.0–31.0 mm thick organism cover. In subtidal samples, Phoronida worms have formed endolithes ranging from 2.0–12.0 mm depth and 0.6–1.3 mm diameter, whilst bivalve *B. pharaonis* have burrowed both Phoronida worm mats and fresh hard rock surfaces forming gastrochaenolites 8.0–25.0 mm deep and 8.0–10.0 mm wide with some ichnofossils (Tables 1, 2; Fig. 4b). Macroscopically, the greenish intertidal zone has more diverse organisms than the gray spray zone (Fig. 4a). Within the intertidal zone, Phoronida worms have formed endolithes of 1.0–9.0 mm depth and 0.4–1.3 mm diameter, whilst bivalve *B. pharaonis* have not caused any significant bioerosive effects within the host rocks (Tables 1, 2; Fig. 4c). The gray spray zone can easily be delineated from cream-white fresh reefal limestone blocks of filling (unweathered zone), due to their color difference and sparsely attached limpet *Patella* sp. (Fig. 4a, d). Grazing and scraping effects of limpet *Patella* sp. were not notably observed on the armourstone blocks.

Mersin Marina

Both intertidal and subtidal zones of this area have been affected by the Phoronida worms and bivalve *B. pharaonis* colonies in this area (Fig. 5a, b). Both zones are covered by a maximum of 25.0 mm thick organic cover (Fig. 5c). In the subtidal zone, Phoronida worms have opened holes of 4.0–12.0 mm depth and 0.6–1.3 mm diameter. whilst bivalve *B. pharaonis* have burrowed gastrochaenolites of 7.0–14.0 mm depth and 6.0–12.0 mm diameter (Tables 1, 2). In the intertidal zone, Phoronida worms have formed endolithes of 2.0–5.0 mm depth and 0.8–1.3 mm diameter (Table 1; Fig. 5d). Limpet *Patella* sp. have attached themselves within the spray zone without any easily visible bioerosive influence.

Mersin port

Organism activities were separately evaluated in and on the Jurassic–Cretaceous limestone and Miocene reefal limestone blocks within the Mersin port.

The Jurassic–Cretaceous limestone armourplates were totaly used in the wave protected interior side of the Mersin port. However, organic contamination (sourced from the sewage system of the city and marine vehicles) is widely observed in this quiet environment. The milky brown colored and recrystallized Jurassic–Cretaceous limestone are micritic, abundantly fractured, cracked and calcite filled (Fig. 6a). The armourstone of these rocks are covered by a 8.0–15.0 mm thick relatively hard organic cover (Fig. 6b). In the subtidal zone, Phoronida worms have opened holes of 3.0–35.0 mm depth and 0.4–1.5 mm diameter, whilst bivalve *B. pharaonis* have burrowed gastrochaenolites

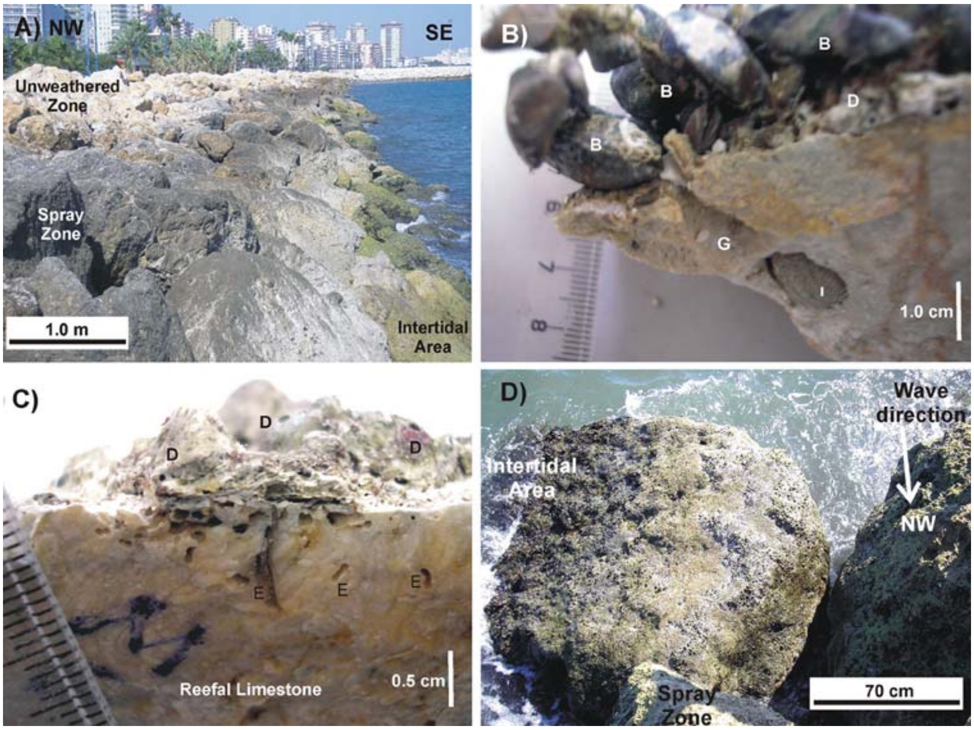

Fig. 4 **a** General view of the zones on the Miocene reefal limestone armourstone in the Mersin metropolitan municipality park filling area. **b** Bioerosive effects on samples from the subtidal zone. *D*, Phoronida worms; *B*, *B. pharaonis*; *G*, gastrochaenolites; *I*, ichnofossil. **c** Bioerosive effects on samples from the intertidal zone; *D*, Phoronida worms, *E*, endolithes. **d** Field view of the intertidal zone and spray zone. Phoronida worm colonies whiten towards the upward area in the intertidal zone under the effect of atmospheric condition

10.0–44.0 mm deep and 5.0–22.0 mm wide (Tables 1, 2; Fig. 6C, 6D). In the intertidal zone, Phoronida worms have formed endolithes of 3.0–13.0 mm depth and 0.4–1.1 mm diameter (Table 1; Fig. 6e, f). The spray zone only includes limpet *Patella* sp. without any easily observable bioerosive influence.

The Miocene reefal limestone blocks have been widely used in the open seaside of the Mersin port under heavy wave conditions that create a well oxygenated and rough environment for organism development. Different petrographical textured reefal limestone such as biomicrite-wackestone (Fig. 7a) and red algae bearing biolithite-bindstone (Fig. 7b) were used in the port construction. Moreover, biosparite-grainstone and biomicrite-packstone blocks were also observed during the field study. Similar organisms and bioerosive activities were fixed despite the

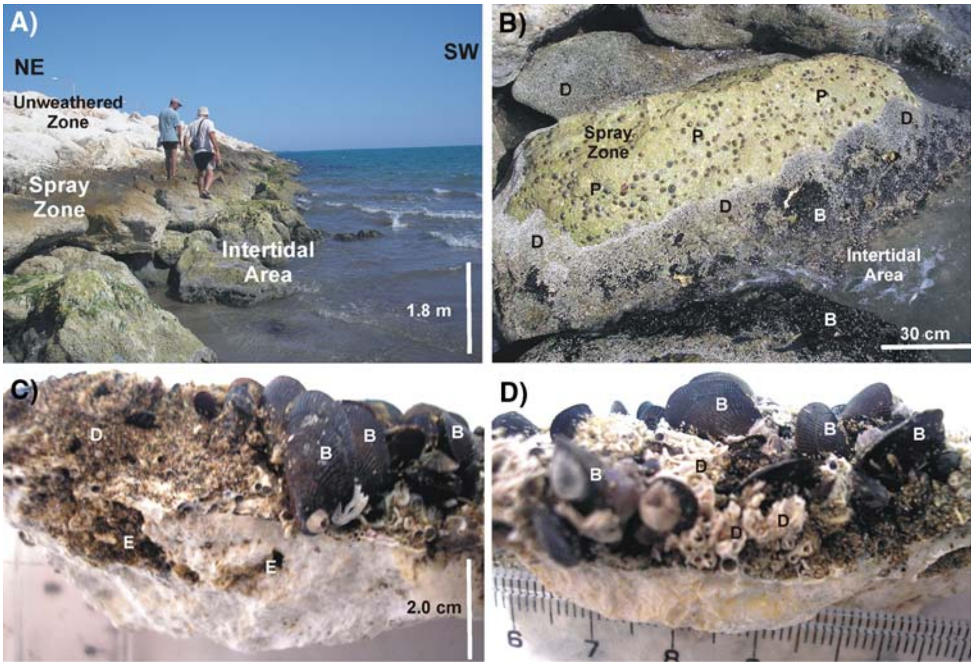

Fig. 5 **a** General view of the marine zones in the Mersin Marina. **b** Close view of the organism distributions in the intertidal and spray zones. *D*, Phoronida worms; *B*, *B. pharaonis*; P, *Patella* sp. **c** Bioerosive effects on samples from the subtidal zone. *D*, Phoronida worms; *B*, *B. pharaonis*; E, endolithes. **d** Bioerosive effects on samples from the intertidal zone. *D*, Phoronida worms; *B*, *B. pharaonis*; *E*, endolithes)

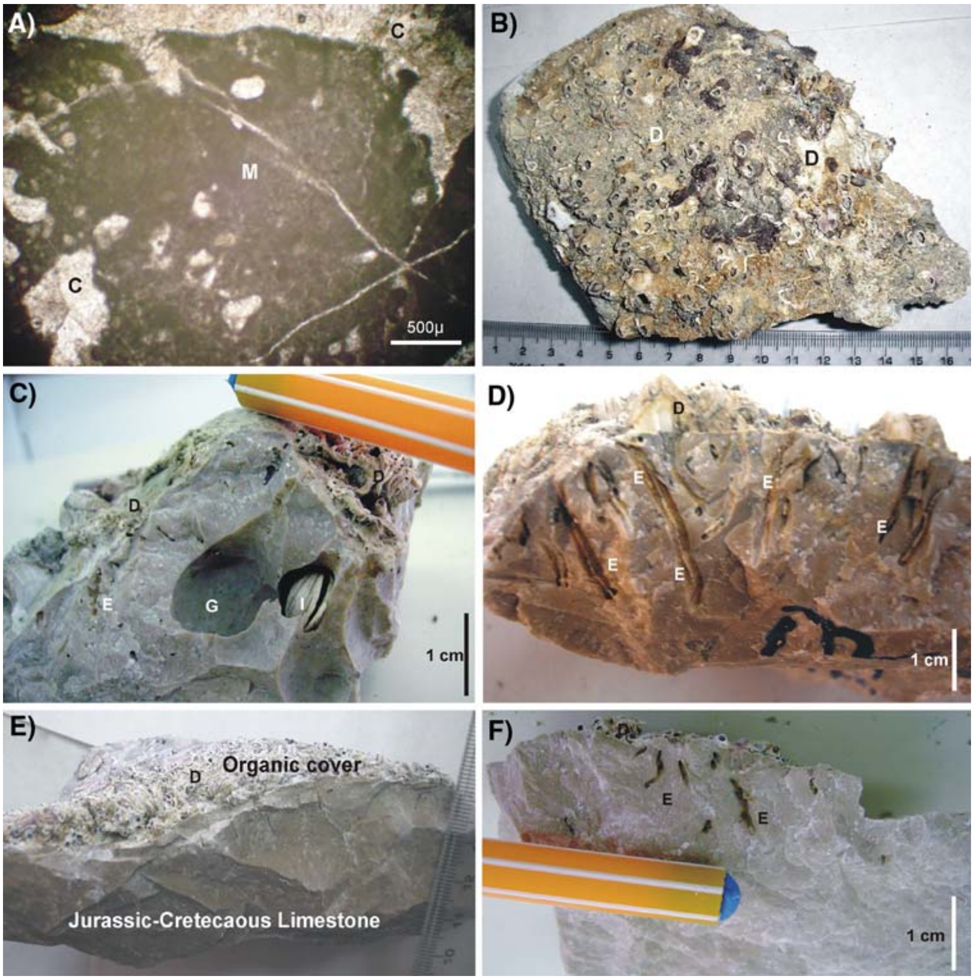

Fig. 6 **a** Microphotograph of the Jurassic–Cretaceous limestone (biomicrite-wackestone; recrystallized limestone) that were used in the construction of the Mersin port. *M*, micrite; *C*, calcite). **b** General view of samples from the subtidal zone. *D*, Phoronida worms. **c** Bioerosive effects on samples from the subtidal zone. *D*, Phoronida worms; *E*, endolithes; *G*, gastrochaenolites; *I*, ichnofossil). **d** Side view of bioerosive effects on samples from the subtidal zone. *D*, Phoronida worms; *E*, endolithes). **e** Side view of bioerosive effects on samples from the intertidal zone. **f** Close view of bioerosive effects on samples from the intertidal zone. *D*, Phoronida worms; *E*, endolithes)

different limestone classes (Fig. 7c). These reefal limestones blocks are covered by a 9.0–15.0 mm organic cover (Fig. 7d). In the subtidal zone, Phoronida worms have made holes of 2.5–18.0 mm depth and 0.5–1.2 mm diameter, whilst bivalve *B. pharaonis* have burrowed gastrochaenolites 11.0–24.0 mm depth and 8.0–11.0 mm diameter (Tables 1, 2; Fig. 7e). The number of endolithes in this zone are higher than the Jurassic–Cretaceous limestone of the same zone, because the breaking sea waves create a well oxygenated, clear and rough environment for the organisms (Figs. 6d, 7e). In the intertidal zone, Phoronida worms have formed endolithes of 3.0–4.5 mm depth and 0.8–0.9 mm diameter (Table 1; Fig. 7f). The spray zone shows characteristics similar to the other areas.

Discussion

In the Mersin Bay, the Phoronida worms and bivalve *B. pharaonis* have colonized in subtidal and intertidal areas where the environmental conditions are rough and semi-rough due to the process of wave breaking. The limpet *Patella* sp. concentrate in the intertidal zone and spray zone, attach to the gravel, fresh armourstone surface and other organism colonies.

In the clastic rocks; if the shallow marine organisms and their secretions develop to the under surface of the sandy level, they can create shear stress that can easily disintegrate the rocks (Young and Urguhart 1998). The Phoronida worms and bivalve *B. pharaonis* colonies have formed endolithes and gastrochaenolites, respectively, in the sandier matrix of the conglomerates of Viranşehir coast. These intense bioerosive activities cause the disintegration of loose sandy matrix resulting in the release of gravels. The released gravels are then transported to the shore by waves and form gravelly beach deposits without matrix (sieve deposits). In the meantime, the sand grains are carried to the area among the sets and open-sea areas. Dependent upon the removal of material, the organisms continue their actions on new exposed surfaces (Fig. 8).

The depth of the endolithes is dependent upon light compensation, thus the tubes can be destroyed by later

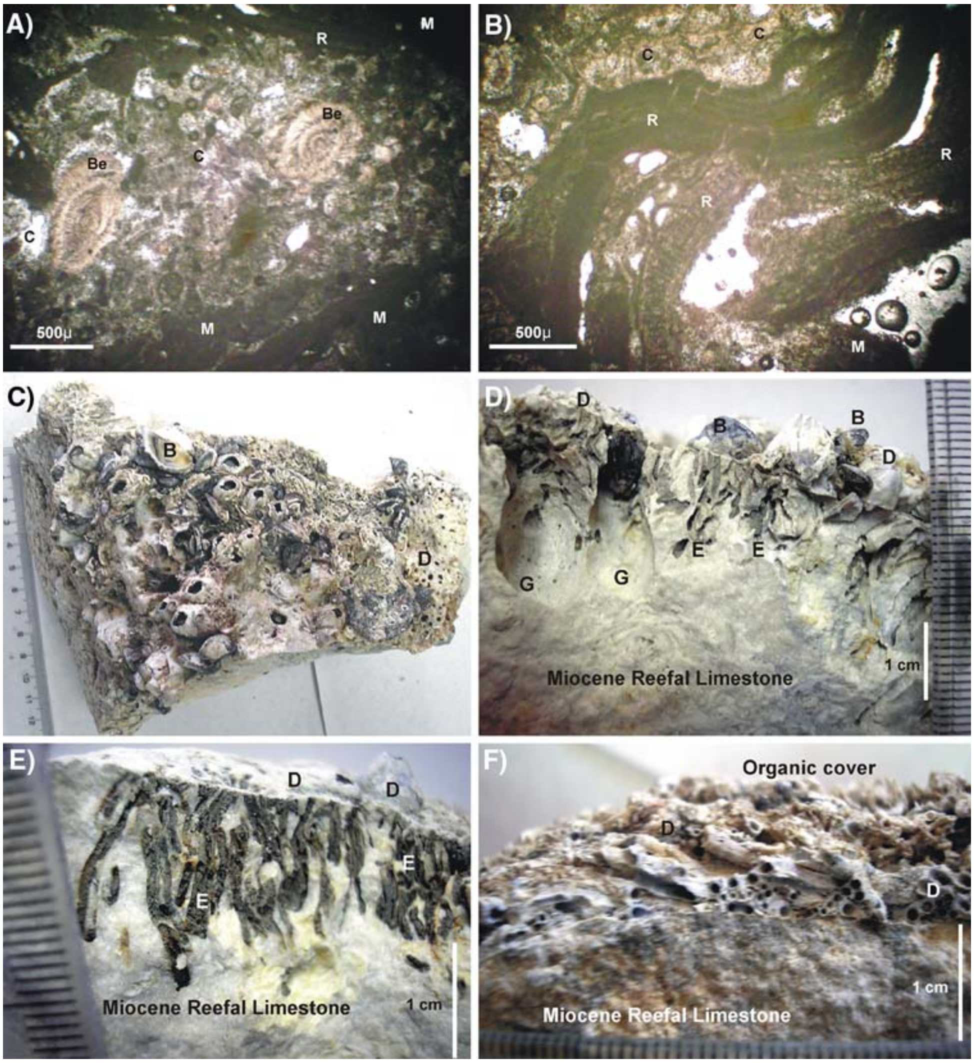

Fig. 7 **a** Microphotograph of the biomicrite-wackestone of Miocene reef limestone used as armourstone in the Mersin port. *Be*, benthic foraminifera; *R*, red algae; *M*, micrite; *C*, calcite. **b** Microphotograph of the biolithite-bindstone of Miocene reef limestone. *R*, red algae; *M*, micrite; *C*, calcite. **c** General view of the organism community in the subtidal zone. *D*, Phoronida worms; *B*, *B. pharaonis*. **d** Close view of bioerosive effects in samples from the subtidal zone. *D*, Phoronida worms; *B*, bivalve *B. pharaonis*, *G*, gastrochaenolites; *E*, endolithes. **e** Close view of endolithes (*E*) that formed by Phoronida worms (*D*) in the subtidal zone. **f** Phoronida worm (*D*) colonization within the intertidal zone

organic activities (Taylor and Wilson 2003). The depth of endolithes in the subtidal zone is higher than in other zones (Table 1). It reaches to depths of 35.0 mm in the Jurassic–Cretaceous limestones armourplate in Mersin port (Table 1). Their growth rate varies between 0.25 and 3.0 mm/year for the youngest armourstone (Mersin metropolitan municipality park). The life span of the Phoronida worms is 1 year (Emig and de Mittelwihr 1999). Thus, it can be expected that the number of endolithes will increase with time (Fig. 9). However, the depth of endolithes in older armourstone are very high and exceed the production expected in a year. Therefore, only reworking of the endolithes by subsequent Phoronida worms may cause this increased depth.

Wilson (2006) suggests that 3 cm long bivalves can form holes in the order of 2–15 mm/year in tropical areas.

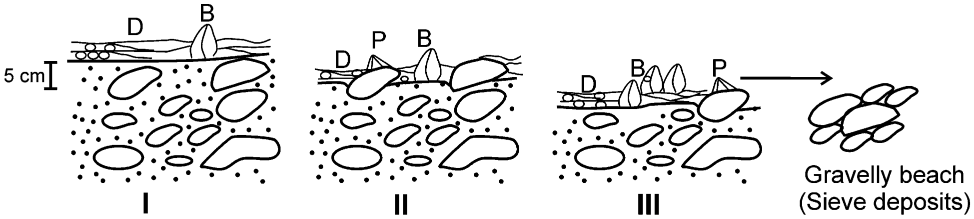

Fig. 8 Bioerosion development in conglomerates. Initially unweathered conglomerates (*I*) are bored and eroded by organisms (*II*). This process is followed by the sandier, loose matrix being completely disintegrated and transported through the open sea area, whilst released gravels are transported towards the shore to form gravelly beaches (*III*; sieve deposits). *D*, Phoronida worms; *B*, *B. pharaonis*; *P*, *Patella* sp.)

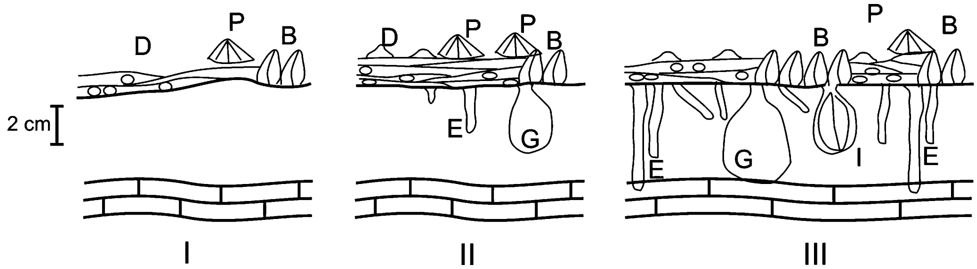

Fig. 9 Within the Mersin Bay, the limestone blocks used as armourstone have a different texture and age. Initially, unweathered limestone blocks (*I*) are disintegrated by endolithes (*E*) and gastrochaenolite (*G*) formation (*II*) under the effect of Phoronoids (*D*) and *Brachidontes pharaonis* (Fischer P. 1870) colonies (*B*), respectively. As this process advances, the number of holes increases, whilst some endolithes deepen (*III*). *P*, *Patella* sp.; *I*, ichnofossil)

Kleman (2001) emphasized that bivalve holes can reach up to 10 cm in depth. Within the youngest armourstone of the Mersin Bay there are 8.0–25.0 mm deep gastrochaenolites. Thus, their growth rate ranges between 2.0 and 6.3 mm/year within the range suggested by Wilson (2006). The maximum gastrochaenolites depth recorded is 44.0 mm within the Jurassic–Cretaceous limestone armourplate of the Mersin port (Table 2). Thus, the maximum gastrochaenolite depth should be limited to the activities of bivalve *B. pharaonis* during their life span. However, the number of gastrochaenolites is increasing with time.

Limpets (*Patella vulgata*) living on the high cliffs and wide shore platforms of the soft, fine-grained Upper Chalk in the coast of East Sussex (UK) caused on average 0.15 mm/year surface lowering, but this ratio increased to 0.49 mm/year where a high population was observed (Andrews and Williams 2000). The limestone in the study area is most probably stronger and more resistant to erosion than the chalk. Moreover, apparent grazing trails on the fine-grained chalk of East Sussex (Andrews and Williams 2000) were not observed in this study. Thus, the same surface lowering of the crystallized, resistant limestone of the study area must require a longer time than for the soft chalk. Therefore, the surface-lowering ratio of the study area can be estimated to be lower than an average 0.15 mm/year.

Trudgill and Viles (1998) pointed out that organic activities could limit the rock deterioration process. Despite variation in age and texture of the limestone, a maximum of 0–44.0 mm thick, biologically weathered sections were found within the oldest homogeneous armourstone plates in the Mersin port. The Phoronida worms that covered all the rock surfaces as a mat (0–31.0 mm thick), from subtidal to intertidal areas, formed hard ground (due to calcareous shell accumulation) on the armourplates. This hard ground may elude the deteriorating effect of the waves and prevent subsequent organism activity on the host rock and assist in the stability of the armourstone. It is observed that sometimes these armourplates have been broken during the operating activities and new, fresh rock surfaces exposed in the Mersin port. These new surfaces are immediately worked on by new shallow marine organisms.

Conclusion

The coastal areas of the Mersin coast have been shaped by both natural and man-made structures. Similar environmental conditions (temperature, salinity, light penetration, wave action) are observed in both natural clastic rocks and artifically transported carbonecaeous armourplates of various ages and textures. Thus, communities of the same organism have flourished on all rock types.

In the Mersin Bay, the Phoronida worms and bivalve *B. pharaonis* have colonized subtidal and intertidal areas where the environmental conditions are rough to semi-rough due to wave breaking processes. In contrast, the limpet *Patella* sp. concentrates within the intertidal and spray zones. Bioerosive activities of these organisms such as endolithes formation by Phoronida worms, gastrochaenolites by bivalve *B. pharaonis* and lesser grazing trails of limpet *Patella* sp. have completely destroyed the loose conglomerates and caused gravelly beach formation. In addition, they have also formed thick biologically weathered zones up to 44.0 mm depth within the limestone armourplates.

However, the weathering rate of the limestones has not threatened their stability, at least within a short time period (approximately 40 or 50 years). In contrast, the Phoronida worms and bivalve *B. pharaonis* cover the hard surface of the rocks as a 3 cm thick resistant mat, which protects the rocks from successive organism activities and wave actions, and may ultimately have a positive effect on the stability of the rock.

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