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RELATIVE SEA-LEVEL CHANGES RECORDED IN BORINGS FROM A MIOCENE ROCKY SHORE OF THE MUT BASIN, SOUTHERN TURKEY

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Abstract: Cretaceous limestones from the basement of the Neogene Mut Basin are strongly sculptured by borings, including mainly clionid sponge borings *Entobia* ispp., bivalve borings *Gastrochaenolites torpedo* and *G. lapidicus*, the polychaete boring *Caulostrepsis taeniola* and *Meandropolydora* isp. The borings are replaced subsequently; as a rule the succession begins with *C. taeniola* and terminates with *Entobia* ispp.

The discussed boring producers display various tolerance for light, energy and depth conditions, hence their succession may reflect environmental changes, related to marine transgression, proceeded upon rocky coast area. Since such a coast could be devoid of sedimentation for a long time, the possible reconstruction of relative sea-level change may be inferred exclusively from nonsedimentological criteria i.e. from the succession of endolithic borings. Therefore the borings may be employed as useful tool in sequence stratigraphic procedure.

Key words: borings, rocky shore, palaeobathymetry, Mut Basin, Miocene, Turkey.

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INTRODUCTION

Relative sea-level changes are one of the major factors controlling development of sedimentary basins, especially when considered in terms of sequence stratigraphy (e.g., Sarg, 1988; Walker, 1990). Record of the sea-level changes is very reduced during non-deposition or erosion when usually various discontinuities develop. One of the rare opportunities to study the changes give trace fossils associated with the discontinuities, especially macroborings. Macroborings are useful tools in determining several parameters of palaeoenvironments, including bathymetry or hydrodynamic conditions (e.g., Bromley, 1992). In the past, the environmental parameters were reconstructed on the base of particular ichnotaxa or an assemblage of borings, considered as a work of one community of borers (e.g., Radwański, 1969, 1977). Recently, it becames obvious that one assemblage of borings can be a product of a few superimposed communities of bores (e.g., Bromley & Asgaard, 1993a). Recognition of the communities and their changes allows reconstruct the bathymetric trends. This method can be applied even for relatively small outcrops. As an example, an assemblage of borings from a single locality, located on the edge of the Mut Basin in southern Turkey (Figs 1, 2) is presented in this paper.

Some of the specimens described in this paper are housed in Department of Geological Engineering, Faculty of Sciences, Ankara University, Ankara, Turkey (K2.99), and in the Institute of Geological Sciences (Geological Museum) of the Jagiellonian University in Kraków (Poland).

GEOLOGICAL SETTING

The Mut Basin, developed on the Tauride Mountain Belt, pertains to system of Mediterranean Neogene basins (Fig. 1A) stretching in southern Turkey (Sengör & Yilmaz, 1981). The Mut Basin was formed as an irregular depression formed in the forefront of a tectonic thrust belt (Derman & Derman, 2000). Origin of this foreland basin is attributed to crust extension and subsequent orogenic collapse in Early Oligocene time (Kelling *et al.*, 1995) or alternatively to back-arc extension forced by crust subduction in the Cyprus region (Robertson, 1998). Basement of the basin is com-

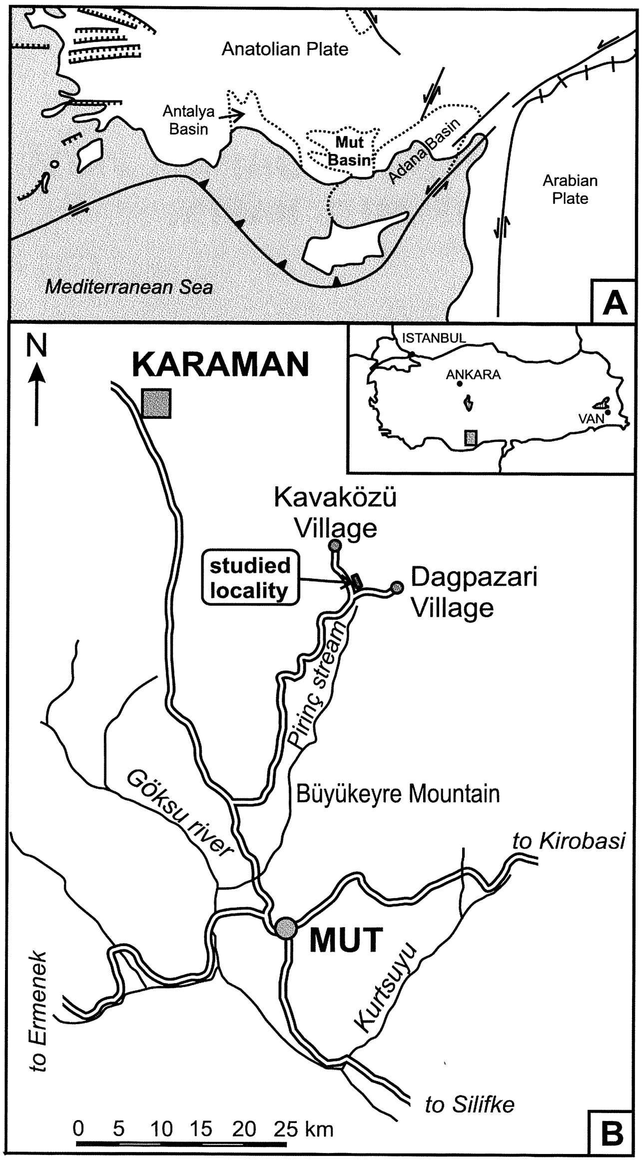

Fig. 1. **A.** Tectonic map of the studied region (modified after Bassant, 1999). **B.** Geographic location of the studied locality

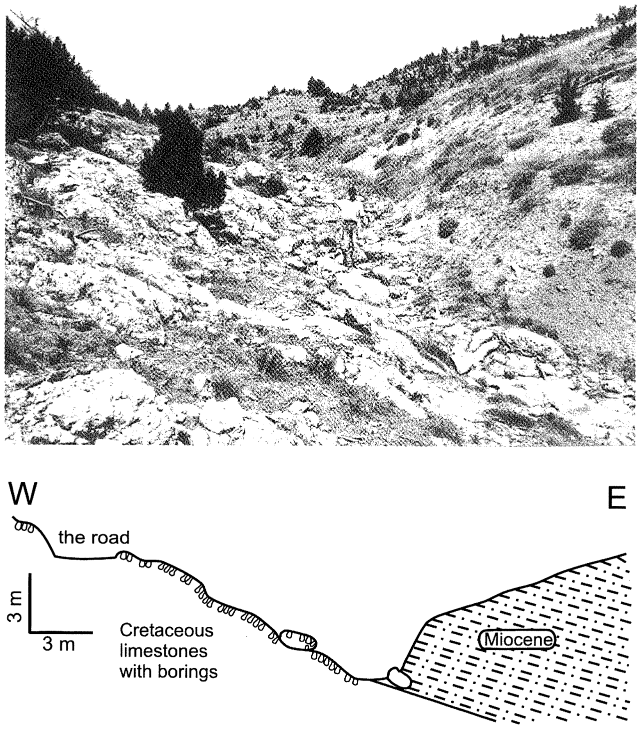

Fig. 2. A view of the location of borings and simplified cross section of the area

posed of different Palaeozoic to Paleogene metamorphic and sedimentary rocks and a Mesozoic ophiolitic melange.

Mut Basin filling is dominated by Upper Oligocene continental (lacustrine and fluvial) deposits followed by Miocene marine limestones and marlstones. Spectacular large outcrops and lack of significant tectonic disturbances make the basin very attractive for carbonate sedimentological and sequence stratigraphic studies. Eurasia-Arabia collision starting by the end of Early Miocene time forced regression within the Mut Basin and led finally to its uplift up to altitude of 2 km.

The oldest deposits of the Mut Basin overlying the basement rocks are represented by locally occurring scree and alluvial fan deposits (Derman & Derman, 2000). They are overlain unconformably by lacustrine carbonates (Derman & Özdogan, 1999; Derman & Derman, 2000). These rocks belong to the Derinçay and Fakirca formations of Gedik *et al.* (1979), respectively. Locally, fluvial channel conglomerates and sandstones surrounded by red and grey coloured mudstones (Yapinti Formation; Bolukbasi *et al.*, 1994) are incised in the lacustrine deposits. The overlying deposits represent 2000 m-thick marine succession with limestones (mostly developed at the basin margins) and with marls and mudstones filling the basin centre (Mut and Köselerli formations; Gedik *et al.*, 1979, respectively). Deposits of the Mut Basin are subdivided in terms of sequence stratigraphy. Bassant (1999) distinguished four Miocene sequences (A to D), and Derman (2001) seven sequences (MS-1 to MS-7). Coral-algal buildups and surrounding carbonate facies are very common in most of the sequences and form locally barrier rims.

The borings described in this paper occur at the base of the sixth sequence (MS-6). In general, it begins with sandy carbonates, grainstones and packstones with large skeletal fossils. Facies of the sequence are very changeable depending on the position of the shoreline and the availability of siliciclastics. The sequence is capped by lagoonal carbonates and siliciclastics with abundant oyster beds, which are thinning on palaeotopographic rises and thickening in depressions. Siliciclastics are more common behind barriers rimming basin margins (Derman, 2001).

BORINGS

Six ichnogenera have been recognised. They are shortly described below.

Conchotrema? isp. (Fig. 3A) is a system of straight to slightly curved branched grooves, which are about 0.8–1.2 mm wide. They densely cut the rock surface and commonly

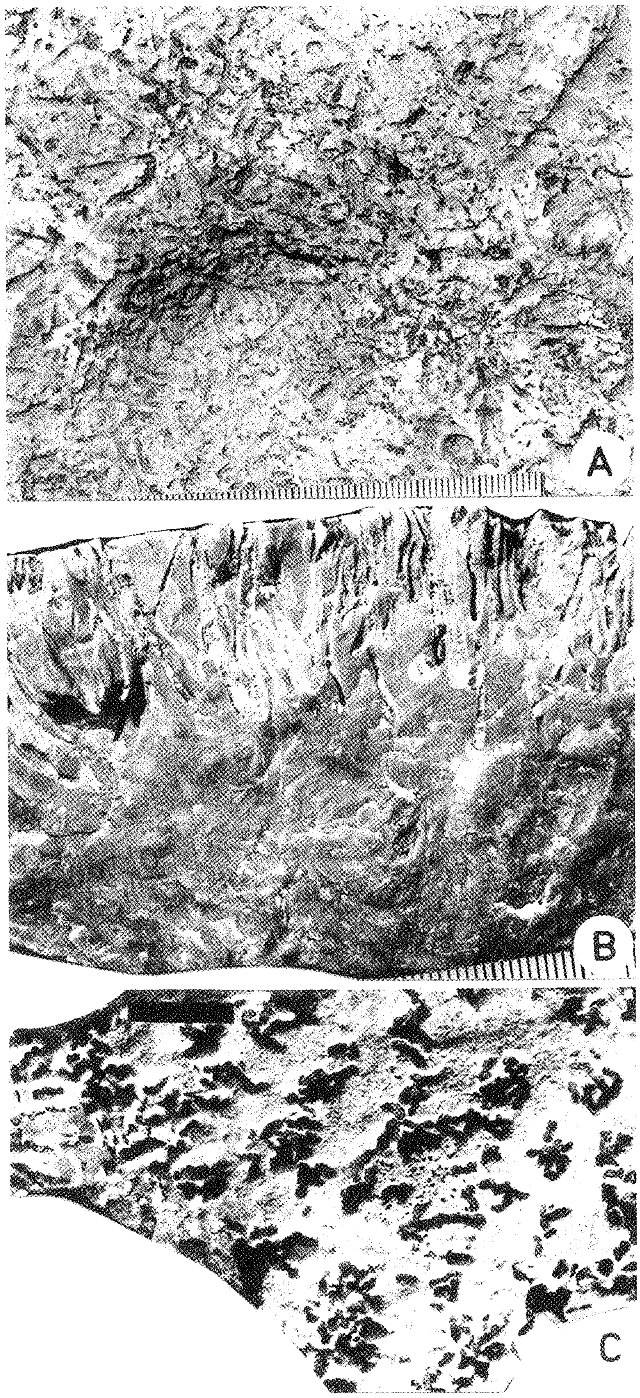

Fig. 3. Polychaete borings from the Mut Basin. **A.** *Conchotrema*? isp., upper surface of limestone bed, field photography; **B–C.** *Caulostrepsis taeniola*, 168P1; B: side view, C: top view. Scale in A, B in mm, and scale bar in C – 1 cm

cross each other. *Conchotrema* is typically thinner than 0.25 mm. The described forms are distinctly larger and can only be reservedly included in this ichnogenus. Voigt (1975) suggested that *Conchotrema* is produced by endolithic phorodnids. Bromley & D'Alessandro (1987) discussed its taxonomy.

Caulostrepsis taeniola Clarke 1908 (Figs 3B–C, 4B) is a narrow u-shaped gallery with distinct limbs and an interconnecting vane. The limbs converge toward the aperture. The trace fossil is 15–25 mm long and maximum 3.5–4.0 mm wide. The limb is about 0.6–0.8 mm in diameter. This trace fossil is produced mainly by the polychaetes of the genus *Polydora* (Radwański, 1969). For discussion of taxonomy of *C. taeniola* see Bromley & D'Alessandro (1983).

Entobia cf. *goniodes* Bromley & Asgaard 1993a (Figs 5A, 6) is a system of small, camerate to nodular chambers, up to 3 mm in diameter, developed mostly in the grow stage C and D *sensu* Bromley & D'Alessandro (1984). In the Mediterranean Sea, *E. goniodes* is produced by *Cliona viridis* and rarely by *C. schmidti* in the photic zone. *Cliona viridis* is still abundant there at the water depth of 20 m (Bromley & Asgaard, 1993a).

Entobia laquea Bromley & D'Alessandro 1984 (Fig. 5B) is composed of tunnel system and chambers in well developed grow stages A and C *sensu* Bromley & D'Alessandro (1984). The structures of the stage A are composed of thin, almost straight tunnels, about 0.5 mm in diameter. The stage C is represented by irregular, oval, elongate to subangular chambers, 1.5–3.0 mm in diameter.

Entobia cf. *ovula* Bromley & D'Alessandro 1984 (Fig. 5C) is structures preserved in the A to C grow stages exposed on the surface. The structures of the stage A occur as a system on narrow tunnels, which are less than 1 mm in diameter, and branched tunnels, about 1 mm in diameter, with indistinct swellings and enlargements at the branching point. The structures of the stage B consist of curved rows of elongate chambers, 2–3 mm long, 1.8–2.2 mm wide, connected by constrictions. The stage C is poorly developed and composed of oval, closely spaced chambers, which are up to 3.5 mm wide. Taxonomy of the ichnogenus *Entobia*, produced mostly by sponges of the genus *Cliona*, has been extensively discussed by Bromley & D'Alessandro (1984). In the Mediterranean Sea, *E. ovula* is produced by *Cliona schmidti*, *C. vermifera* and *C. vastifica* (Bromley & Asgaard, 1993a).

Entobia cf. *solaris* Mikuláš 1992 (Fig. 5D) is preserved as irregularly hemispherical depressions, 9–22 mm across, which display rare, almost straight radiating tunnels. The tunnels are about 1 mm wide and up to 10 mm long. *Entobia solaris* has been described from the Lower Cretaceous of the Czech Republic.

Gastrochaenolites lapidicus Kelly & Bromley 1984 (Fig. 4B) is a smooth ovate chamber with an apertural neck. It is circular in cross-section throughout. The neck is also circular in cross-section or elliptical. The widest diameter is located slightly below the centre of the chamber. The boring is 14–28 mm long and maximum 8–12 mm wide. Borings of this type are produced recently by some bivalves of the genus *Lithophaga* and *Hiatella* (Kelly & Bromley, 1984).

Gastrochaenolites torpedo Kelly & Bromley 1984 (Figs 4A, 5A) is a smooth, strongly elongate chamber, the upper (neck) part of which displays ellipsoidal cross-section. The chamber is at least 95–100 mm long. The maximum diameter (23–33 mm) is located at the centre of the chamber. *Gastrochaenolites torpedo* commonly displays a calcite lining (e.g., Jones & Pemberton, 1988), which, however, have not been observed in the investigated material. Today, borings of this type are produced by some bivalve species of the genus *Gastrochaena* and *Lithophaga* (Kelly

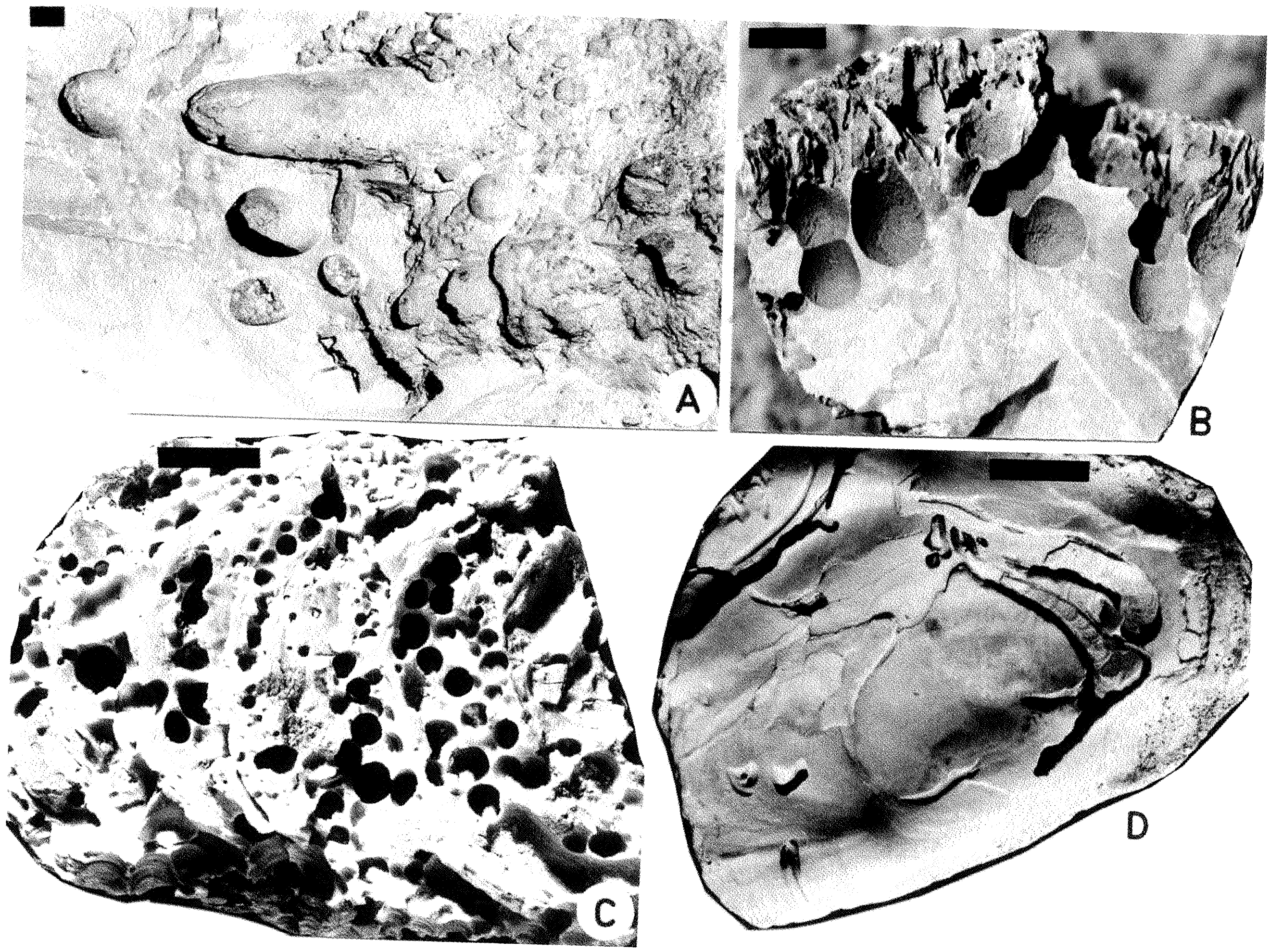

Fig. 4. Other borings from the Mut Basin. **A.** *Gastrochaenolites torpedo*, field photography; **B.** *Gastrochaenolites lapidicus* crosses *Caulostrepsis taeniola* (K2.99); **C.** *Gastrochaenolites* isp. in an oyster shell (168P3). **D.** *Meandropolydora* isp. in the inner part of an oyster shell (168P4). Scale bar – 1 cm

& Bromley, 1984), and in the Mediterranean region by *Lithophaga lithophaga* (Linneus). *Gastrochaenolites torpedo* has been reported from Miocene rocky shores of many areas of Europe and adjacent areas (e.g., Radwański, 1969, 1977).

Gastrochaenolites isp. (Fig. 4C) occurs exclusively in the upper side of oyster shells. It is relatively small, rounded, smooth cavity, 2.5–5.0 wide, up to 9 mm deep, without distinct neck. It is similar to the borings of *Petricola* described by Radwański (1969), but the latter displays oval outline of the upper edge.

Meandropolydora isp. (Fig. 4D) occurs exclusively in oyster shells as cylindrical, u-shaped galleries, which are 2.0 mm wide and at least 30 mm long. Similar borings from oyster shells have been described by Mikuláš & Pek (1996). Taxonomy of *Meandropolydora* has been discussed by Bromley & D'Alessandro (1983). It is produced by polychaetes (Bromley & Asgaard, 1993a).

Branched grooves (Fig. 6) are surface, smooth, short structures, up to 120 mm long and 7–14 mm wide. The branches are blind, and thinner than the main groove. Similar grooves are produced by echinoid *Echinometra lucunter* scraping algae in the Bermuda reefs (Bromley, 1978). It is not excluded that the described form has been produced by an organism of similar behaviour.

Distribution of borings

The most common boring in the studied site is *Gastrochaenolites lapidicus*, which occupies surfaces of different morphology. *Gastrochaenolites torpedo* is much less frequent and occurs only in isolated patches on very steep surfaces. *Caulostrepsis taeniola* is very common. It occurs in patches (Fig. 3C) on differently oriented surfaces. In many places it is cross-cut by *G. lapidicus* (Fig. 4B). Among sponge borings, *Entobia laquea* is the most frequent. It occurs in patches. *Entobia* cf. *ovula* is much less frequent, and *E.* cf. *solaris* is very rare. Small entobian borings are formed on partially abraded older bivalve borings (Fig. 5A). Large *E. solaris* cross-cuts the surface bored by small entobians (Fig. 5D).

All the described borings occur at rocky limestone substrate. A separate substrate is formed by patchy layers of thick oyster shells. At least part of the shells are intensively bored. The borings are dominated by *Entobia laquea*, whereas *Meandropolydora* isp. penetrates along layers of

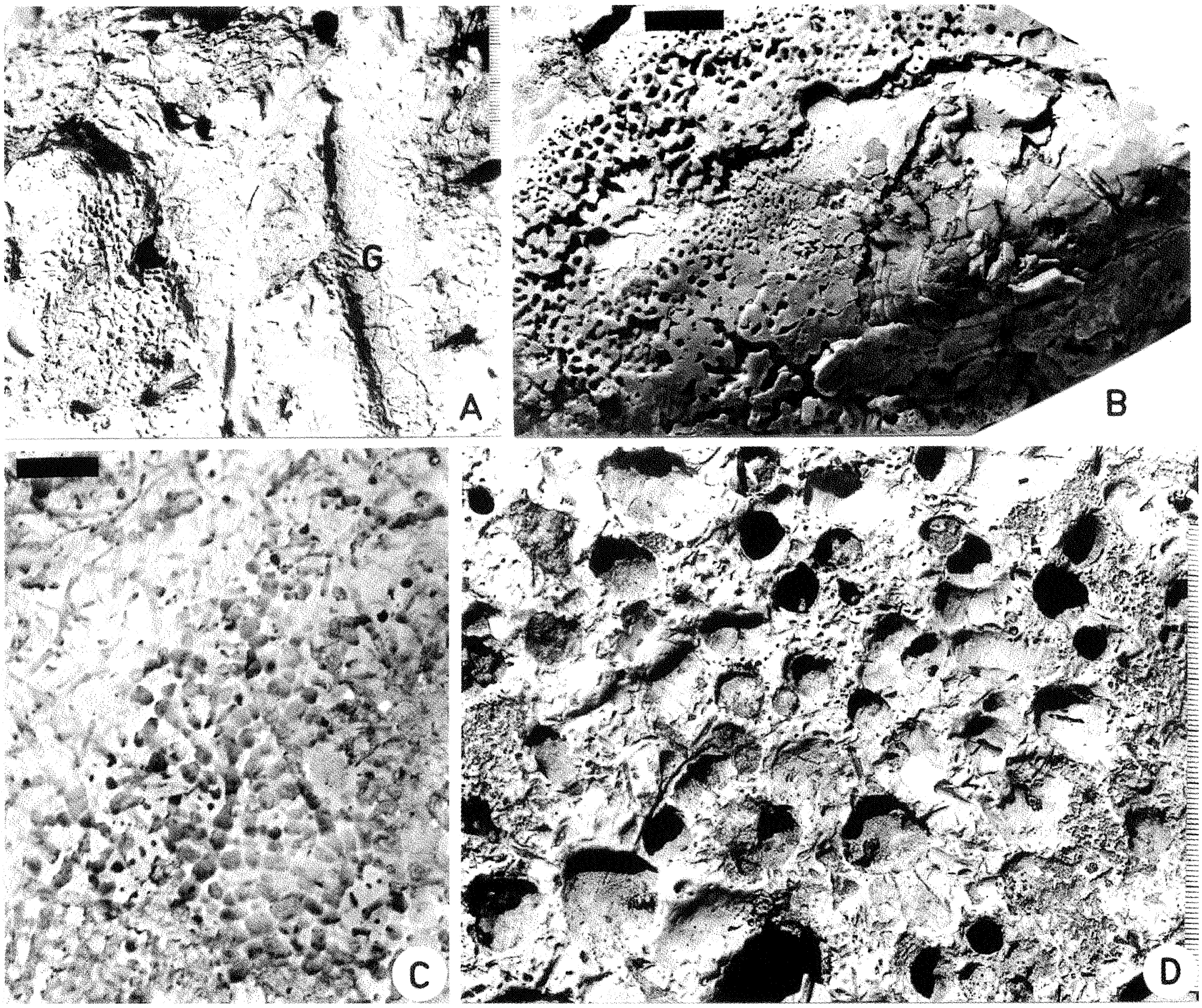

Fig. 5. Sponge borings from the Mut Basin. **A.** *Entobia* cf. *goniodes* and *Gastrochaenolites torpedo* (G), field photography; **B.** *Entobia laquea* in an oyster shell (168P2); **C.** *Entobia* cf. *ovula*, field photography; **D.** *Entobia* cf. *solaris*, field photography. Scale in A, D in mm, scale bars in B, C – 1 cm

some shells. Some of shells are intensively bored by *Gastrochaenolites* isp. (Fig. 4C). The borings are oriented perpendicular to the surface of shells. Generally, the upper side of the shells is more intensively bioeroded than the lower side.

DISCUSSION AND CONCLUSIONS

The assemblage of borings is typical of the *Entobia* ichnofacies *sensu* Bromley & Asgaard (1993b) (see also Gibert *et al.*, 1998), that normally occurs above normal wave base. It indicates deep and long (several years) bioerosion. *Gastrochaenolites torpedo* is restricted to shallow, euphotic zone. *Lithophaga lithophaga*, producer of this boring in the Mediterranean Neogene is abundant to the depth of 1m, and less common up to 10 m depth (Kleeman, 1973, 1974; *vide* Bromley & Asgaard, 1993a).

Distribution of some borings depends on inclination of the substrate (Fig. 7). Occurrence of *G. torpedo* on steep surfaces is consistent with observations by Bromley & Asgaard (1993a) from the Pliocene rocky coast of Rhodes, Greece. They related this fact to strong intolerance of *L. lithophaga* to sediments. Similar observation has been made earlier by Bromley & D'Alessandro (1987) from Plio-Pleistocene coast of Southern Italy and latter by Gibert *et al.* (1998) from Pliocene rocky coasts of the western Mediterranean basin. *Gastrochaena dubia*, main producer of *G. lapidicus* in the Mediterranean Sea shows wider bathymetric range than *L. lithophaga* and greater tolerance to sediment particles suspended in the water and settled on the substrate (Bromley & Asgaard, 1993a). It is found on inclined and locally horizontal surfaces, with extremely low accumulation rate.

The described assemblage of borings is composed of overprinting of a few boring communities (Fig. 8). Surfaces colonised by polychaetes producing *Caulostrepsis* have been afterward colonised by bivalves producing *Gastrochaenolites*. Due to deepening caused by the Miocene transgression, at a depth up to 20 m (upper photic zone) sea floor

Fig. 6. Branched groove cuts surface with *Entobia* cf. *goniodes*, field photography. Scale in mm

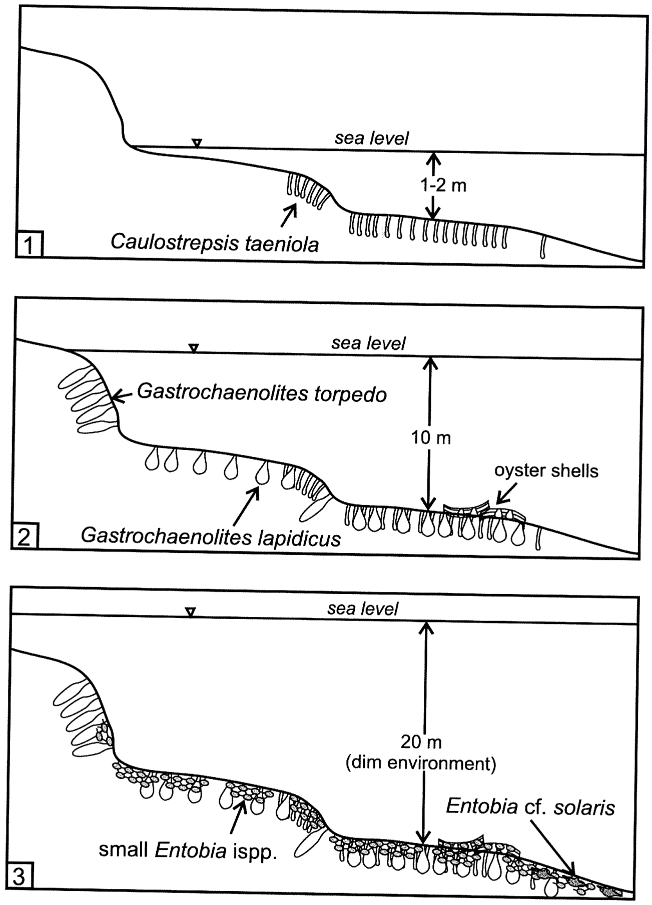

Fig. 8. Succession of borings (from 1 do 3) in relation to changing water depth during a single transgressive cycle of the 4th order (example from the Miocene regional transgression in the Mut Basin, southern Turkey). The borings and proportions not to the scale

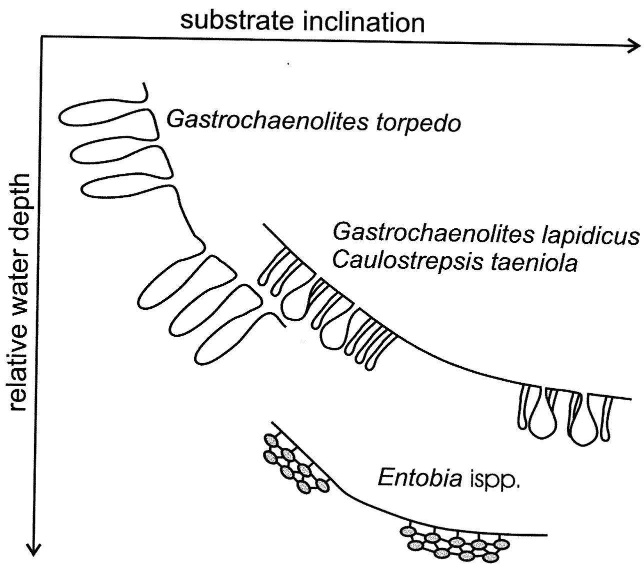

Fig. 7. Schematic distribution of borings in relation to inclination of substrate and water depth on the basis of observations from various sites (further explanations in the text)

was progressively colonised by sponges of the genus *Cliona*. Commonly, they abraded bivalve borings of the ichnogenus *Gastrochaenolites*, which were formed earlier in shallower waters. Then, within mostly dim environment, larger sponges produced *Entobia* cf. *solaris*, which cross cuts the smaller entobian borings.

The oyster shells, which occur locally at the lowermost part of the Miocene deposits, are also intensively bored, mostly with *Entobia* and small *Gastrochaenolites*. *Meandropolydora* isp. is relatively rare. External side of their shells is more intensively bored than the internal side, probably because the oysters have been infested with boring organisms during their life.

The boring assemblage does not represent one community, but several communities overprinted during migration of shoreline and increasing water depth. In general, they indicate a change from very shallow turbulent, well-oxygenated waters, dominated by boring polychaetes and bivalves, to deeper lower-energy waters dominated by boring sponges at a depth of several or even a few tens of meters (Fig. 8). This change was caused by the major regional transgression (Bassant, 1999), which can be attributed to the 4th (or even 3rd) order eustatic fluctuations.

As shown in this paper, the distribution and succession of the borings can reflect bathymetric trends, and hence could be crucial in recognition of relative sea level changes. Therefore, borings may be applied as a useful accessory tool in sequence stratigraphy, especially in transgressive rocky coast settings.

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Streszczenie

WZGLĘDNE ZMIANY POZIOMU MORZA ZAPISANE W DRĄŻENIACH Z MIOCEŃSKIEGO WYBRZEŻA SKALISTEGO BASENU MUT W POŁUDNIOWEJ TURCJI

Alfred Uchman, Huriye Demírcan, Vedia Toker, A. Sami Derman, Serkan Sevim & Joachim Szulc

W skalistym mioceńskim brzegu morskim kopalnego basenu Mut w południowej Turcji (Fig.1), zbudowanym z wapieni kredowych (Fig. 2), występują liczne drążenia powstałe w czasie mioceńskiej transgresji. Rozpoznano drążenia gąbek (*Entobia laquea* Bromley & Asgaard 1984 (Fig. 4B), *Entobia* cf. *goniodes* Bromley & Asgaard 1993a (Fig. 6), *Entobia* cf. *ovula* Bromley & D'Alessandro 1984 (Fig. 5C), *Entobia* cf. *solaris* Mikuláš 1992; Fig. 5D), małży (*Gastrochaenolites torpedo* Kelly & Bromley 1984 (Fig. 4A) i *Gastrochaenolites lapidicus* Kelly & Bromley 1984; Fig. 4B), wieloszczetów (*Caulostrepsis taeniola* Clarke 1908 (Fig. 3A,

B), *Meandropolydora* isp. (Fig. 4D) i *Conchotrema* isp.; Fig. 3A) oraz prawdopodobnie jeżowców (Fig. 6).

Omawiana asocjacja drążeń jest typowa dla ichnofacji *Entobia* (*sensu* Bromley & Asgaard, 1993b), która zwykle występuje powyżej podstawy normalnego falowania i jest charakterystyczna dla wieloletnich okresów ekspozycji i bioerozji. Drążenia *Gastrochaenolites torpedo*, produkowane przez małże *Litophaga lithophaga* występują wyłącznie w płytkiej (10 m głębokości), bardzo czystej, pozbawionej zawiesiny wodzie, na stromym skalistym podłożu. Bardziej toleracyjne na dostawę materiału osadowego, *G. lapidicus* i *C. taeniola* mogą być tworzone na bardziej połogim podłożu i nieco większych głębokościach (Fig. 7).

Zaobserwowano nakładanie się jednych drążeń na drugie. Powierzchnie skolonizowane najpierw przez wieloszczety (*Caulostrepsis*) były następnie drążone przez małże (*Lithophaga* i *Hiatella*) produkujące *Gastrochaenolites* ispp. (Fig. 4B). Później, w większych głębokościach wkroczyły drążące gąbki z rodzaju *Cliona* produkujące *Entobia* ispp. (Fig. 5A).

Drążenia występują także w muszlach ostryg (Fig. 4C, D; Fig 5B), licznych w dolnej części utworów transgresywnych. Zewnętrzna powierzchnia muszli jest zdecydowanie silniej podrążona niż ich strona wewnętrzna, co wskazuje na początek bioerozji jeszcze za życia ostryg.

Przedstawiona sukcesja drążeń jest wynikiem stopniowo zmieniających się warunków środowiskowych, związanych z postępującą transgresją (Fig. 8). Wynika z tego, że drążenia mogą być użytecznym narzędziem do rekonstrukcji różnorodnych zmian środowiskowych, w tym względnych zmian poziomu morza, zachodzących w obrębie skalistych stref brzeżnych zbiorników morskich.