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Bioerosion and encrustation on a middle Miocene *Gigantopecten nodosiformis* shell from Tășad, Bihor, Romania

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Abstract. The studied specimen of *Gigantopecten nodosiformis* manifests bioerosion and bioencrustation traces, caused by sponges, bivalves, worms and bryozoans. The high frequency of well developed bioerosional and encrustation structures on a single specimen of *Gigantopecten nodosiformis* suggests a slow burial of the shell with a significant amount of time being exposed on the sea bottom. The analyses of these traces revealed four ichnospecies. These include *Entobia cateniformis* borings, produced by clionaid sponges, *Gastrochaenolites lapidicus* produced by lithophagian bivalves and channel-like traces identified as *Maeandropolydora sulcans* and *Caulostrepsis* isp, produced by polychaete annelids. Bivalve and bryozoan overgrowth, as well as polychaete dwelling tubes can be observed among encrustation structures. The spatial distribution and relationship between the bioerosion structures allow the reconstruction of the succession of the bioerosion stages. First a sponge-dominated community colonized the shell, followed by the polychaete annelid-dominated community, which produced traces cross-cutting those produced by sponges. The last bioeroder was probably the bivalve-dominated community, which made their dominchia first in the sediment which already has been deposited on the surface of the shell, penetrating only partially the shell surface. The bioerosion trace fossil assemblage can be regarded as the *Entobia* ichnofacies, which indicates a near-shore, shallow marine environment with low sedimentation rate.

Introduction

Although bioerosion traces reveal so many data regarding the depositional environment, the sea-level changes in shallow marine deposits, as well as the determination of palaeoenvironmental aspects (Uchman et al. 2001, Dávid et al. 2006, El-Hedeny 2007, Santos et al. 2010, Dermican 2012, Brlek et al. 2016, Brlek et al. 2018), there are few publications in Romania dealing with bioerosion.

Brustur (1997a, 1997b) synthesized the contributions made on Romanian ichnological studies, including the identification of worms' tubes in the Badenian of Șimleu Basin or the borings produced by *Cliona* and *Polydora* on *Ostrea* shell in the Sălătruc Formation.

In the last decades more and more attention has been paid to the study of bioerosion structures worldwide, thus the number of papers dealing with Neogene bioerosion traces and epibiont fauna from Romania is increasing as well (Hladilova 2004, Munteanu & Munteanu 2001, Anistoroae & Miclăuș 2015).

Experimental studies of bioerosion allowed more precise determinations of the tracemakers and observations on the temporal patterns of macro and microbioerosions (Bromley & D'Alessandro,–1989, Bromley et al. 1990).

Temporal pattern of bioerosion can be assessed by analyzing the spatial distribution of bioerosion and encrustation structures. Thus, Santos et al. (2008) defined three colonization stages: stage I – structures produced when the host bivalve was still alive; stage II – structures produced immediately after the death of the bivalve, and stage III – structures produced post-mortem, when the bivalve was already disarticulated.

Long-term experimental studies revealed more information related to the temporal sequence of bioerosion, the relationship between traces and bioeroders, respectively their impact made in different rocky shorelines throughout different geographic regions (Färber et al. 2016).

Location

The specimen described in this paper came from the Badenian deposits of Cuții Valley (Fig. 1), from Tășad, Bihor County, Romania, which is located 22 km away from Oradea.

The Middle Miocene marine deposits are cropping out along the Morii Valley and Cuții Valley with a rich invertebrate fauna, consisting of bivalves, corals, gastropods and echinids. The analysed *Gigantopecten* shell was embedded in a bio-lithoclastic limestone in Cuții Valley, located in the close vicinity of corraligeno-

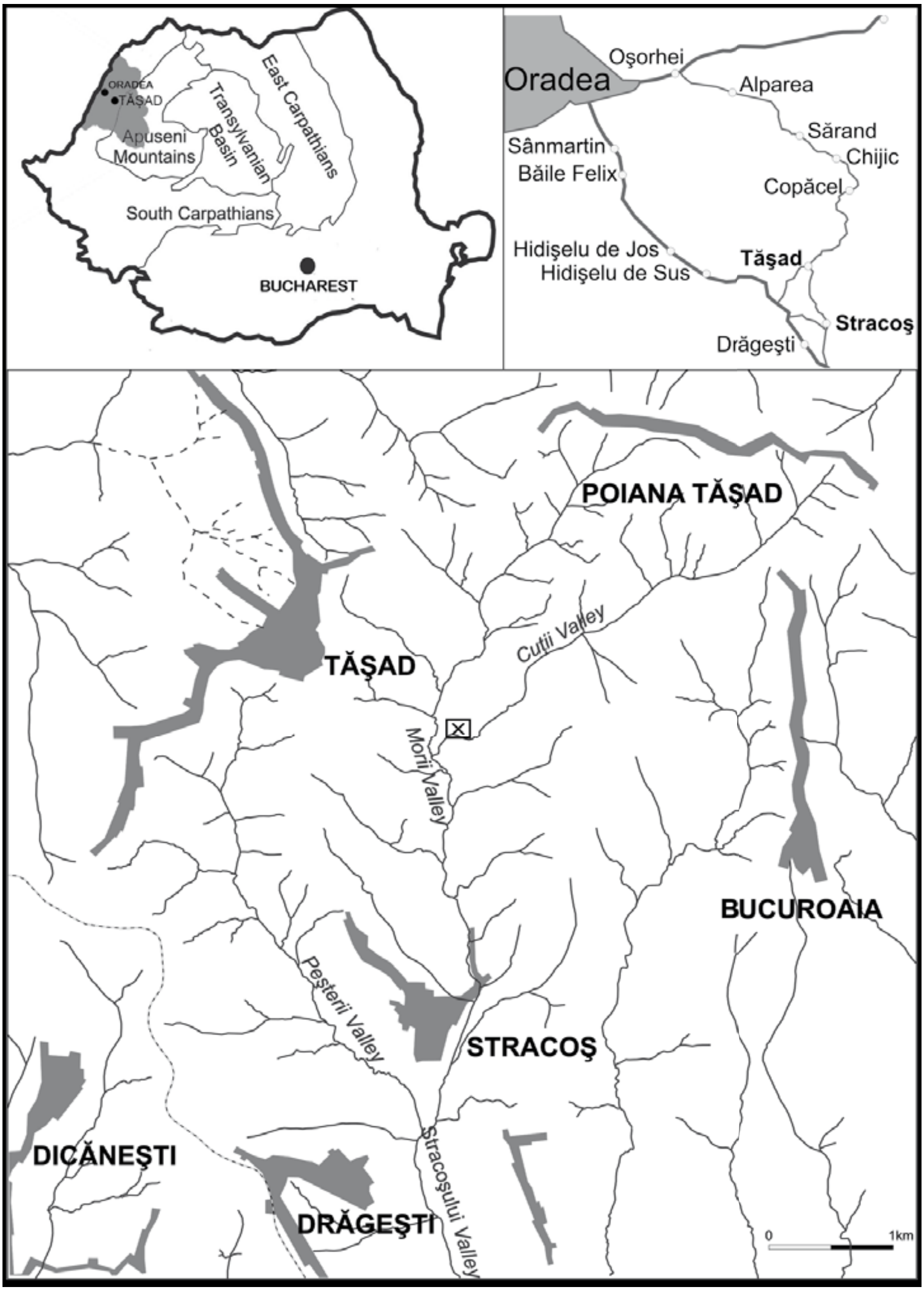

Figure 1. Location of the Middle Miocene site. The collecting site of *Gigantopecten nodosiformis* is marked with **X**

us deposits. The sediment also contains clasts of different rocks, which may have been incorporated in the sediment due to wave-action during storm events.

Palaeogeographically this area belongs to the Pannonian Basin, to the Eastern compartment of the Central Paratethys.

Material and methods

A total number of six specimens of *Gigantopecten nodosiformis* were collected: three articulated specimens from the Cuților Valley, one disarticulated specimen and two specimens preserving both valves were found in the Morii Valley. Four of the articulated specimens are hosted by the Association for Conservation and Promotion of the Local Natural and Cultural Heritage "Tasadia".

The present paper is based on a single specimen of *Gigantopecten nodosiformis* (MTCO 25700), hosted in the collection of the Department of Natural Sciences - Țării Crișurilor Museum Oradea. The shell preserved both valves in connection, which are filled with coarse-grained sediment.

The shell was prepared mechanically, using a vibrating cutter connected to an air compressor, which permitted the elimination of the bio-lithoclastic matrix without damaging the shell surface. Microscopic analyses of the shell surface and of the bioerosion structures were made using a NIKON SMZ 800 stereoscopic microscope.

On the surface of the right valve there are 7 sections presenting intense bioerosion and encrustation, marked by squares (Fig. 2). The left valve is poor in bioerosion, but encrustation structures are present in two sections (Fig.3). The bioerosion traces and encrustations are described for each section separately.

Abbreviations used: MTCO – Țării Crișurilor Museum, Oradea; **LV** – left valve; **RV** – right valve.

Gigantopecten nodosiformis

The taxonomy of this Neogene extinct genus is controversial, there are different opinions whether *Gigantopecten* (Bongrain 1988, Micuž 2009) or *Macrochlamis* (Mandic 2004) should be used as the name of the genus.

Thomas Waller and Madeleine Bongrain (2006) asked the International Commision on Zoological Nomenclature to preserve the name *Gigantopecten* Rovereto, 1899. The above mentioned authors counted the usage of the different names designating this genus for the last 20 years and mentioned 12 articles which used the name *Macrochlamis*, eight that used *Macrochlamys* and 48 articles using the name *Gigantopecten (*Waller & Bongrain 2006). The majority of the authors recently agreed that the usage of the name *Macrochlamys* Sacco, 1897 is incorrect, being a junior homonym of the gastropod name *Macrochlamys* Benson, 1832.

The authors of the present paper will use the name *Gigantopecten* in order to designate the studied specimen.

Genus *Gigantopecten* Rovereto, 1899
Gigantopecten nodosiformis Pusch, 1837

Material: completely articulated shell MTCO 25700 (Fig. 2-3)

Dimensions: Right valve – disc height = 194 mm, disc length=208 mm, anterior auricle length = 52 mm, anterior auricle height = 44 mm.

Description. The large, thick, articulated shell is lacking the posterior auricle. The shell is biconvex, possessing radial ribs with wide interspaces. The dorso-ventral diameter of the shell is smaller than the antero-posterior one.

The outer surface of the right valve presents eight radial ribs, which widen towards the ventral margin. The central ribs are wider than the rest of the ribs and are also slightly wider than the interspaces. The ribs are flattened towards the ventral margin, having shallow grooves on their lower part. The left valve has a lesser number of radial ribs (seven), with more rectangular borders, the three central ribs being wider than the lateral ones. The ribs of the left valve are ornamented with nodular structures which are more prominent in the dorsal region of the shell.

The stratigraphic range of the genus *Gigantopecten* is documented from Miocene to Pliocene. *Gigantopecten nodosiformis* is common in the Middle and Late Miocene, when it is replaced by *Gigantopecten latissima*.

Trace fossil description

The studied specimen of *Gigantopecten nodosiformis* (MTCO 25700) preserved exceptionally structures of bioerosion and encrustation. The bioerosion traces are frequent on the right valve and consist of borings and galleries made by sponges, bivalves and polychaete worms. Encrustation is indicated by the presence of bivalve and bryozoan owergrowth on both valves, as well as dwelling tubes of polychaete worms, which occurs only on the right valve.

Bioerosion - Borings of clionaid sponges

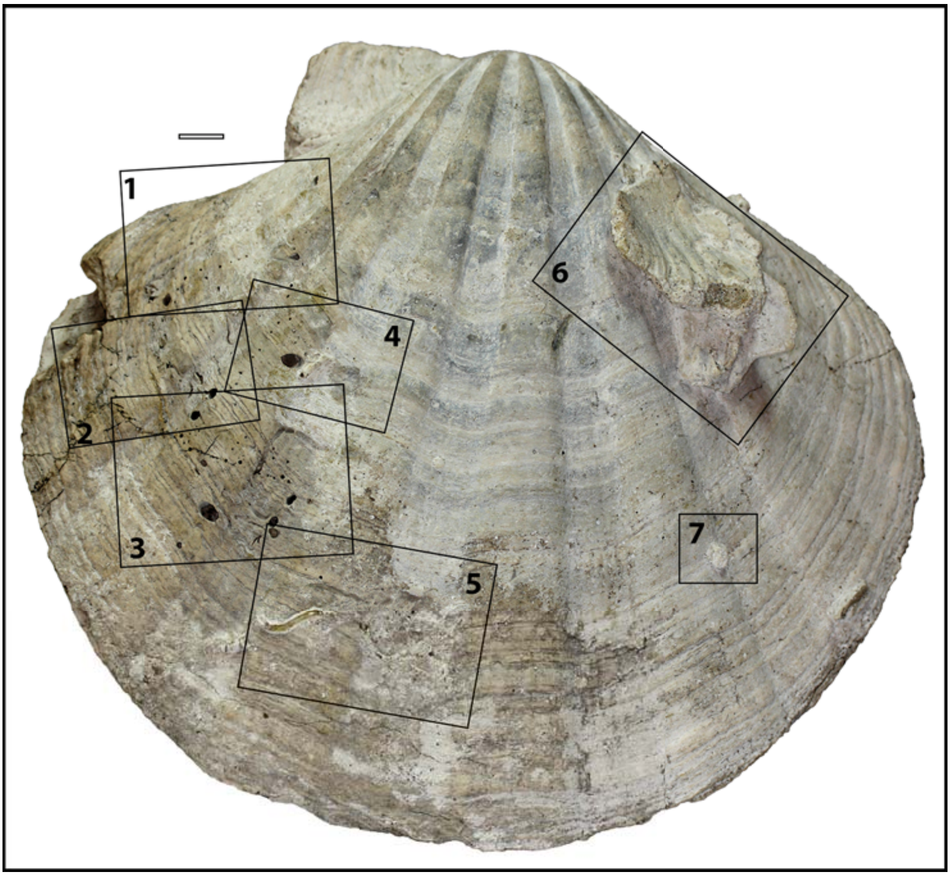

Figure 2. Right Valve of *Gigantopecten nodosiformis* (MTCO 25700), with bioerosion and encrustation structures. 7 sections manifest intense bioerosion and encrustation, marked with squares. Line indicates 1 cm.

Ichnogenus *Entobia* Bronn, 1837

The RV of the shell is covered with chamber openings bored by clionid sponges. The borings occur on the anterior part of the shell, especially in the dorsal half. The borings are disposed more or less parallel to the ribs, occupying the interspace as well as the ribs.

In order to conserve the shell, we did not perform analyses using "cast-embedding technique" which would permit 3D visualization of the borings and the structure of the chambers' network.

The borings are small, rounded and relatively close to each other in order to connect the chambers (Figs. 4-7). There are several interconnected chambers with

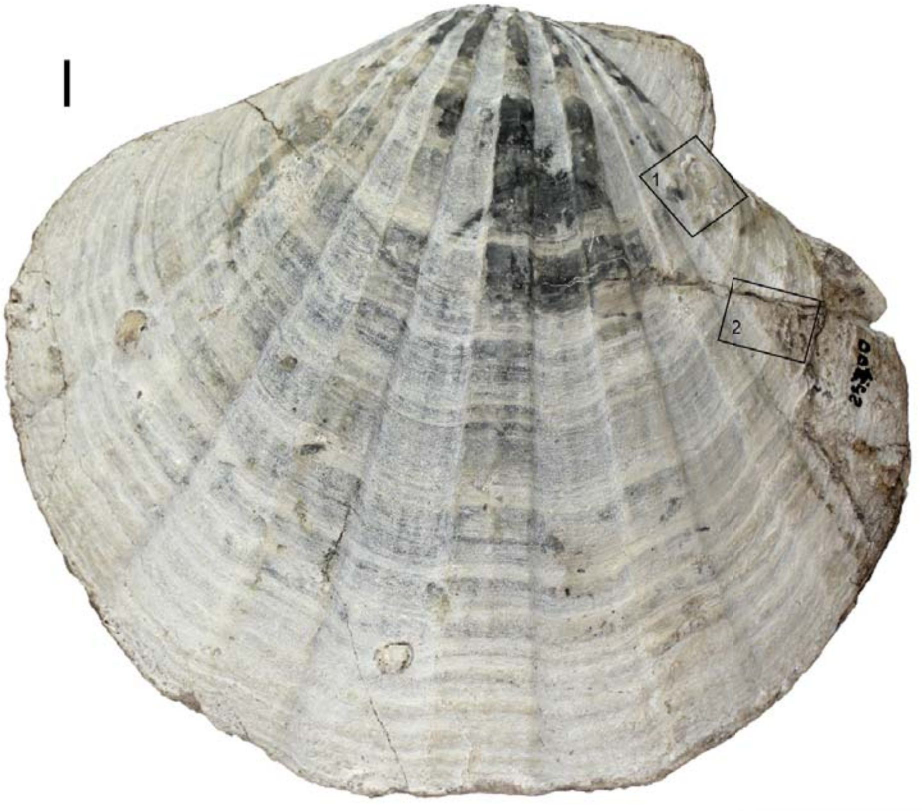

Figure 3. Left Valve of *Gigantopecten nodosiformis* (MTCO 25700), with encrustation structures. Two sections with bivalve and bryozoans encrustation are marked with squares. Line indicates 1 cm.

aperture diameter ranging between 0.2 and 1 mm, with a maximum depth of 3 mm.

The morphology of the borings corresponds to the B - C growth phase (Figs. 4-7), described by Bromley and D'Alessandro, 1989. In the lower part of Section 1 of the RV (Fig. 3) there is a portion where the borings were subject of subsequent erosion, partly exposing the internal chamber network. The chambers are fused together, lacking inter-cameral canals. This part corresponds to the D growth phase. Phase A is not distinguishable.

The openings are disposed sublinear chains (Figs. 4-5, Fig. 7) and show a changing of direction of growth at an almost right angle or are disposed in a T-shaped arrangement (Figs. 6-7). The morphology of the exposed chambers and the appearance of the rectilinear network, forming right angles to each other indicate the *Entobia cateniformis* ichnospecies.

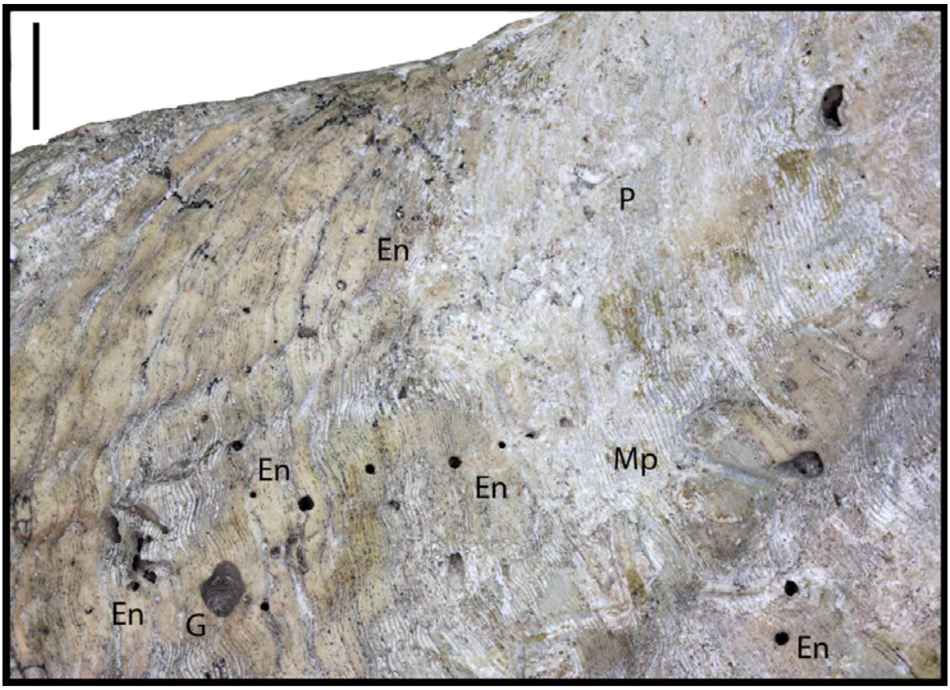

Figure 4. Close-up of Section 1 of the RV. Bioerosion traces of *Entobia cateniformis* (En)., *Gastrochaenolithes* (G) and *Maeandropolydora* isp. (Mp). and Polychaete encrustation (P). Line indicates 5 mm.

Entobian borings are produced by endolithic sponges. According to Bromley and D'Alessandro (1989), *Entobia cateniformis* is produced by several species of *Cliona*, such as *Cliona vastifica*, which inhabit the lowest part of the shore (Radwanski et al. 2011).

Experimental studies have shown that borings of sponges are invisible in the first year of exposure (Bromley et al. 1990, Färber et al. 2016). Färber et al. (2016) observed the first distinct sponge borings on the experimentally exposed blocks after two years. Färber et al. (2016), using micro-computed tomographic visualisation of bioerosion traces in experimental blocks deployed for two years, identified cylindrical chambers of sponge boring that were arranged in long, sublinear chains that coalesced in cross-, T-, or L-shape, which is characteristic for *Entobia cateniformis* Bromley and D'Alessandro, 1984 in the late ontogenetic growth phase C.

The preferential arrangements of the *Entobian* borings, corroborated with previous experimental studies, show that the clionaid sponges were the first bioeroders, which affected the *Gigantopecten* shell.

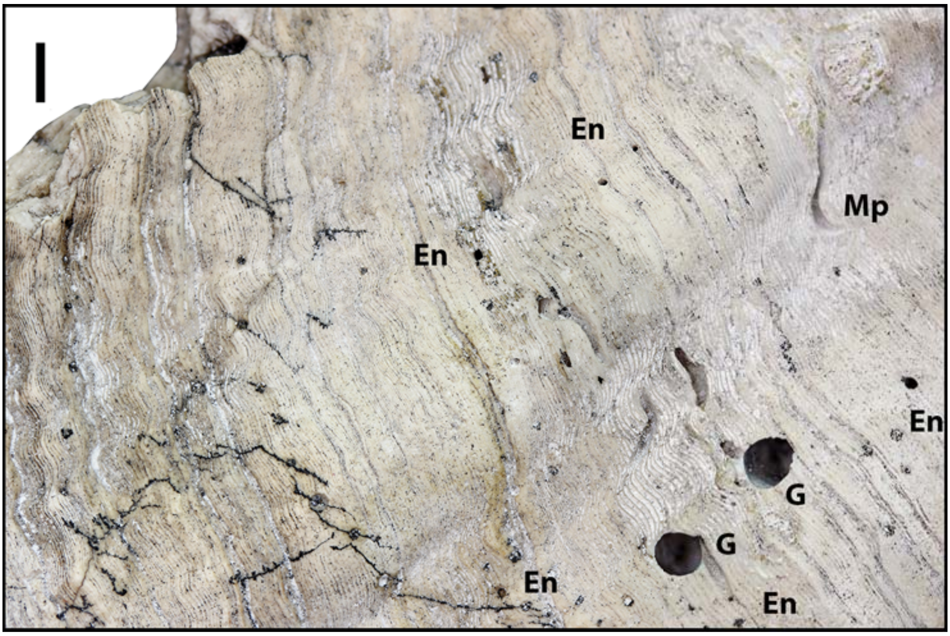

Figure 5. Close-up of Section 2 of the RV. Bioerosion traces of *Entobia cateniformis* (En)., *Gastrochaenolithes* (G) and *Maeandropolydora* isp. (Mp). Line indicates 3 m

Entobia cateniformis was reported in several European Miocene sediments, e. g. in Hungary, Ukraine and Turkey (David et al. 2006, Radwanski et al. 2011, Dermican 2012).

The presence of *Entobia* indicates shallow marine environment (Bromley & D'Alessandro 1989, Santo & Mayoral 2008, Santos et al. 2010, El-Hedeny & El-Sabagh 2018), the producers of *Entobia cateniformis* preferring habitats with little wave action and low energy environments (El-Hedeny 2007).

Borings of mytilid bivalves

Ichnogenus *Gastrochaenolithes* Leymerie, 1842

The analysed *Gigantopecten nodosiformis* specimen includes *Gastrochaenolithes* trace fossils on the right valve of the shell. The distribution of the bivalve made borings is the same as that of *Entobia*, respectively the anterior half of the right valve, appearing in the region below the anterior auricle down to the dorsal half (Fig. 2). The borings are perpendicular (Fig. 5) or oblique (Figs. 4, 6, 7) in relation to the surface of the shell. The neck region is eroded completely, thus the dimensions of the entire chamber cannot be determined. The bioeroder bivalve must have bored

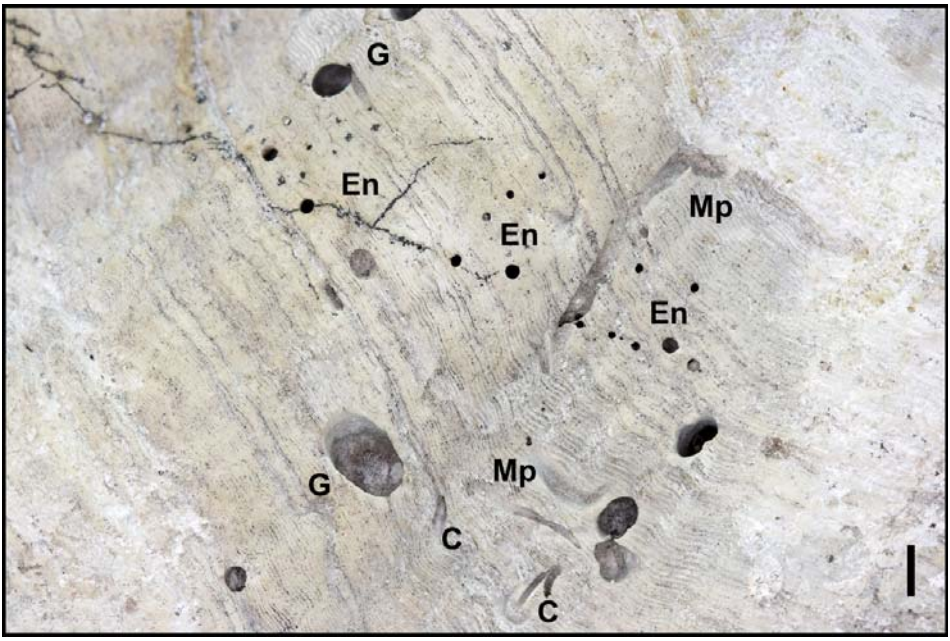

Figure 6. Close-up of Section 3 of the RV. Bioerosion traces of *Entobia cateniformis* (En)., *Gastrochaenolithes lapidicus* (G) and *Maeandropolydora* isp. (Mp) and *Caulostrepsis* (C). Line indicates 3 mm.

its perforation by penetrating the sediment first, already deposited on the surface of the shell. Subsequent erosion cleared the sediment, exposing only the remains of the bivalve borings, which have reached and penetrated the shell.

The main chambers of the borings are ovate, slightly elongate. The outline of the borings is semicircular (Fig. 5) to oval (Figs. 4, 6, 7) in cross section. The size of the borings varies from 2 mm to 7 mm in length and 2-3 mm in width, with a maximum depth of 3.5 mm. The internal wall of the chamber is smooth, without any sign of ornamentation. Kelly and Bromley (1984) described two *Gastrochaenolithes* species based of the shape of the distal parts of the borings, *G. lapidicus* displaying a bluntly paraboloid, rounded base, which distinguished it from *G. torpedo*, where the base is more acutely paraboloid or pointed.

Based on the subcircular to oval cross-section and rounded shape of the bottom part, these borings can be assigned to *Gastrochaenolithes lapidicus* Kelly and Bromley1984 ichnospecies. According to Kelly and Bromley (1984), borings of this type are produced by several bivalve species, including *Lithophaga* and *Hiatella*.

The analyzed borings *of Gastrochaenolithes* did not preserve its producer, probably due to the fact that it had thin valves which were rapidly destroyed after

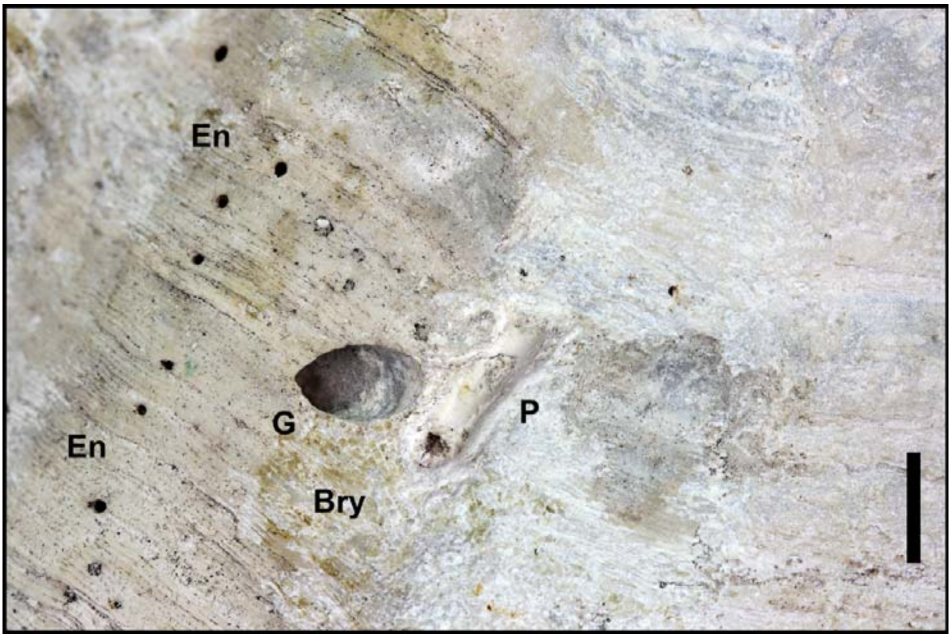

Figure 7. Close-up of Section 4 of the RV. Bioerosion traces of *Entobia cateniformis* (En). and *Gastrochaenolithes lapidicus* (G). Encrustation of polychaete annelid (P) and bryozoans colony (Bry). Line indicates 3 mm.

its death.

Gastrochaenolithes occurs in near shore, shallow marine environments with a low sedimentation rate (Kelly & Bromley 1984, Farinati & Zavala 2002), being a common ichnotaxon in Miocene deposits (Uchman et al. 2001, David et al. 2006, El-Hedeny 2007, Santos et al. 2010, Dermican 2012).

Bioerosion - Borings of polychaete worms

Ichnogenus *Maeandropolydora* Voigt, 1965

The RV of the *Gigantopecten nodosiformis* shows several traces of polychaete worms. The traces are straight (Fig. 6) or sinuous galleries (Figs. 4-5, Fig. 8), for which the authors measured the length and the maximum width, as well as observed their relation with other boring traces on the surface of the shell.

In the Section 1 of the RV there is a sinuous gallery, which describes a loop (Fig. 4), with a constant width measuring 0.5 mm. The length of the trace is 8.5 mm. Based on constant diameter and shape of the trace, this boring is identified as *Maeandropolydora* isp.

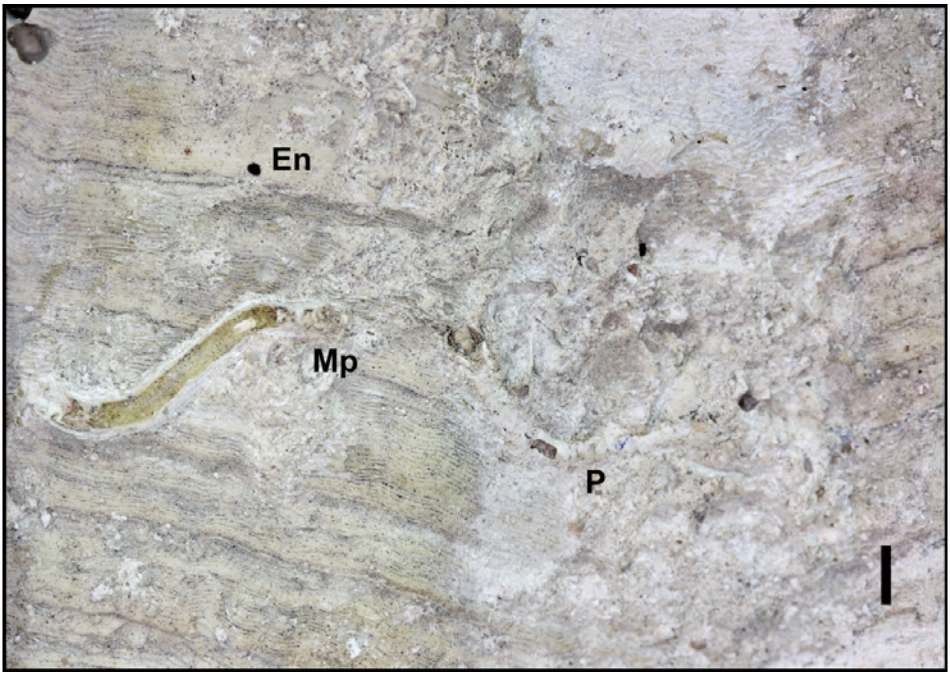

Figure 8. Close-up of Section 5 of the RV. Bioerosion trace of *Maeandropolydora sulcans* (Mp) and polychaete encrustation (P).

In Section 2 of the RV there is a boring referable to *Maeandropolydora* isp. (Fig. 5), it is 7.8 mm in length and 0.3 mm in width.

The straight, tube-like trace in the Section 3 of the RV is positioned parallel with the ribs, along the border between the rib / inter-rib space (Fig. 6). The trace has a constant width of 1 mm and shows two openings in the proximal end, penetrating the shell. The length of the tube-like gallery is 13 mm. There is a cross-cutting relationship between this *Maeandropolydora* trace and former *Entobia*n borings. This section of the shell manifests a second trace identified as *Maeandropolydora* boring, measuring 6 mm in length and 0.8 mm in width.

More ventrally on the shell (Section 5 of the RV – Fig. 8), a sinuous, cylindrical boring is found, partly preserving the dwelling tube of its producer, a polychaete annelid. Its diameter is 2 mm and is constant through its entire length, which measures 26 mm. This trace is preserved in semi-relief on the shell surface as a result of the erosion of the polychaete tube, exposing its remained internal structure. On the base of its morphology, this trace is attributed to *Maeandropolydora sulcans* Voigt, 1965.

Maeandropolydora is regarded as a domichnion of suspension-feeding polychaete worms and is a frequent ichnotaxon in Miocene deposits (Dávid 2006,

Figure 9. Close-up of Section 6 of the RV, with bivalve encrustation. Line indicates 5 mm.

Dávid et al. 2006, El-Hedeny 2007, Dermircan 2012, El-Hedeny & El-Sabagh 2018). According to Herman et al. 2012, *Maeandropolydora* has palaeoecological significance, its producer attacking the shells of dead mollusks, never those of living species.

Ichnogenus ***Caulostrepsis*** Voigt, 1965

Smaller polychaete galleries can be observed on Section 3 of the right valve (Fig. 6). The galleries are cylindrical, showing a clear U-shape in the first trace, the second preserving only the united branches of the U-shaped boring, lacking its base due to subsequent erosion. The limbs of the U-shaped borings are connected by a vane, a characteristic morphology for *Caulostrepsis* isp.

This trace fossil was mainly produced by polychaete annelids of the genus *Polydora* (Radwanski 1969) and is recorded in Miocene sediments (David 2006, David et al. 2006, Dermican 2012, El-Hedeny & El-Sabagh 2018).

Encrustation structures

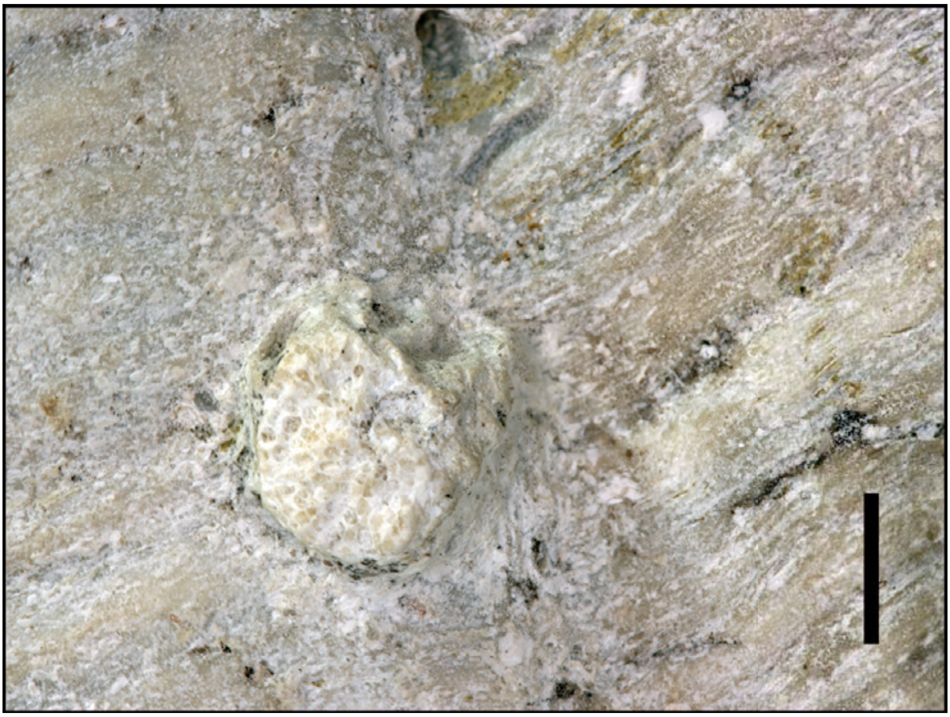

Figure 10. Close-up of Section 7 of the RV, with bryozoan encrustation. Line indicates 3 mm.

Encrustation structures are present on both valves of the studied *Gigantopecten nodosiformis* shell. On the right valve polychaete annelids, bivalves and bryozoans encrusted the shell (Fig. 2 Sections 4, 5, 6, 7). The left valve shows bivalve and bryozoans encrustation (Fig. 3, Sections 1 and 2).

Polychaete annelid encrustation occurs only on the RV. There is a short dwelling tube of a polychaete worm in Section 4, near the *Gastrochaenolithes* boring (Fig. 7). It has a constant diameter of 1.8 mm and a length measuring 8 mm.

Near the *Maeandropolydora* isp. of Section 5 of the RV there is a sinuous tube of spionid polychaete, which is slightly in touch with the trace identified as *Maeandropolydora sulcans* (Fig. 8). This spionid tube has a circular cross section with 2 mm diameter and a total length 16 mm.

Bivalve encrustation occurs on both valves. The right valve preserved an ostreid encrusting the *Gigantopecten nodosiformis* shell in its postero-dorsal region, just under the auricle, which is missing (Fig. 2 – Section 6; Fig. 9). Bivalve encrustation is preserved on the left valve as well, in the antero-dorsal region of the *Gigantopecten* nodosiformis shell (Fig. 3 – Section 1; Fig. 11).

Bryozoans encrusted the *Gigantopecten* shell on both sides, colonies can

Figure 11. Close-up of Section 1 of the LV, with bivalve encrustation. Line indicates 5 mm

Figure 12. Close-up of Section 2 of the LV, with bryozoan encrustation. Line indicates 3 mm.

be observed in Section 4 (Fig. 7) and Section 7 of the right valve (Fig. 7). The left valve preserved a bryozoan encrustation, represented by a fan-shaped colony (Fig. 3, Section 2; Fig. 12).

Conclusions

The high frequency of well developed bioerosion and encrustation structures on a single specimen of *Gigantopecten nodosiformis* suggests a slow burial of the shell with a significant amount of time being exposed on the sea bottom.

The bioerosion consists of the following ichnotaxa: *Entobia cateniformis, Gastrochaenolithes lapidicus, Meandropolydora sulcans, Maeandropolydora* isp. *and Caulostrepsis* isp. The bioerosion trace fossil assemblage can be regarded as the *Entobia* ichnofacies, which is frequent worldwide on the Miocene rocky shorelines. The producers of the bioerosion are suspension feeders, indicating clear waters and high plankton productivity, which is their main food source.

The spatial distribution and relationship between the bioerosion structures allow the reconstruction of the succession of these ichnocoenoses. First a sponge-dominated community colonized the shell, followed the polychaete annelid- dominated community, which produced traces which cross-cut those produced by sponges. The last bioeroder was probably the bivalve-dominated community, which made their dominchia in the thin sediment which has already been deposited on the surface of the shell, producing shallow borings while penetrating the shell. Thus the borings represent truncated chambers of *Gastrochaenolithes lapidicus* after the sediment was eroded.

The shell surface is encrusted by worms, bivalves and bryozoans, but it is impossible to establish if the shell was encrusted during the bivalve's life or after its death.

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