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General palaeontology, systematics and evolution (Palaeoichnology)

Determination of a Late Miocene rocky palaeoshore by bioerosion trace fossils from the Bozcaada Island, Çanakkale, Turkey

Détermination d'un paléorivage rocheux du Miocène supérieur par des traces fossiles de bio-érosion dans l'île de Bozcaada, Çanakkale, Turquie

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ABSTRACT

Bioerosion is a common process in hard substrates. This study introduces an example from the rocky palaeoshore cropping out at a sea cliff on the Bozcaada Island. It includes bioerosion trace fossils preserved in limestone boulders of the shallow marine and lacustrine Alcitepe Formation of Late Miocene age. The ichnotaxa include borings produced by duraphagous drillers (*Oichnus* isp.), phonorids (cf. *Conchotrema* isp.), clionid sponges (*Entobia* cf. *goniodes, Entobia geometrica, Entobia laquea, Entobia ovula, E.* cf. *solaris, Entobia* isp.), endolithic bivalves (*Gastrochaenolites torpedo, Gastrochaenolites lapidicus, Gastrochaenolites* isp., *Phrixichnus* isp.), polychaete annelids (*Maeandropolydora* isp., *Maeandropolydora sulcans, Maeandropolydora decipiens, Caulostrepsis taeniola, Caulostrepsis* isp.), echinoids (cf. *Circolites* isp.) and spinculid worms (cf. *Trypanites* isp.). Barnacles are also common as encrusters. The borings can be ascribed to the *Gastrochaenolites-Entobia* assemblage, which is typical of Neogene rocky-shores. They belong to the *Entobia* ichnofacies indicating various conditions of light, energy, and depth. Therefore they can reveal environmental changes and play an important role in forming palaeo-rocky shores and wave-cut platforms during marine trangressive events.

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RÉSUMÉ

La bio-érosion est un processus commun dans les substrats durs. L'étude présentée ici introduit un exemple de paléorivage rocheux affleurant au niveau d'une falaise marine sur l'île de Bozcaada. Il inclut des traces fossiles de bio-érosion conservées dans des blocs calcaires de la Formation Alçitepe lacustre et marine peu profonde, d'âge Miocène supérieur. Les ichnotaxa comportent des creusements provoqués par des organismes foreurs duriphages (*Oichnus* isp.), phonoriés (cf. *Conchotrema* isp.), éponges clionidées (*Entobia* cf. *goniodes, Entobia geometrica, Entobia laquea, Entobia ovula, E.* cf. *solaris, Entobia* isp.), bivalves endolithiques (*Gastrochaenolites torpedo, Gastrochaenolites lapidicus, Gastrochaenolites* isp., *Phrixichnus* isp.), annélides polychètes (*Maeandropolydora* isp., *Maeandropolydora sulcans, Maeandropolydora decipiens, Caulostrepsis taeniola, Caulostrepsis* isp.), échinoïdes (cf. *Circolites* isp.) et vers spinculidés (cf. *Trypanites* isp.). Les barnacles sont aussi des organismes encroûtants. Les creusements peuvent être attribués à l'assemblage *Gastrochaenolites-Entobia*, typique des rivages rocheux néogènes. Ils appartiennent à l'ichnofaciès *Entobia* indiquant

des conditions variées de lumière, d'énergie et de profondeur. C'est pourquoi, ils peuvent révéler des changements environnementaux et jouer un rôle important dans la formation de paléorivages rocheux et de plates-formes d'érosion marine au cours des évènements marins transgressifs.

1. Introduction

Bioerosion, designed by Neumann (1966) as an abbreviation of 'biological erosion', identifies every form of biological erosion of hard substrates, including lithic and woody substrates (Bromley, 1992). Organisms can erode hard substrates by mechanical or chemical means, resulting in the formation of scrape traces, borings and other biogenic structures. Encrustation is the behaviour by which organisms attach to hard substrates. Encrusting and boring organisms represent a community that changes with the substrate that sustains them (Hohman, 1993).

Rocky-shores, as hard surfaces exposed in shallow marine environments associated with null or low sedimentation, offer excellent conditions for colonization by marine bioeroding organisms (Cachão et al., 2008). These environments represent a unique marine sedimentary environment where wave-cut marine erosion platforms are formed. Therefore, the identification of rocky-shores in the geological record is very important, because they represent major flooding surfaces and provide us with crucial information about palaeoshorelines and sea level changes. Bioerosional structures play a major role in their recognition (Ghibaudo et al., 1996; Jia-Yu and Johnson, 1996; Martinell and Domènech, 1995; Santos et al., 2008).

Bioerosional evidence is also excellent for the study of the evaluation of marine communities in these types of environments (Johnson, 1992) since their remains are often preserved in situ, connected to the hard surface itself (Brett, 1988; Johnson, 1992; Taylor and Wilson, 2003). The case of ancient marine hard substrate communities has been described from the Lower Cambrian (e.g. Kobluk, 1981a, b; Kobluk and James, 1979; Kobluk et al., 1978) to the Neogene (e.g. Bromley and Asgaard, 1993a, b; Bromley and D'Alessandro, 1987; Domènech et al., 2001; Gibert et al., 1998; Martinell and Domènech, 1995; Radwański, 1970; Watkins, 1990).

Although bioerosional structures are very important in revealing the effects of biological factors on coastal morphology, there are very few publications on bioerosion in Turkey. The first paper related to bioerosion in Turkey, 'Neogene borings from rocky-shore', is Uchman et al. (2002), who explained the relative sea level changes recorded in borings from a Miocene rocky-shore of the Mut Basin, southern Turkey. The present study uses bioerosional structures to contribute to the interpretation of palaeoenvironmental conditions in the rocky-shore of the Late Miocene depositional sequence of the Alcitepe Formation. It firstly focuses on the identification and the description of bioerosion structures with their tracemakers and then analyses the borings in terms of their substrate nature.

2. Geological setting

The studied rocks of the Alcitepe Formation are located along the southwestern coast of Bozcaada Island (Fig. 1A–C), on the southern edge of the Thracian Basin (e.g. Göncüoglu, 2010). Previous palaeontological and sedimentological studies on the Neogene deposits of the island are quite limited (e.g. Çağatay et al., 2006; Druit, 1961; Kesgin and Varol, 2003; Önem, 1974; Sakınç et al., 1999; Siyako et al., 1989; Temel and Çiftçi, 2002). These Neogene sediments are composed of various coeval lithofacies with lateral and vertical transitions (Dermitzakıs and Papanikolaou, 1981; Sakınç and Yaltırak, 1997; Sakınç et al., 1999; Yaltırak, 1996; Yaltırak and Alpar, 2002; Yaltırak et al., 1998, 2000).

Regarding previous studies, the lowermost unit in the generalized stratigraphical section (Fig. 2) is represented by the Eocene-Oligocene Ayvacik Volcanics, mainly comprising andesitic lavas and pyroclasts. Pillow lavas at some localities characterize quiescent submarine volcanic activity. The Ayvacik Volcanics are disconformably overlain by the Gazhanedere Formation, which is characterized by mudstone and conglomeratic sandstone (Middle Miocene–Lower Pliocene), representing a fluvial and lagoonal environment. On top of the Gazhanedere Formation, with lateral and vertical transitions, rests the Kirazli Formation. This consists of massive and semi-consolidated sandstone representing beach and back-beach lithofacies of the Late Miocene (Sakınç et al., 1999). Both formations are overlain by the Alcitepe Formation (Late Miocene) with lateral and vertical transitions. This formation consists of bioclastic and oolitic limestone with basal clastic rocks, and contains molluscan and ostracod faunas in the western outcrops. These faunas indicate deposition in shallow, brackish to fresh water environments. On the other hand, previous studies (Çağatay et al., 2006) on faunal and palaeomagnetic analyses of the Alcitepe Formation in other parts of the Aegean Sea show that the formation represents chron C3r (6.04–5.24 Ma). The ostracod analysis also indicates that during the deposition of the Alcitepe Formation salinity increased from brackish in the lower part to more saline conditions in the upper part (Çağatay et al., 2006).

In the study area, a non-depositional and denudational period continued until the Pleistocene. During the transgression in the Middle-Late Pleistocene (Yaltırak et al., 2002), the valleys and broad coastal plains were affected by warm sea conditions. The terrace deposits formed during this transgression include conglomerates and sandstones, which are rich in *Ostrea edulis* shells (Sakınç et al., 1999; Yaltırak, 1996; Yaltırak et al., 2002). In general, they overlie the Miocene rocks with an angular unconformity in this area.

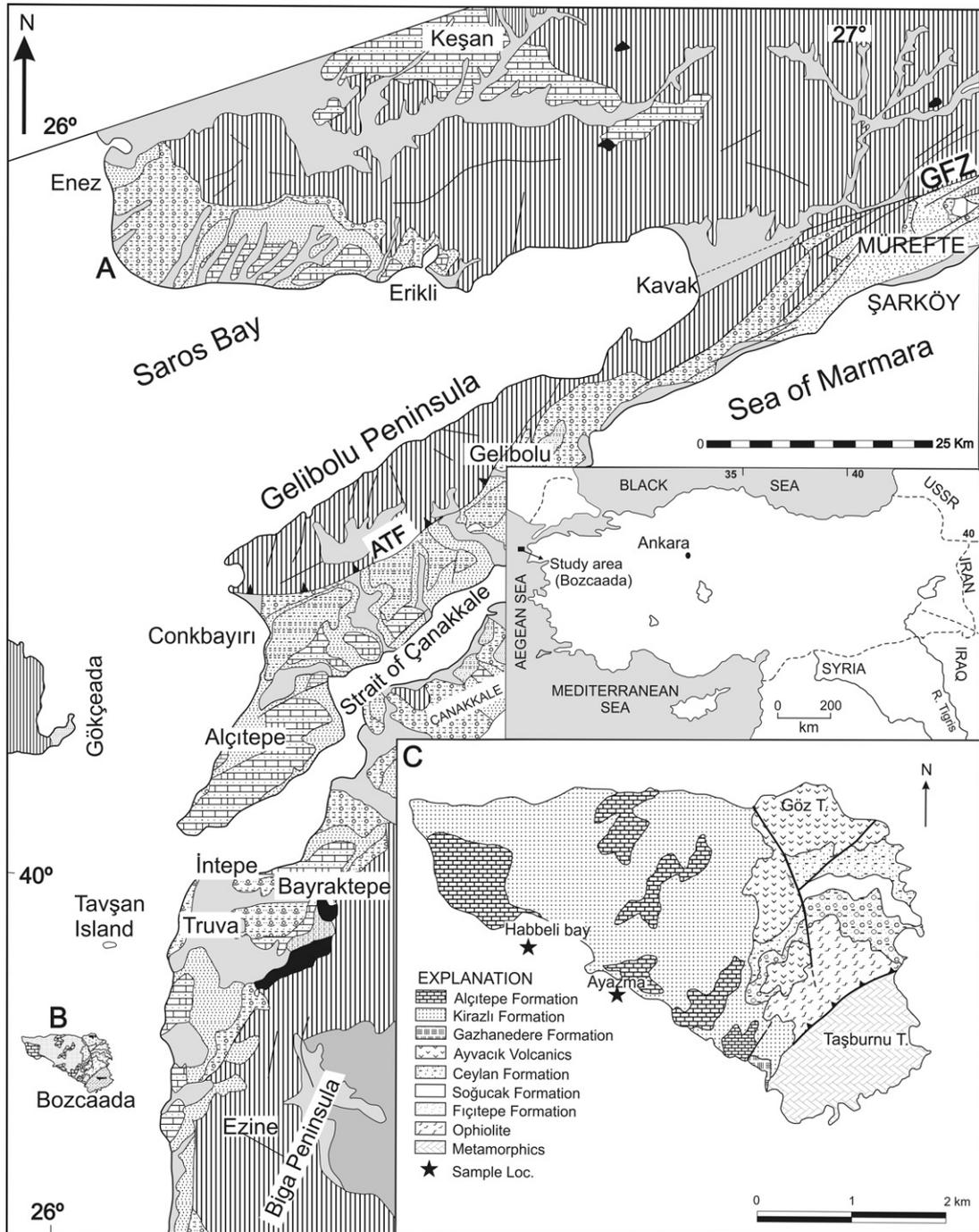The borings described in this article occur within the Alcitepe Formation.

Fig. 1. A, B. Geological map of the northeastern Aegean region (modified from Sakınç and Yaltırak, 2005). C. Close up view of the study area (modified from Temel and Çiftçi, 2002).
Fig. 1. A, B. Carte géologique de la région égéenne nord-orientale (modifié selon Sakınç et Yaltirak, 2005). C. Encart montrant la zone d'étude (modifié selon Temel et Çiftçi, 2002).

3. Description of the locality

The Alcitepe Formation is quite extensive in Bozcaada Island and shows up as elevations and hills due to its physical features (e.g. erosion-resistence). The formation shows different characteristics from place to place. For instance, along the northern coast of the Gulf of Saros, the formation consists of *Mactra*-bearing bioclastic and cross-bedded limestones, interbedded with *Cardium*-bearing sandstones and *Ostrea* banks. These sediments indicate fluctuations in salinity from brackish water to normal marine conditions. In the Gelibolu and Biga peninsulas the formation consists

AGE	LITHOLOGY AND FORMATION	EXPLANATION
QUATERNARY		Mud, clay with marine shells, laterally passing to alluvial deposits
LATE PLIOCENE	3.4-3.7 My	Erosional period (starting of the North Anatolian Fault)
MIDDLE MIOCENE LOWER PLIOCENE	ALÇITEPE FM	Limestone-mud intercalations bivalve and gastropoda (lacustrine and shallow marine environments)
	KİRAZLI FM GAZHANEDERE FM	Massive sandstone bivalve and gastropoda (beach and back-beach environments)
EOCENE OLIGOCENE	AYVACIK	Sandstone-shale Mainly andezidic lava and pyroclastics (not to scale)

Fig. 2. Generalized measured section of the study area (modified from Sakınç and Yaltırak, 2005).
Fig. 2. Section générale de la zone étudiée (modifié selon Sakinç et Yaltirak, 2005).

of mudstone and marl in the lower part, and bioclastic and oolitic limestones with marl, mudstone, and sandstone intercalations in the upper part (Çağatay et al., 2006).

The best exposure of the Alcitepe Formation in the studied area is located along Habbeli Bay in the southwestern part of the island (Fig. 1C), between N 39° 49′ 107; E 025° 59′ 026 and N 39° 49′ 2877; E 025° 59′ 369, along the cliff of Ayazma beach in Habbeli Bay, and southeast of the few inland localities which are represented by carbonate and siliciclastic units (Figs. 3 and 4).

At Habbeli Bay, the Alcitepe Formation is approximately 30 metres thick and rests on the Kirazli Formation. The formation starts with *Mactra*-bearing, beige-grey coloured, medium-bedded, pebbly to coarse-grained sandy limestone, and continues with conglomerates alternating with sandstones, succeeded by marls (18 cm thickness) in the study area. The marls of the formation contain a brackish water fauna with *Mactra* shells (Fig. 5).

Towards the top of the section, *Ostrea*- and *Pecten*- bearing calcareous marine sandstones occur. Directly on top of this level is a 70-cm thick coquin composed of bivalve and gastropods shells, which can be traced as a marker. The bivalves are almost completely dissolved with only their moulds remaining. The unit continues as whitish grey coloured, thin-medium layered limestone, sandy limestone and mudstone towards the top.

Oolitic limestone can be observed in some localities, as can large- scaled tabular cross stratification (Fig. 6) and lightly cemented spherical sand clumps. The presence of large-scaled cross stratification and widespread ooids

Fig. 3. Wave-cut platform produced by wave erosion in the Alcitepe Formation (Habbeli Bay).
Fig. 3. Plate-forme d'érosion marine produite par l'érosion des vagues dans la Formation Alçitepe (Baie d'Habbeli).

Fig. 4. General view of the Alcitepe Formation (Habbeli Bay).
Fig. 4. Vue générale de la formation Alçitepe (Baie d'Habbeli).

Fig. 5. *Mactra* shells in the grey coloured marls at Alcitepe Formation (Bozcaada Island, Turkey).
Fig. 5. Coquilles de Mactra dans les marnes grises de la Formation Alçitepe (île de Bozcaada, Turquie).

Fig. 6. Shallow marine-shore face cross lamination, Alcitepe Formation.
Fig. 6. Stratification entrecroisée sur une face de rivage marin peu profond, Formation Alçitepe.

indicates high-energy levels with agitated shallow marine or lacustrine deposition progressing towards the open sea.

Towards the top of the section, *Ostrea*- and *Pecten*-bearing calcareous marine sandstone occurs. The uppermost part of the formation is made up of an alternation of *Mactra*-bearing limestones and sandstones containing *Ostrea*, followed by another alternation of *Mactra*- and *Ostrea*-bearing limestones. The presence of *Ostrea* the upper part of the Alcitepe Formation indicates normal marine depositional conditions.

The section from the middle to top of the succession is rich in fossils, represented by bivalves (Fig. 7: 1–9; 12), some echinoids (Fig. 7: 10, 11) and gastropods (Fig. 7: 13, 14). Bivalves produce *Gastrochaenolites torpedo* (Fig. 8), and *Gastrochaenolites lapidicus* is produced by some bivalves of the genera *Lithophaga*. They all are observed on a heavily karstified and brecciated Miocene carbonate hard-substrate bioeroded surface, on limestone boulders and cobbles.

In the study area, the most conspicuous trace fossil is *Gastrochaenolites*, which was produced by bivalve bioerosion preserved in epirelief and hyporelief (*G. torpedo* and *G. lapidicus*), and on the boulder surfaces (Fig. 9a, b). *Gastrochaenolites lapidicus* casts (Fig. 10) and clavate borings *Phryxichnus*-like *Gastrochaenolites* have also been recognized. These borings are perpendicular to the surface, are truncated, and some include the trace-producing organisms (Fig. 11).

Entobia is the second dominant trace fossil that is mostly observed from penetrating outer and inner parts of shells and boulders. In some cases, it is mostly seen together with *Gastrochaenolites*. The polychaete annelid borings *Caulostrepsis* and *Maeandropolydora* are observed occasionally. *Trypanites* was identified in the substrate from the walls of *G. torpedo*. Also, some skeletons of encrusting worms were frequently observed.

4. Relationship between substrate and borings

The bioerosional structures in the study area occur together with fossil assemblages including bivalves, gastropods, echinoids and also remains of encrusting organisms. Their traces are widely distributed within carbonate boulders, and shells of ostreids, and were formed by the activities of macrobioeroders. The borings are preserved in concave hyporelief and epirelief morphology, and display intense biogenic activity with abundant skeletal remains of endo and epilithic organisms. Most of the borings are common on the upper parts or the lateral surfaces of the boulders. They are perpendicular to the surface and are proximally truncated. The outer parts of the borings have been destroyed by the marine erosion. Their ethological categories, tracemaker interpretations and the relationship between the substrates and borings in the study area are summarized in Table 1.

5. Taxonomic description

The Late Miocene rocky-shore of the studied area is intensively affected by bioerosion. Bioerosional structures are widely distributed on the tops of the limestone boulders
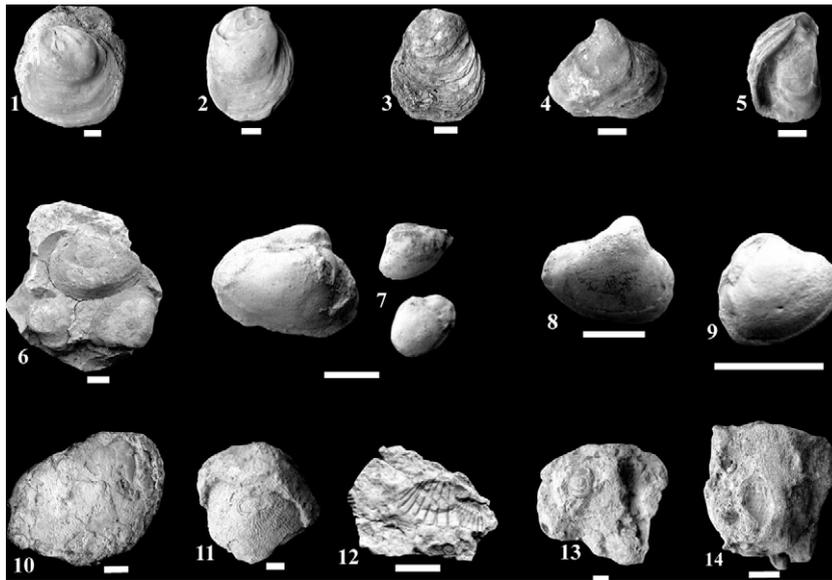
Fig. 7. Well-preserved marine macrofossils at Alcitepe Formation (Scale: 1 cm).
Fig. 7. Macrofossiles marins bien conservés de la Formation Alçitepe (échelle = 1 cm).

and on shells. The most common bioerosional traces belong to macrobioeroders, e.g., phoronids (*Conchotrema*), polychaete worms (*Caulostrepsis*, *Maeandropolydora*), clionid sponges (*Entobia*), and boring bivalves (*Gastrochaenolites*).

Nine ichnogenera have been recognized. Taxonomic description is prepared according to their ethology and morphology distinguished by Bromley (1992), Ekdale et al. (1984), Martinell (1989), and recently, Taylor and Wilson (2002). All material figured in this article is housed in the Natural History Museum, General Directorate of Mineral

Research and Exploration, MTA Ankara, Turkey (B1. 09).

Conchotrema Teichert, 1945
cf. *Conchotrema* isp. (Plate 1, Fig. A)
Description: A system of straight to slightly curved branched grooves. The grooves are 1.5–2, 0.1–0.25 mm in wide. The surfaces of the boulders were cut by their dense scrapings and they cross each other.
Remarks: Generally, these are subsurface borings, which have been exposed at the surface by erosion.

Table 1
Relationship between substrate and borings, identified at the Habbeli Bay/Ayazma beach (LB: Limestone Boulders; S: Shell).
Tableau 1
Relation entre substrat et creusements, déterminée sur l'exemple de la baie d'Habbeli/plage d'Ayazma (LB : blocs calcaires ; S : coquille).

| Ichnotaxon	Tracemaker	Substrate	Ethological category
cf. *Conchotrema* isp.	Endolithic *phoronid*	LB	Domichnia
Caulostrepsis isp.	*Polychaete*	LB/S	Domichnia
C. taeniola	*Polychaete*	LB/S	Domichnia
Circolites isp.	*Echinoid*	LB	Domichnia
Maeandropolydora isp.	*Polychaete*	LB/S	Domichnia
M. sulcans	*Polychaete*	LB/S	Domichnia
M. decipiens	*Polychaete*	LB/S	Domichnia
Entobia isp.	*Clionid sponge*	LB/S	Domichnia
E. geometrica	*Clionid sponge*	LB	Domichnia
E. cf. *gonioides*	*Cliona viridis*	LB	Domichnia
E. laquea	*Cliona*	LB	Domichnia
E. ovula	*Cliona*	LB	Domichnia
E. cf. *solaris*	*Cliona*	LB	Domichnia
Gastrochaenolites isp.	*Bivalve*	LB/S	Domichnia
G. lapidicus	*Lithophaga*	LB/S	Domichnia
G. torpedo	*Lithophaga & Gastrochaena*	LB/S	Domichnia
Phrixichnus isp.	–	LB	Domichnia
Oichnus isp.	Carnivorous gastropods & Cephalopods	S	Praedichnia
Trypanites cf.	*Spinculids*		Domichnia
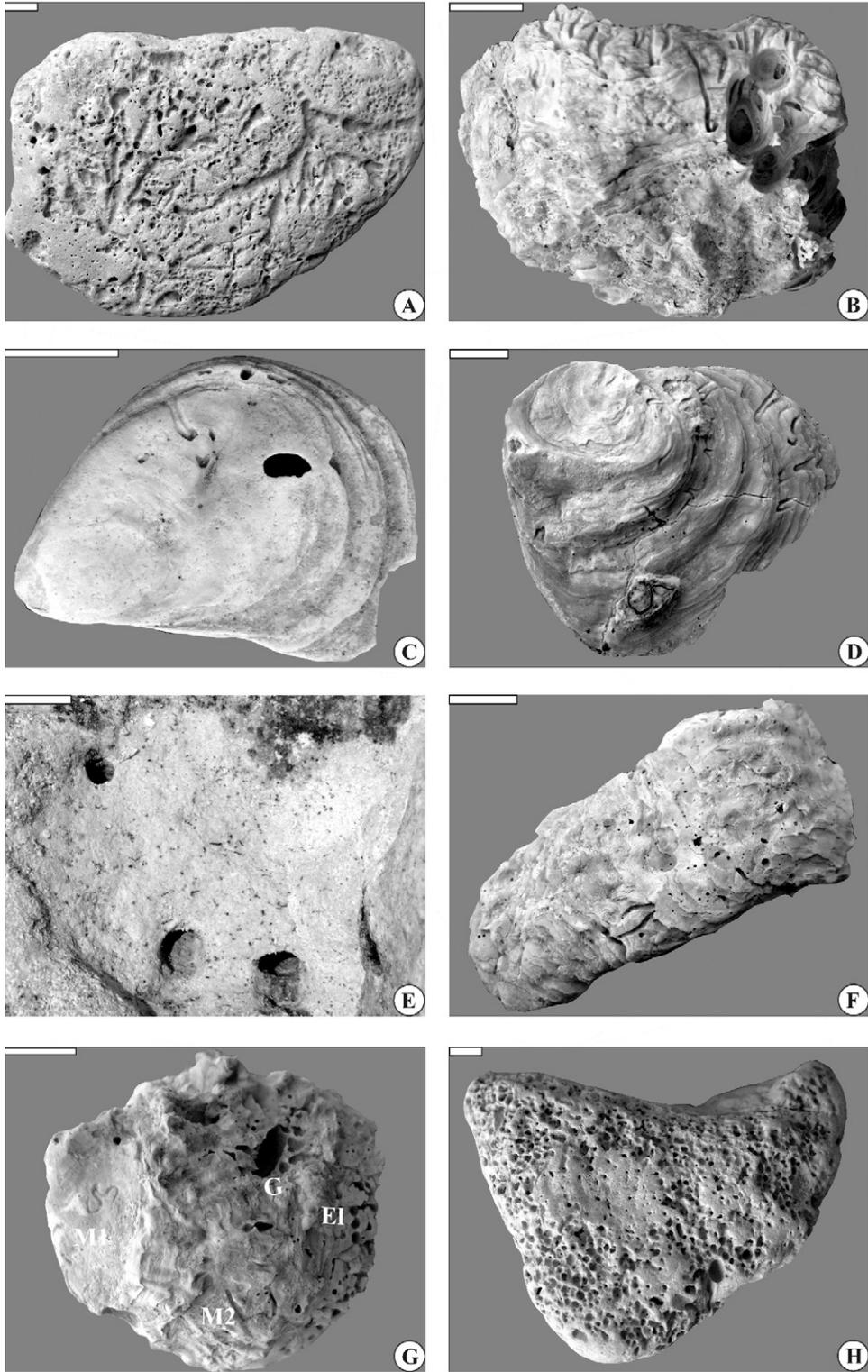
Plate 1.

Fig. 8. Plan view of *Gastrochaenolites torpedo*.
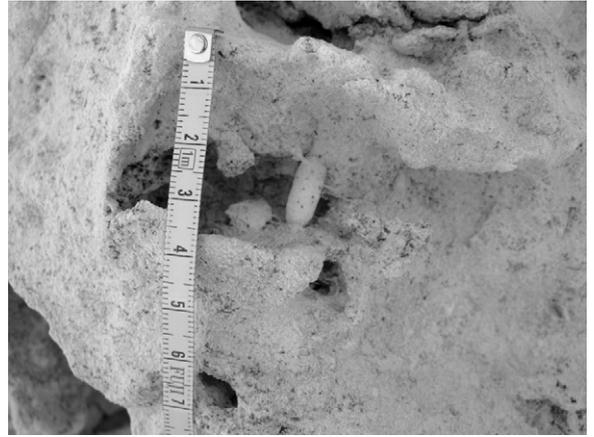**Fig. 8.** Vue de *Gastrochaenolites torpedo*.

Fig. 10. Casts of *Gastrochaenolites lapidicus*.
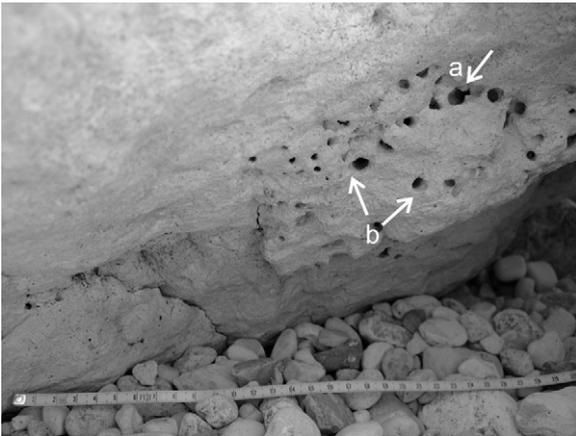**Fig. 10.** Moulages de *Gastrochaenolites lapidieus*.

Fig. 9. View of Gastrochaenolites torpedo (a), Gastrochaenolites lapidicus (b).
Fig. 9. Vue de Gastrochaenolites torpedo (a) et de Gastrochaenolites lapidieus (b).
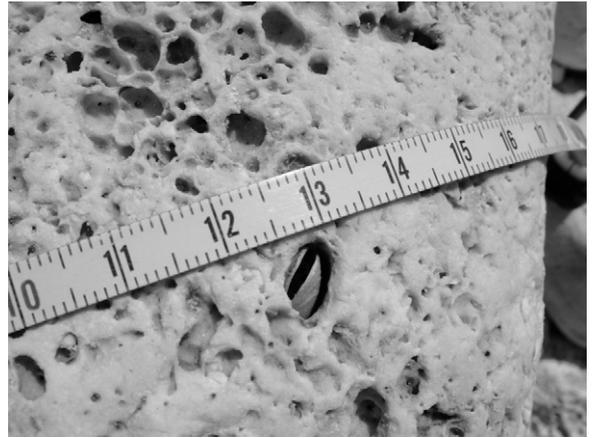

Fig. 11. *Gastrochaenolites* with its producer inside.
Fig. 11. *Gastrochaenolites* avec l'organisme à l'intérieur du trou.

Voigt (1975) suggested that *Conchotrema* is produced by endolithic phoronids.

Caulostrepsis Clarke, 1908
Caulostrepsis isp. (Plate 1, Fig. B)
Description: *Caulostrepsis* is a pouch-shaped boring resembling a very tight U-gallery with limbs. The limbs merge towards the aperture. The aperture is 1 mm in diameter.

Remarks: Bromley and D'Alessandro (1983) revised the systematics of this ichnotaxon and recognized several ichnospecies. It is produced by polychaetes (Radwański, 1969).

Caulostrepsis taeniola Clarke, 1908
(Plate 1, Fig. C, D)
Description: This is a smooth, elongate and narrow U-shaped gallery with distinct limbs and an interconnecting vane. The trace fossils range from 5 mm long, 0.5 mm wide (Fig. C), to 7 mm long, 0.8 mm in wide (Fig. D).

Remarks: This trace is seen on the exterior surfaces of *Ostrea* shells. *Caulostrepsis* is mainly considered to be produced by the polychaetes of the genus *Polydora* (Radwański, 1969).

Caulostrepsis occurs in shallow water environments, e.g., *Caulostrepsis cretacea* Voigt, 1971 was found between 7 and 15 m water depth (Wisshak et al., 2005).

Circolites Mikuláš, 1992
cf. Circolites isp. (Plate 1, Fig. E)
Description: *Circolites* is a subcircular, bowl-shaped boring 3 to 4.5 cm in diameter.

Remarks: This boring is interpreted as a dwelling structure of regular echinoids (Warme, 1975), and is always restricted to very shallow waters.

Maeandropolydora Voigt, 1965
Maeandropolydora isp. (Plate 1, Fig. F)

Description: *Maeandropolydora* occurs as long, shallow and sinuous borings on boulders and shells that extend like 'U'-shaped pouches in the study area. It is 0.2 mm in diameter.

Remarks: This boring is produced by polychaetes of various families (Bromley and D'Alessandro, 1983).

Maeandropolydora sulcans Voigt, 1965
(Plate 1, Fig. G)

Description: *M. sulcans* is a sinuous, cylindrical boring found in *Ostrea* shells in the study area small in diameter (0.5 mm) and with a narrow vane.

Remarks: It is usually attributed to annelid worms (Bromley and D'Alessandro, 1983). *M. sulcans* is commonly preserved in semirelief on rock or shell surfaces as a result of the erosion of very shallow borings.

Maeandropolydora decipiens Voigt, 1965
(Plate 1, Fig. G)

Description: A single specimen is preserved on a small fragment of an oyster shell and comprises a sinuous, looped and continuous, smooth, unbranched, internally structure-less gallery that parallels but clearly penetrates the shell surface. The looped limbs do not touch or intersect and the intervening oyster shell material is unaffected. Diameter of the gallery, relatively constant at both levels, is approximately 0.5 mm.

Remarks: Though incomplete, the specimen can clearly be assigned to the ichnotaxon *Maeandropolydora*, discussed in detail by Bromley and D'Alessandro (1983). *Maeandropolydora* is interpreted as the domichnion of suspension-feeding polychaete annelids (Bromley, 1994).

Entobia Bronn, 1837
Entobia isp. (Plate 1, Fig. H)

Description: This boring shows camerate morphology and consists of networks of chambers in planar arrangement. The shapes of chambers are from subrounded to subrectangular. The chambers are 3 mm wide.

Remarks: Entobian borings are produced by endolithic sponges. Such borings can be made by several species of *Cliona* (Bromley and D'Alessandro, 1989).

Entobia cf. *goniodes* Bromley and Asgaard, 1993a
(Plate 2, Figs. A, B)

Description: This boring is observed as a system of small and camerate to nodular chambers. The chambers are 1–1.5 mm in diameter.

Remarks: *E. goniodes* is produced today by *Cliona viridis* and rarely *Cliona schmidti* in the photic zone of the Mediterranean Sea. *C. viridis* is found at the 20 m water depth (Bromley and Asgaard, 1993a).

Entobia laquea Bromley and D'Alessandro, 1984
(Plate 2, Figs. C, D)

Description: This bioerosional structure is composed of a system of tunnels and chambers in well-developed growth stages A and C sensu Bromley and D'Alessandro (1984). It is seen here as growth stage C and is represented by irregular, oval, elongate to subangular chambers, 1.5–2 mm in diameter.

Remarks: This ichnospecies covers the surface of boulders. *Entobia laquea* is produced by sponges of the genus *Cliona* in the photic zone of the Mediterranean Sea at the present day (Bromley and Asgaard, 1993a).

Entobia ovula Bromley and D'Alessandro, 1984
(Plate 2, Fig. E)

Description: This trace fossil is preserved in the A to C growth stages exposed on the surface of the boulders. The structures of stage A occur as a narrow tunnel system, with tunnels less than 1 mm in diameter. The structures of stage B are composed of curved rows of elongate chambers that are 2 mm in wide. Stage C is developed as oval, closely spaced chambers, which are 3 mm wide.

Remarks: The ichnogenus *Entobia* is produced mostly by sponges of the genus *Cliona*. Its taxonomy was discussed by Bromley and D'Alessandro (1984). *Entobia ovula* is produced in the Mediterranean today by *C. schmidti*, *Cliona vermifera* or *Cliona vastifica* (Bromley and Asgaard, 1993a).

Entobia cf. *solaris* Mikuláš, 1992
(Plate 2, Fig. F)

Description: This boring is preserved as an irregularly hemispherical depression. It also has straight radiating tunnels. The tunnels are about 1 mm in width.

Remarks: *Entobia solaris* has been described from the Late Cretaceous of the Czech Republic (Mikuláš, 1992). These borings are produced by sponges.

Entobia geometrica Bromley and D'Alessandro, 1984
(Plate 2, Figs. G, H)

Description: This is a camerate ichnospecies. Apertures are of two distinct size groups. The larger apertures are circular and 4–5 mm in diameter, the smaller are between 1 mm and 2 mm in diameter.

Remarks: *E. geometrica* differs from *E. cretacea* in several respects (Bromley and D'Alessandro, 1984). The apertures of *E. geometrica* are larger and the chambers to a greater extent leave thinner dividing walls than *E. cretacea* in which the chambers are normally connected by single intercameral canals.

Gastrochaenolites Leymerie, 1842
Gastrochaenolites isp. (Plate 3, Fig. A)

Description: *Gastrochaenolites* is a flask-shaped boring with a narrow aperture and larger, round, elongate, straight, ovoid chambers. It is preserved as large, elongate, straight openings, steeply inclined to the host substrate. Lengths are up to 49 mm and a single observed opening is 5 mm in wide.

Remarks: This ichnogenus is produced by boring bivalves (Kelly and Bromley, 1984) such as Pholadidae, Gastrochaenidae, and Mytilidae (Fisher, 1990a, b; Warme, 1975).
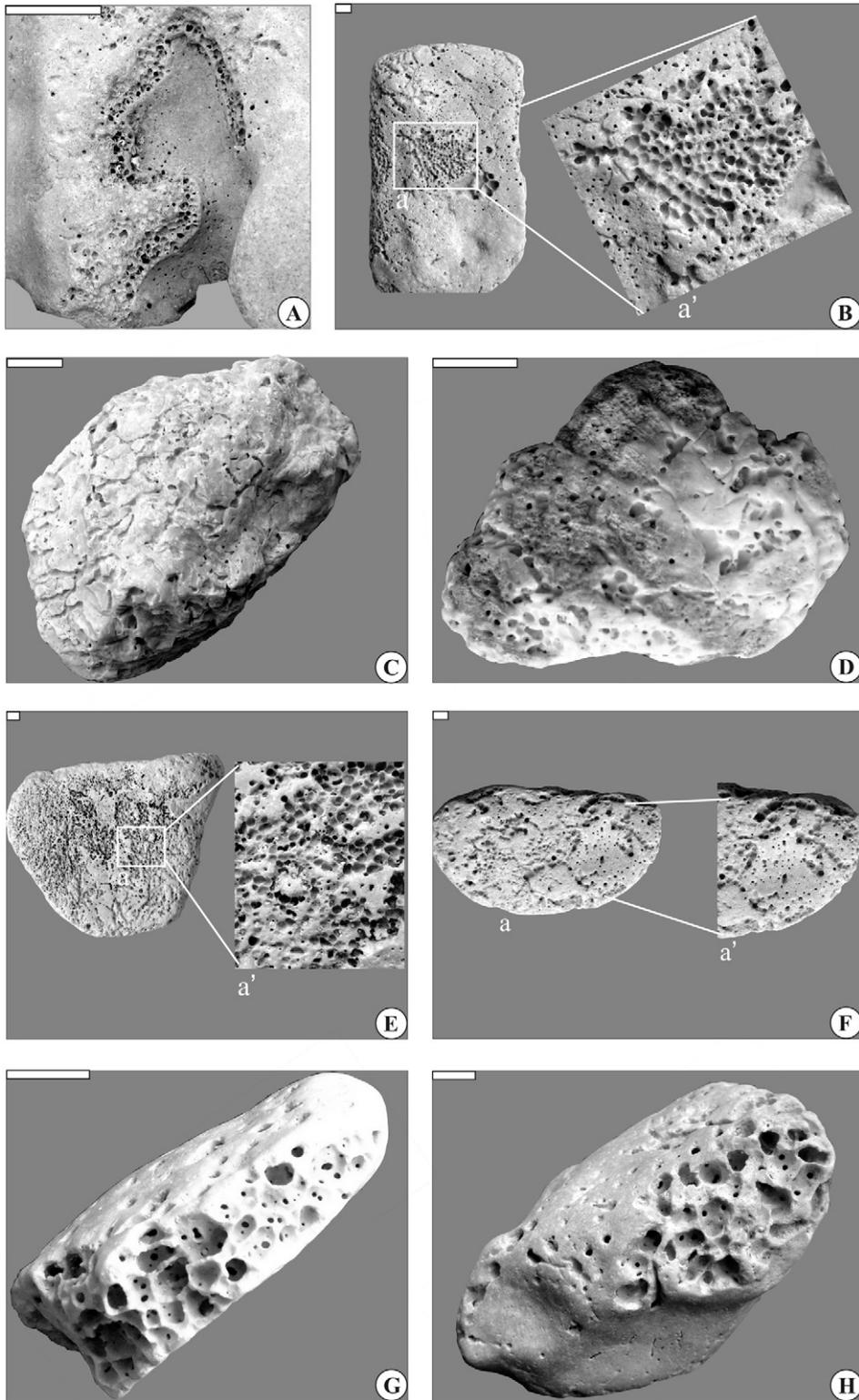
Plate 2. Field photographs of inferred clionid sponge borings from the Alcitepe limestone boulders and shells (All scales: 1 cm). **A.** *Entobia* cf. *goniodes*. **B.** *Entobia goniodes*. **C.** *Entobia laquea*. **D.** *Entobia laquea*. **E.** *Entobia ovula*. **F.** *Entobia* cf. *solaris*. **G.** *Entobia geometrica*. **H.** *Entobia geometrica*.

Planche 2. Photos sur le terrain de creusements supposés d'éponge clionidée, dans des blocs et coquilles calcaires de la Formation Alçitepe (toutes échelles = 1 cm). **A.** *Entobia* cf. *goniodes*. **B.** *Entobia goniodes*. **C.** *Entobia laquea*. **D.** *Entobia laquea*. **E.** *Entobia ovula*. **F.** *Entobia* cf. *solaris*. **G.** *Entobia geometrica*. **H.** *Entobia geometrica*.

Gastrochaeonolites lapidicus Kelly and Bromley, 1984
(Plate 3, Fig. B)

Description: *G. lapidicus* displays a rounded bottom. It is a smooth ovate chamber with an apertural neck and is circular throughout cross-section. The neck is also circular in cross-section or elliptical. The boring nearly 6 mm in diameter.

Remarks: This type of boring is produced by some bivalves of the genus *Lithophaga* (Kelly and Bromley, 1984).

Gastrochaenolites torpedo Kelly and Bromley, 1984
(Plate 3, Figs. C, D)

Description: This is a smooth, strongly elongate chamber, 49 mm long, up to 17 mm in depth and 8–16 mm in diameter (Fig. C).

Remarks: *G. torpedo* may show a calcite lining (Jones and Pemberton, 1988) which is not observed in the studied material. This type of borings is produced by some bivalves of the genus *Lithophaga* and *Gastrochaena* (Kelly and Bromley, 1984), and in the Mediterranean region by *Lithophaga lithophaga* (Linnaeus). *G. torpedo* has been reported from Miocene rocky-shores of many regions in Europe and neighbouring areas (Radwański, 1969).

Phrixichnus Bromley and Asgaard, 1993a
Phrixichnus isp. (Plate 3, Fig. E)

Description: This is a smooth, strongly elongated clavate chamber. The chamber is 24 mm long and 13 mm in diameter. Its clavate shape is clearly seen.

Remarks: A clavate, *Gastrochaenolites*- like boring but exhibiting a very particular ornamentation on the walls consisting of arcuate or concentric grooves in two gently concave or flat areas that meet along one edge of the boring.

Phrixichnus was previously recorded in the Pleistocene of Rhodes (Bromley and Asgaard, 1993a). It was also recognized on the Middle Miocene rocky-shores of Catalonia, Spain (Domènech et al., 2001).

Oichnus Bromley, 1981
Oichnus isp. (Plate 3, Figs. F, G, H)

Description: Smooth, vertical, circular to subcircular holes with axes oriented perpendicular to host substrates (gastropods and bivalves), completely or incompletely penetrative. Diameters range from 1.5–2 mm.

Remarks: *Oichnus* are generally interpreted as praedichnia of the gastropod families Naticidae and Muricidae respectively (Bromley, 1981; Pickerill and Donovan., 1998).

Trypanites Mägdefrau, 1932
cf. Trypanites isp. (Plate 3, Fig. D)

Description: *Trypanites* is a simple, vertically to obliquely oriented boring that can curve slightly and have rounded terminations. The boring extends into the substrate from the walls of *G. torpedo* and is 1 mm diameter and up to 7 mm in length.

Remarks: *Trypanites* is generally considered to have been produced by sipunculid worms (Bromley, 1992; Pemberton et al., 1980). This trace occurs in marine carbonate deposits, including firm- to hardgrounds, pebbles and skeletal substrates (Bromley and D'Alessandro, 1987).

6. Discussion

The Miocene succession in the northeastern Aegean region indicates the first Mediterranean marine transgression affecting these areas. Frequent marine flooding occurred during the Late Miocene in the northeastern Aegean region. This period in the study area is represented by brackish to fresh water carbonates with some marine sandstone-siltstone interbeds of the Alcitepe Formation, with endolithic bivalves, endolithic clionid sponges, echinoids, polychaetes, annelids and ostracods.

Nineteen ichnotaxa producing bioerosional structures are identified in this environment: *G. torpedo, G. lapidicus, Gastrochaenolites* isp., *Phrixichnus* isp., *E. goniodes, E. geometrica, E. laquea, E. ovula, E. solaris, Entobia* isp., *Maeandropolydora* isp., *M. sulcans, M. decipiens, Caulostrepsis taeniola, Caulostrepsis* isp., cf. *Circolites* isp., cf. *Trypanites* isp., cf. *Conchotrema* isp., cf. *Oichnus* isp..

The foremost trace fossil in the studied area is *Gastrochaenolites*, which is a typical hardground colonizer. Two ichnospecies of *Gastrochaenolites* have been identified on the basis of the shape of the distal part of the boring. *G. lapidicus*, which displays a rounded base, and *G. torpedo*, which is larger with a sharper base. Some of the borings contain the trace-producing organism in living position, and in some the proximal part of *Gastrochaenolites* is truncated by submarine erosion. *Phrixichnus* has also been observed for the first time. *Phrixichnus* is a clavate boring resembling *Gastrochaenolites*.

Entobia is the second most dominant ichnogenus in the studied material. Five ichnospecies are identified in the study area. It is frequently observed together with *Gastrochaenolites*. The inferred polychaete annelid borings, sipunculid worms, mollusc drill holes, and duraphagous scars are also present with *Gastrochaenolites* and *Entobia*.

The rocky-shore in the study area is covered with limestone boulders, which correspond to the bioeroded surfaces of wave-cut platforms. These result from cliff retreat, which is on relatively large sub-horizontal rocky surfaces. As a stratigraphic point of view, the above mentioned bioeroded rockground surfaces reflect hard substrate marine flooding surfaces (transgressive surfaces). The hardground surface shows well-developed macrobioerosional structures. According to previous workers (Santos et al., 2010) the hardground marine flooding surfaces (transgressive surfaces) are characterized by the presence of *Gastrochaenolites* borings, especially vertical *G. torpedo*.

Therefore, the rocky-shores at Bozcaada Island, including bioerosional structures with an abundance of the borings *Gastrochaenolites*, especially *G. torpedo*, can be interpreted as horizontal wave-cut platforms with low or no sedimentation. Moreover, the occurrences of this ichnogenus (*Gastrochaenolites*) characterize shallow water environments (Bromley, 1992; Bromley and Asgaard,
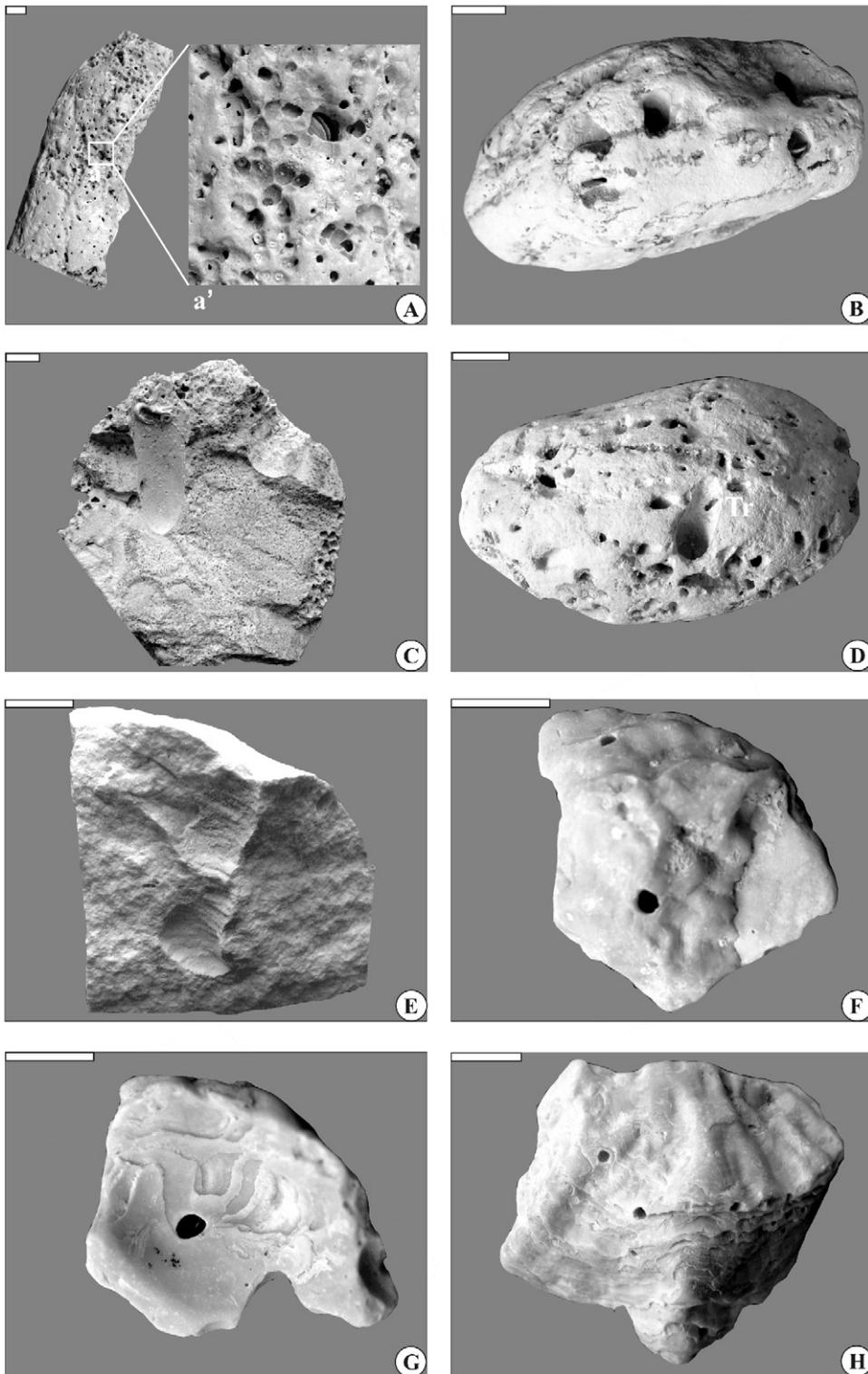
Plate 3. Images of inferred bivalve borings and drill holes-duraphagous scars from the Alçitepe limestone boulders and shells (All scales: 1 cm). **A.** *Gastrochaenolites* isp. **B.** *Gastrochaenolites lapidicus.* **C.** *Gastrochaenolites torpedo.* **D.** *Gastrochaenolites torpedo* with *Trypanites* isp. **E.** *Phrixichnus* isp. **F.** *Oichnus.* isp. **G.** *Oichnus* isp. **H.** *Oichnus* isp.

Planche 3. Images de trous et creusements supposés de bivalves-traces de duriphages dans des blocs et coquilles calcaires de la Formation d'Alçitepe (toutes échelles = 1 cm). **A.** *Gastrochaenolites* isp. **B.** *Gastrochaenolites lapidicus.* **C.** *Gastrochaenolites torpedo.* **D.** *Gastrochaenolites torpedo* with *Trypanites* isp. **E.** *Phrixichnus* isp. **F.** *Oichnus.* isp. **G.** *Oichnus* isp. **H.** *Oichnus* isp.

1993a, b), according to Bromley (1992), indicating only a few metres of water depth. Water depth is restricted to 1–2 m in the Neogene of the Mediterranean areas affected by *G. torpedo* (Kleemann, 1973). However, unpublished work has recently revealed that *Gastrochaenolites* may have occurred in several tens of meters water depth in the past. G.R. Bromley and U. Asgaard (personel communication) have observed *Gastrochaenolites* in ancient Greek marble statues from a Roman shipwreck at an approximate depth of 45 m. Also Danian *Gastrochaenolites* in Denmark seems to have inhabited deeper–water (Kleemann, 1973).

On the other hand, all endolithic organisms, especially *Entobia* borings (endolithic sponges), require low rates of sedimentation. In this context, the studied ichnoassemblage suggests a rocky-shore with a low rate of sedimentation. In addition, low sedimentation or non-deposition are revealed by bioeroded hardgrounds (Cachão et al., 2008). The bioeroded surfaces, recognized in the field on the wave-cut platform, being hardground transgressive marine flooding surfaces, are characterized by *Gastrochaenolites* borings. The assemblages found on wave-cut platforms are composites resulting from the overprinting of successive ichnocenoses that could replace each other during a transgression. As the transgression progressed and the substrate was exposed to deeper conditions, an initial bivalve-dominated community was progressively replaced by a sponge-dominated community.

7. Conclusions

1. The study of the Late Miocene rocky-shore in the Habbeli Bay area (western part of Bozcaada Island) in the Alcitepe Formation revealed an assemblage consisting of the following 19 ichnotaxa: *Oichnus* isp., cf. *Conchotrema*, *Circolites* isp., *Entobia* isp., *E. goniodes, E. geometrica, Entobia laquea, Entobia ovula, Entobia* cf. *solaris., Gastrochaenolites* isp., *G. torpedo, G. lapidicus, Phrixichnus* isp., *Maeandropolydora* isp., *Maeandropolydora sulcans, Maeandropolydora decipiens, Caulostrepsis* isp., *Caulostrepsis teniola*, and cf. *Trypanites*.

2. The ichnoassemblage associated with the limestone boulders collected from the rocky-shore is dominated by the trace of endolithic bivalves, endolithic sponges, echinoids, polychaetes, and annelids. These are marine organisms, which belong to a marine hard substrate community showing the existence of an ancient wave-cut platform.

3. *Gastrochaenolites* and *Entobia* are dominant borings in the studied locality.

4. Although bivalve borings of the ichnogenus *Gastrochaenolites* and the sponge boring *Entobia* are dominant in this region, in the shallower part, *Gastrochaenolites* is more dominant (Bromley and Asgaard, 1993a; Martinell and Domènech, 1995). As the transgression progressed and substrate was exposed to deeper conditions, an initial bivalve-dominated community was progressively replaced by a sponge-dominated community. During this period of time, bioerosion combined with physical erosion lowered the substrate, thus destroying a great part and truncating the *Gastrochaenolites* and *Entobia*.

5. *Phrixichnus* has been for the first time reported in Turkey.

6. The bioerosional assemblage found in boulders consists of small *Gastrochaenolites* and *Entobia*. They indicate that endolithic communities on unstable substrates were affected by physical factors.

7. The borings can be classified as a *Gastrochaenolites-Entobia* assemblage, which is typical of Neogene rocky-shores and belongs to the *Entobia* ichnofacies. This characterizes littoral rockground environments indicating wave-cut platforms and marine flooding surfaces (transgressive surfaces) in the stratigraphical record.

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