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BIOEROSIVE STRUCTURES ON THE PLIOCENE ROCKY SHORES OF CATALONIA (SPAIN)

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ABSTRACT

Bioerosive structures relating to rocky shores active during the Pliocene and associated pebbles in three basins at Baix Ebre, Baix Llobregat and Alt Empordà areas (Catalonia, Spain) are reviewed. A high degree of uniformity exists between the basins from the ichnological point of view, although each one presents certain particular characteristics. The main bioerosive structures observed are the following: *Entobia* ichnospp.; borings of cheilostomata bryozoans of *Spatipora* and *Terebripora* types; *Gastrochaenolites lapidicus* and *G. torpedo*; *Meandropolydora* ichnosp.; *Centrichnus eccentricus; Caulostrepsis taeniola* and *Caulostrepsis* ichnosp.; *Trypanites* ichnosp.; *Gnatichnus pentax* and bowl-shaped pits attibuted to regular echinoid activity. Apart from these bioerosive structures, the etching scars caused by cirripedes and epilithic bivalves are also common. The extensive presence of the *Gastrochaenolites-Entobia* ichnocenosis in Neogene rocky shores is emphasized.

Keywords: Bioerosion, Rocky shores, Ichnofacies, Pliocene, Spain.

RESUMEN

En el presente trabajo se revisan las estructuras bioerosivas que afectan tanto las costas rocosas activas durante el Plioceno en las cuencas del Baix Ebre, Baix Llobregat y Alt Empordà (Catalunya) como los cantos asociados a ellas. Se ha podido observar un alto grado de uniformidad entre las tres cuencas, aunque cada una presenta ciertas características particulares. Las principales estructuras bioerosivas detectadas en estas cuencas son *Entobia* icnospp., perforaciones de briozoos queilostomados del tipo *Spatipora* y *Terebripora; Gastrochaeonolites lapidicus* y *G. torpedo; Meandropolydora* icnosp.; *Centrichnus eccentricus; Caulostrepsis taeniola* y *Caulostrepsis* icnosp.; *Trypanites* icnosp.; *Gnatichnus pentax* y depresiones en forma de cuenco atribuidas a equínidos regulares. También son comunes las estructuras de incrustación producidas por cirrípedos y bivalvos epilíticos. En el Baix Ebre la bioerosión pliocena sólo se detecta en los conglomerados de Sant Onofre (donde *G. torpedo* es localmente abundante), y en el paleo-acantilado aflorante. En la cuenca del Baix Llobregat la bioerosión se halla mejor representada, con la asociación de *G. lapidicus* y *G. torpedo*, abundancia de *Entobia, Caulostrepsis, Meandropolydora* y *Trypanites*, en la cuenca del Alt Empordà aparece una gran variedad de icnotaxones, incluyendo los ya mencionados y otros de exclusivos, como las cubetas de equínidos y *Centrichnus eccentricus.* La presencia y abundancia de *G. lapidicus, G. torpedo* y *Entobia* icnospp. en el Baix Llobregat y el Alt Empordà revelan un ambiente deposicional muy poco profundo y de aguas muy claras. Los conglomerados del yacimiento de Els Olivets (Alt Empordà) revelan dos fases de bioerosión relacionadas con dos posibles oscilaciones del mar, sólo observables en este yacimiento. Se resalta asimismo la presencia generalizada de la icnoasociación *Gastrochaenolites-Entobia*, que caracteriza muchos ambientes poco profundos de las costas rocosas del Neógeno.

Palabras clave: Bioerosión, Costas rocosas, Icnofacies, Plioceno, España.

INTRODUCTION

Until some years ago, the fossil rocky shores had not aroused any great interest among geologists or paleontologists. The causes for this lack of incidence may have been the absence in the geological record of paleoenvironments similar to those of recent cliffs, the possibility that they were not well registered and the assumed recent development of the faunas inhabiting these environments (Boucot, 1981). See Johnson (1988) for more geological and paleontological data.

Nevertheless, the paleogeographical information provided by fossil rocky shores referring to the position of the former coast lines is of high interest for the knowledge of the evolution of the basins, and the associated biota could provide us with documentation for the corresponding paleoenvironments.

From a more paleontological point of view, there is little documentation about the temporal evolution of the biotas of rocky shores in comparison with data concerning the inhabitants of soft substrata (e.g. Bottjer and Ausich, 1986). Various circumstances have given rise to this situation, but it is convenient to emphasize two: first, the soft substata environments are depositional and, thus, hardly favourable to the accumulation of sediments and to the organic remains preservation. Secondly, a large proportion of the inhabitants of rocky shore environments do not fossilize directly but rather leave traces of their activity. Rocky shores are basically erosive and indicative of negative sedimentation. In fact, practically all of the papers published in this subject (see further on) have to centre their studies in the bioerosive activity recorded, deducing the possible producer of such activity from present data. Skeletal remains

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are scarce and are usually restricted to very specific groups, usually with an encrusting habit (barnacles, ostreids).

Johnson (1988) reviewed the difficulties related to the preservation of rocky environments from the geological past. According to him, rocky coasts represent more than 33 % of recent ocean coast lines. These frequencies suggest that the old rocky coasts must have been a regular characteristic of the stratigraphic record, representing periods of high and low continentality. The physical environments of the rocky coasts have remained unchanged qualitatively during the greatest part of the Phanerozoic, and the organisms which inhabit this environment are not in fact a phenomenon of recent appearance.

Recently, paleontologists have discovered the potential of information generated from the study of the hardgrounds corresponding to marine omission surfaces. Now is the moment to make an effort to understand the unconformities that rocky shores represent.

Recent studies (especially in the Tertiary) in differing geographical areas (Aigner, 1983; Bromley and D'Alessandro, 1987; Watkins, 1990; Bromley and Asgaard, 1993) have increased the data regarding these marine environments.

The purpose of the present study is to describe and interpret the ichnocenoses recognized on the Pliocene rocky shores of the Catalan basins and thus serving to augment our knowiedge of trace fossils on hard substrate and of marginal biofacies.

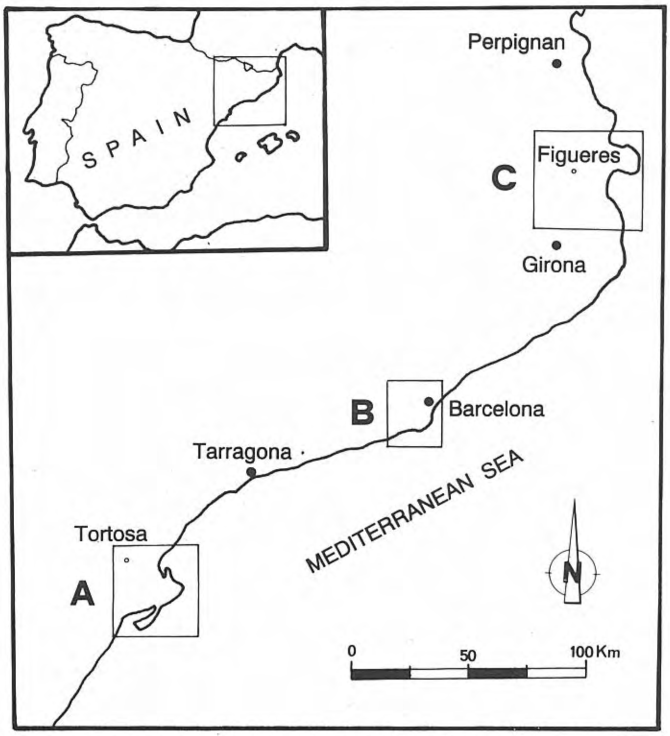

Figure 1. Geographical situation of the Pliocene marine basins of Catalonia (NE Spain): A) Baix Ebre, B) Baix Llobregat and C) Alt Empordà.

GEOGRAPHICAL AND GEOLOGICAL SETTINGS

From S to N, the marine Pliocene of Catalonia crops out in the basins of Baix Ebre, Baix Llobregat and Alt Empordà (Fig. 1). The sediments filling these basins consist of different types of grey-blue clays, yellow sands and conglomerates, with varying sandy matrix and carbonate cement contents. In general, the clays are highly fossiliferous. The sediments have been dated of a Zanclean (Early Pliocene) age (Martinell, 1988; Matias, 1990).

The Pliocene sediments lie upon materials of different ages (Paleozoic, Cretaceous, Paleocene, Miocene) and lithologies (shales, limestones, trachytes), which in some cases acted as cliffs during the Pliocene.

The bioerosive phenomena are found on the high relief surfaces representing ancient cliffs, on conglomerate pebbles and penetrating skeletal remains (mainly molluscan shells). The present study is centred on the first two cases, as the third one has been studied extensively over the last few years (Martinell and Marquina, 1980; Martinell, 1982 a, b; Bromley and Martinell 1991; Hoffman and Martinell, 1984; Kitchell *et al.*, 1986; Martinell and Domènech, 1986).

The bioerosive structures upon inorganic substrates recognized up to the present are produced by the following groups of organisms (Table 1): sponges (*Entobia* ichnospp.), *Spatipora* and *Terebripora*-like cheilostomata bryozoan; bivalve molluscs (*Gastrochaenolites lapidicus* Kelly and Bromley, *G. torpedo* Kelly and Bromley, *Centrichnus eccentricus* Bromley and Martinell); worm-like organisms (*Meandropolydora* ichnosp., *Caulostrepsis taeniola* Clarke, *Caulostrepsis* ichnosp., *Trypanites* ichnosp.); echinids (*Gnatichnus pentax* Bromley and bowl-shaped pits). Apart from these bioerosive structures, the etching scars caused by cirripedes and epilithic bivalves are also common (Fig. 2).

PLIOCENE ROCKY SHORES OF CATALONIA

Baix Ebre

The detailed lithological data referring to this basin were described by Arasa (1990). The following principal Pliocene units are distinguished: 1) marine clays and

ICHNOTAXA		RECENT PRODUCERS
Entobia	....	sponges
Gastrochaenolites lapidicus	....	rock-boring bivalves
Gastrochaenolites torpedo	....	rock-boring bivalves
Centrichnus eccentricus	....	anomiid bivalves
Meandropolydora	....	worm-like organisms
Caulostrepsis taeniola	....	worm-like organisms
Caulostrepsis	....	worm-like organisms
Trypanites	....	worm-like organisms
Gnatichnus pentax	....	echinids
Bowl-shaped pits	....	echinids
Cheilostomate bryozoans	....	Terebripora and Spatipora-like bryozoans

Table 1. Main bioerosive structures present in the three basins studied, with indication of their recent producers.

sandstones; 2) calcareous monogenic conglomerates and breccias, and 3) lacustrine limestones and shales.

The main bioerosive phenomena of the Baix Ebre are observed upon the calcareous pebbles of the Pliocene monogenic conglomerates (Fig. 3a) and upon various pre-Pliocene polygenic conglomerates (Fig. 3b), at Sant Onofre outcrop.

In the first materials, the percentage of calcareous pebbles with bioeresive activity traces is relatively low (4-5 %). This result is not surprising, given that the paleoenvironmental conditions were rather restricted, as the fossiliferous content demonstrates (Martinell and Doménech, 1984). The ichnotaxa present are schematized in Table 2.

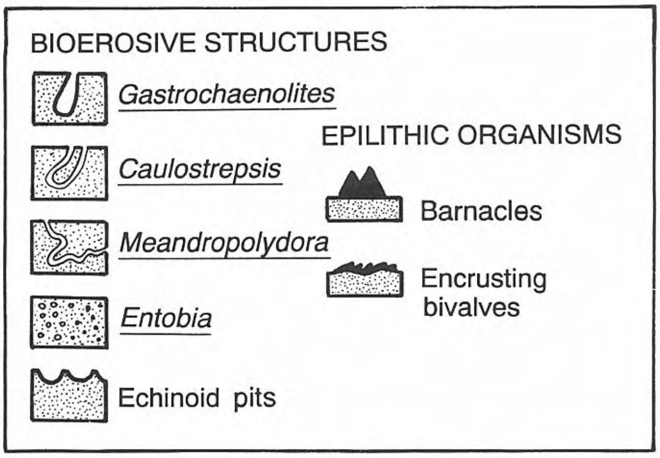

Figure 2. Schematic representation of the main bioerosive structures and epilithic organisms appearing in the Figures 3, 4 and 5.

Frequently, *Entobia* ichnospp. appear enlarged subsequently due to the activity of probable herbivorous gastropods. These borings are generally rather superficial (less than 5 mm deep).

In some pebbles the complete morphology of the bivalve borings are excepcionally preserved, and is noticeable the presence of some large size specimens (greater than 15 cm long) of *Gastrochaenolites torpedo* Kelly and Bromley.

Some pebbles of the conglomerates also present rectilinear *Trypanites* of small diameter (2 mm), which are quite deep (2 cm).

The boring activity normally only affected a restricted area of the pebbles. This indicates that the process took place in conditions of certain calm, subsequent to the settling of the pebbles. With reference to the borings in general, the environmental conditions should be of little depth.

The Pliocene blue clays are unconformable upon various pre-Pliocene polygenic conglomerates, which bear encrusted *Hinnites ercolanianus, Ostrea* sp. and *Balanus* spp. (Fig. 3b). These conglomerates host sporadic *Gastrochaenolites torpedo*, and the encrusting shells in some cases show *Entobia* and borings of cheilostomate bryozoans.

In conclusion, the bioerosive activity in the Plioce-

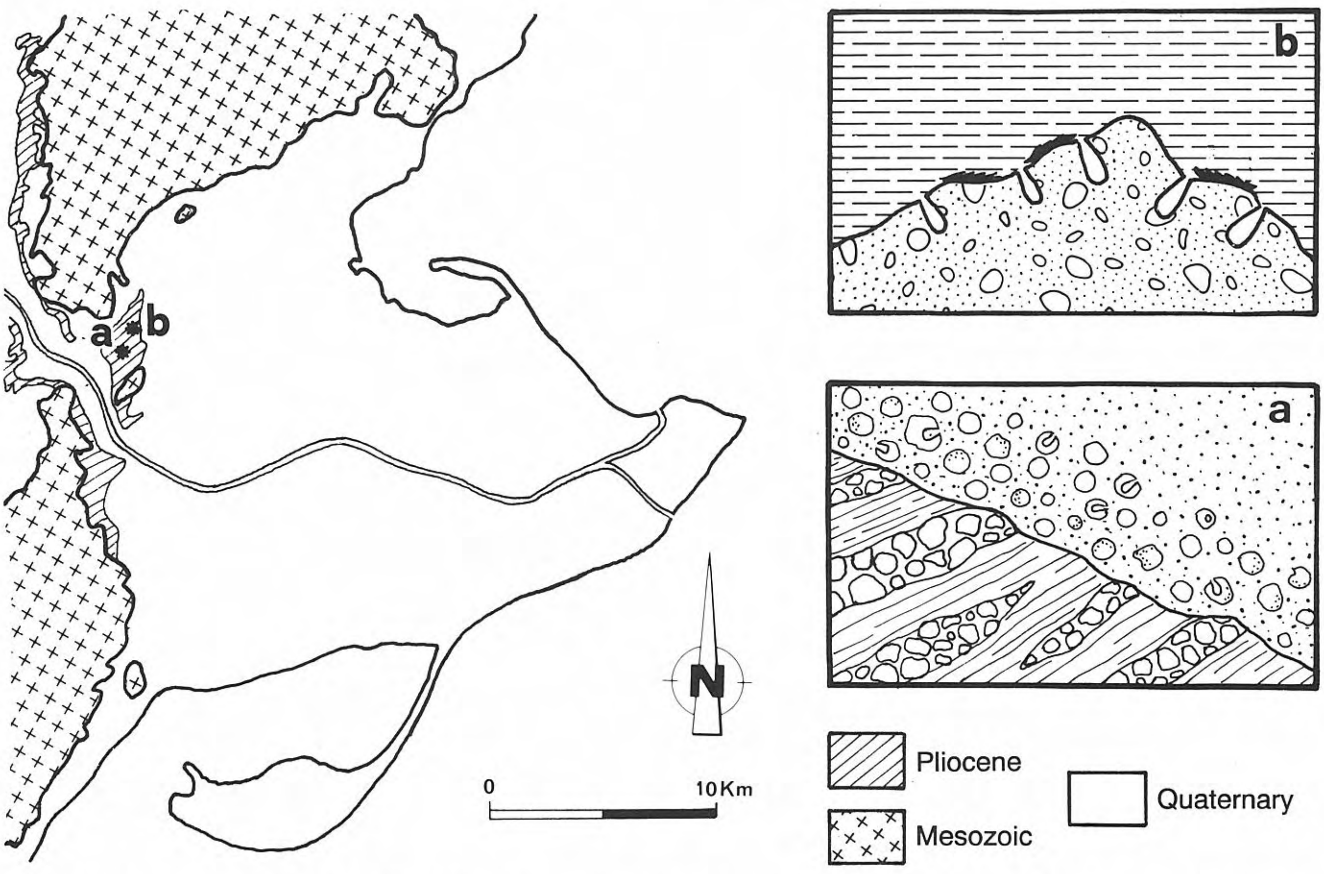

Figure 3. Rocky shores studied in the Baix Ebre Pliocene basin. Idealized sections of: a) the Pliocene monogenic conglomerates, and b) the contact with pre-Pliocene polygenic conglomerates.

ne of the Baix Ebre is scarce, present only in the conglomeratic unit of Sant Onofre (where *G. torpedo* is locally abundant), and in the outcropping paleocliff.

Baix Llobregat

The geological characteristics of the basin have been described by several authors (e.g., Martinell, 1988; Clauzon *et al.*, 1990). Five major lithological units have been defined: 1) Castellbisbal Gravel Unit (fluvial); 2) Transitional Unit (clayey-sandy, deposited under brackish conditions); 3) Blue Clay Unit (marine); 4) Sandy Clay Unit (marine, with continental influences); 5) Conglomerate Breccia Unit (fan delta).

The bioerosive phenomena in the basin appear in two types of substrata: on the Pliocene cliffs (Table 2) and on small hard surfaces (clasts, molluscan shells, etc.) of the Blue Clay Unit.

The old rocky shore is locally recognized in the Pic d'En Valls, El Papiol, Plaça de les Bruixes and Can Albareda outcrops (Fig. 4).

1. El Papiol: the Pliocene paleocliff is here formed by Paleozoic slates (Fig. 4a 1) or by Miocene limestones (Fig. 4a 2). In the first case, the bioerosive activity was poor and only two ichnogenera are observed: *Gastrochaenolites* of small diameter, and *Entobia* with stenomorphic growth upon shells of *Hinnites ercolanianus* and *Ostrea* spp. which encrust the slates.

In contrast, the bioerosive structures on the Miocene limestones are numerous, although with low diversity. The most abundant traces are *Gastrochaenolites lapidicus* and *G. torpedo* which affect both the limestone substratum and the encrusted organisms (*Hinnites ercolanianus* and *Ostrea* sp.). This indicates that the boring activity took place subsequent to the colonization of the rocky shore by epilithic bivalves. The ensemble of these two ichnoespecies displays a high density (more than 400 individuals/m^2), which is typical of shallow environments (Martinell and Domènech, 1986; Bromley and Asgaard, 1993).

Frequently within the shell of the encrusting bivalves are found *Entobia* ichnospp. with a low degree of stenomorphic growth. In the limestone substratum, *Entobia* may be found with xenomorphic growth among the *Gastrochaenolites*. That indicates two different phases of boring activity. In a first step, there was the colonization by rock-boring bivalves; subsequently a possible erosive phase took place, and, finally, encrusting bivalves and sponges occupied the substratum. It seems difficult to affirm that erosion and colonization were developed at the same time, as preservation of traces is not very good. Obviously, the encrusting bivalves and their borers installed themselves after the erosive period. Upon the shells of the bivalves it is also worth pointing out the presence of *Caulostrepsis taeniola* and *Meandropolydora* ichnosp. This last ichnogenus was also recognized in the Miocene limestone, where it reached more than 20 cm length.

2. Pic d'En Valls (Fig. 4b): At this locality, the outcroping Paleozoic slates present an abundant epilithic fauna whith extensive eroded *Gastrochaenolites lapidicus.*

The slates are lightly bored, although small, more or less rectilinear *Trypanites* occur, with a depth of up to 7 mm.

3. Plaça de les Bruixes (Fig. 4c): Bioerosion is very evident near the unconformable contact between the Paleozoic slates and the Pliocene sediments at this locality. The most abundant borings in the Paleozoic slates are *Gastrochaenolites torpedo* and *G. lapidicus*, with locally high densities (aproximately 100 individuals/m^2). *Entobia* ichnospp. are found in abundance, but only on the encrusted bivalves, together with *Caulostrepsis taeniola* and *Meandropolydora* ichnosp., as well as small cheilostomate bryozoans borings.

4. Can Albareda (Fig. 4d): Due to the continuous landslides which occur in this zone, the Pliocene rocky shore outcrops are very restricted. *Gastrochaenolites lapidicus* of large dimensions (2.5 cm diameter and up to 20 cm depth) and irregular distribution have been recognized here. *Entobia* ichnospp. are generally observed with idiomorphic growth.

Furthermore, *Gastrochaenolites torpedo, G. lapidicus, Caulostrepsis* and *Entobia* are also common in calcareous pebbles proceeding from Sant Vicenç dels Horts and Can Albareda outcrops. They are characterized by their small size 0.5 cm diameter), and by their abundance in some pebbles, with *Gastrochaenolites* densities

ICHNOTAXA	1	2	3	4	5	6	7	8	9	10
Entobia	c,d	b,c		c	b,d	d	c	b	c,e	b
Gastrochaenolites lapidicus		b,c	a	a	d	d		b	d,e	b
Gastrochaenolites torpedo	d,e	b,c		a	d	d		b	d,e	b
Centrichnus eccentricus									c	
Meandropolydora sp.		b,c		c				b,d	c,d	
Caulostrepsis taeniola		c		c						
Caulostrepsis sp.					d	d		b,d	c,d	
Trypanites sp.	d		a				c			
Gnatichnus pentax									c	
bowl-shaped pits										b
Cheilostomate bryozoans	c			c						

Table 2. Bioerosive structures in each studied outcrop with indication of the substrata affected. 1: Sant Onofre, 2: El Papiol, 3: Pic d'en Valls, 4: Plaça de les Bruixes, 5: Can Albareda, 6: Sant Vicenç dels Horts, 7: Palau de Santa Eulàlia, 8: Sant Mori-Sant Miquel, 9: Els Olivets 10: Viladamat. a: slates, b: limestones, c: encrusting shells, d: pebbles, e: conglomerates.

up to 20-25 dm^2. The bioerosion on shells and clasts included in the clay deposits has been studied by Martinell and Marquina (1980), Martinell *et al.* (1982) and Gibert and Martinell (1992).

Alt Empordà

Data about geological characteristics of this basin were given by Agustí *et al.* (1990). The lithological sequence is: 1) blue clays deposited in the center of the basin; 2) brown clays with some continental influences; 3) yellow sands, very variable in grain size and in mineral composition, and 4) conglomerates. Lateral and vertical changes between these lithofacies are observable.

The Pliocene rocky shore outcrops are observed at Palau de Santa Eulàlia, Sant Mori-Sant Miquel de Fluvià, Els Olivets and Viladamat (Fig. 5). All these outcrops are topographically located at different levels, and an accurate correlation between them is not possible. In consequence, the sequence of events deduced at each point must be considered not necessarily isochronous.

The ichnotaxa present are listed in Table 2 and described in the following paragraphs.

1. Palau de Santa Eulàlia: This site, located next to the volcanics materials outcroping between Els Olivets and Sant Miquel de Fluvià (Fig. 5), is made up of detritical materials which overlie a basaltic shore of pre-Pliocene age (Donville, 1973). The bioerosive activity here is very weak. *Entobia* ichnospp. was observed on some shells of the attached bivalve *Isognomon maxillatus* Lamarck, and on some basaltic rocks contained small rectilinear *Trypanites?* ichnosp.

2. Sant Mori-Sant Miquel de Fluvià (Fig. 5c): The Pliocene coastal level is clearly seen at this locality, where Pliocene sediments lie unconformably on Cretaceous limestones. These limestones show many borings mainly attributable to rock-boring bivalve activity. In a well defined surface of 2 m long and 0.4 m high it is possible to count more than 200 *Gastrochaenolites* (both *G. lapidicus* and *G. torpedo*). *Entobia* ichnospp. with idiomorphic growth covering small surfaces (some cm^2) can be seen in the calcareous clasts within the overlying sands, and is equally abundant in the paleocliff surface. In the level corresponding to O m depth appear encrusting cirripedes, in association with *Gastrochaenolites*. Moreover, *Meandropolydora* ichnosp. and *Caulostrepsis* ichnosp. were observed both on the paleocliff and on the calcareous clasts. A zonation between *Gastrochaenolites* and *Entobia* similar to that described below for the Viladamat outcrop is suggested for this area.

3. Els Olivets (Fig. 5a): The outcrop comprises approximately 4 m thick yellow sands with an interbedded conglomeratic layer of a thickness varying from 30 to 70 cm, and represents the uppermost Pliocene in the area. These sediments overlie Paleogene sediments (sand-

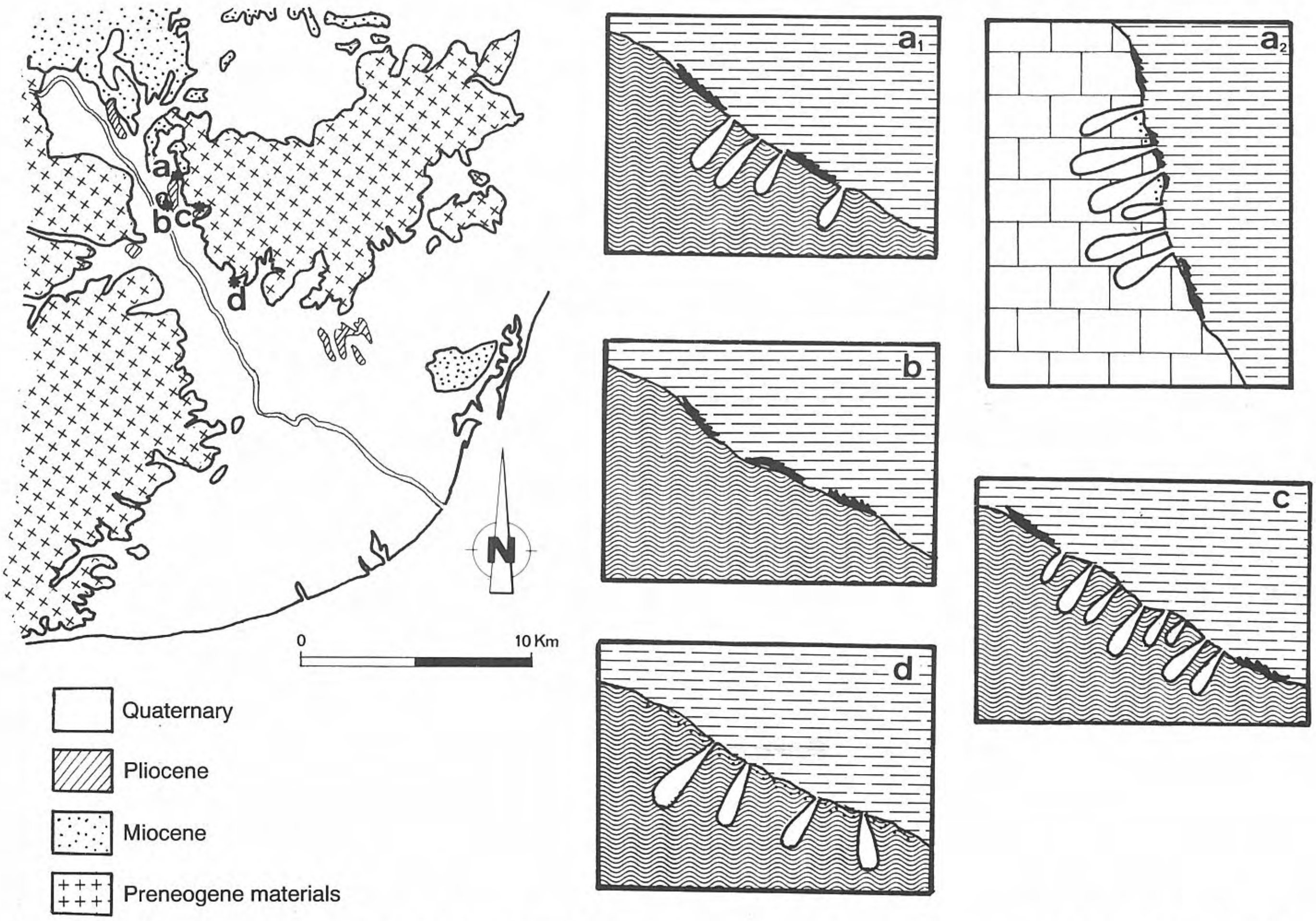

Figure 4. Rocky shores studied in the Baix Llobregat Pliocene basin. Idealized sections at: a 1) El Papiol-slates; a 2) El Papiol-limestones; b) Pic d'en Valls; c) Plaça de les Bruixes, and d) Can Albareda.

stones and limestones) at this point, in which no evidence of bioerosion has been found until now.

In contrast, a great amount of bioerosive traces can be observed in the conglomerates. This activity affects shells as well as calcareous clasts, in addition to the matrix including the clasts, and the encrusting shells. This fact suggests (Martinell and Domènech, 1986) that there were two phases of bioerosion: one taking place over the unconsolidated pebbles and another occurring after become stabilized and consolidated. During the first step, borers affected the loose pebbles. Subsequently, the conglomerate was cemented and a second set of borings affects clasts as well as the encrusting epilithic fauna and the cemented matrix. The presence of *Gastrochaenolites* and *Entobia* suggests very clear waters, and a very low rate of sedimentation (Bromley and Asgaard, 1993).

The bioerosive activity on shells occuring in the yellow sands was studied by Martinell (1982, a, b) and Bromley and Martinell (1991).

d) Viladamat (Fig. 5b): The gravels forming the deltaic lobe pass laterally to littoral sands which overlie Eocene limestones. On the surface of these limestones bioerosive action by endolithic organisms is evident, and epilithic fauna (balanids, oysters, etc.) is also abundant. The most abundant ichnospecies are *Gastrochaenolites torpedo* and *G. lapidicus*, with an average diameter of 1.5 cm. Also conspicuous is the presence of *Entobia* ichnospp., although always carpeting small surfaces.

At the southeast of the outcrop a considerable increase in the number and size of bivalve borings in the Tertiary limestones can be observed (*G. lapidicus* and *G. torpedo* can reach sizes greater than 5 cm in maximum diameter). Close to these are frequently found bowl-shaped pits with diameters fluctuating between 4 and 9.5 cm and from 1 to 2.5 cm depth.

From the field observations, a clear zonation concerning all these borings appears: *Entobia* takes place in the lower part of the outcroping paleocliff; *Gastrochaenolites* and the echinoid pits appear concentrated in the upper part, 2 m above.

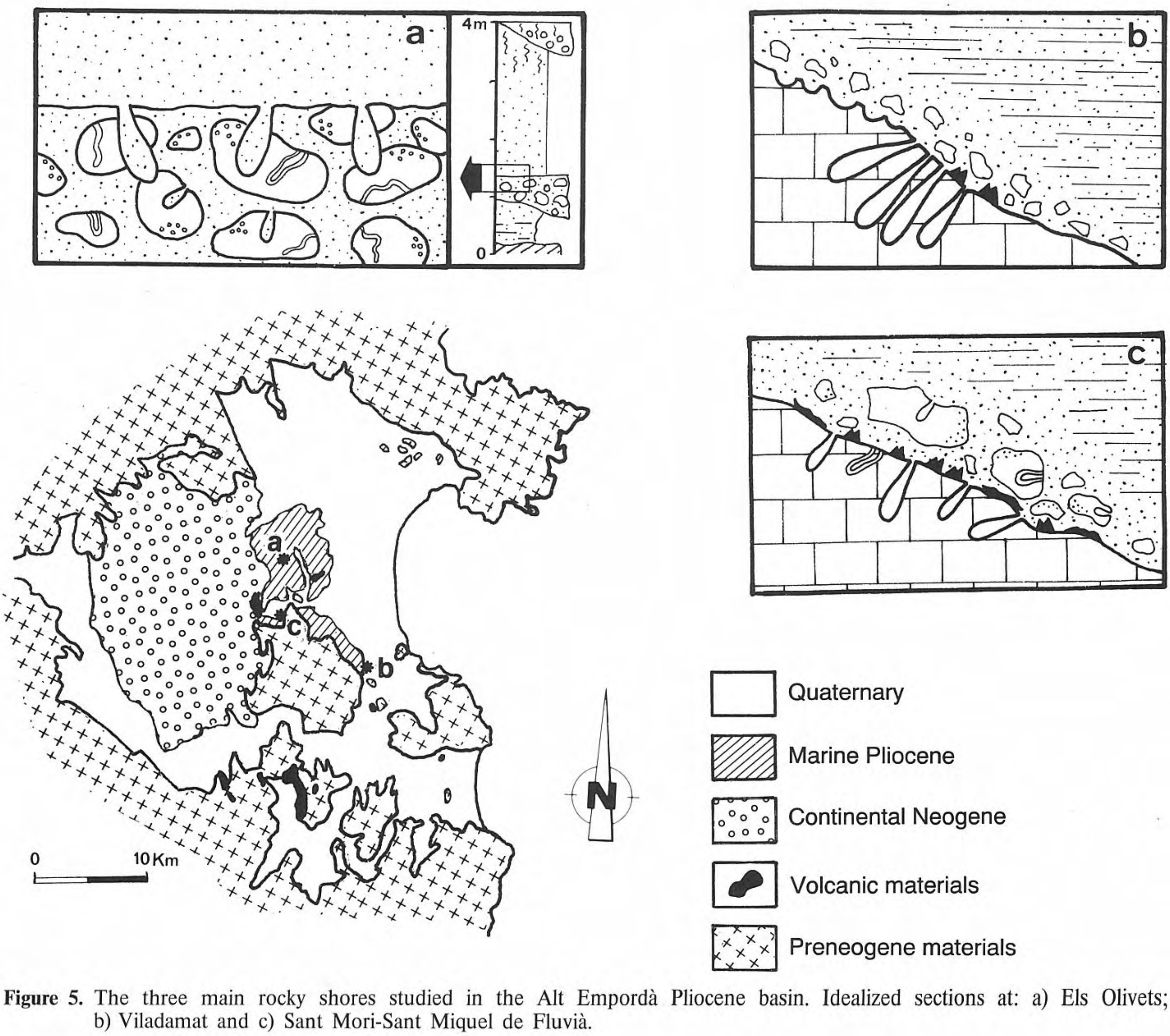

Figure 5. The three main rocky shores studied in the Alt Empordà Pliocene basin. Idealized sections at: a) Els Olivets; b) Viladamat and c) Sant Mori-Sant Miquel de Fluvià.

This zonation coincides with that described by Bromley and Asgaard (1993) during a Pliocene sea-level rise at the coast of Rhodes (Greece). In addition, these authors identified a progressive substitution of the rock-boring bivalve perforations by sponge borings with possible increasing depth.

DISCUSSION

The bioerosive structures along the cliffs which outcrop in the different Pliocene basins of Catalonia are abundant and varied, although the state of preservation of the traces impedes, in the majority of cases, the determining to an ichnospecific level. For example, it has been not possible to identify any of the numerous ichnospecies ascribed to *Entobia* (Bromley and D'Alessandro, 1987) and these traces are left at ichnogeneric level. This has been a generalized situation, and does not allow us to make detailed comparisons with other ichnocoenoses studied in rocky shores of a similar age from other geographical points (Aigner, 1983; Bromley and D'Alessandro, 1987; Watkins, 1990; Bromley and Asgaard, 1993). The surprising richness, diversity and preservation of the traces described by the later authors in the Pliocene of Rhodes led them to the determination of tiers and suites. Unfortunately, the characteristics of the bioerosive content in the Pliocene of Catalonia make not comparables both areas. Nevertheless, some considerations regarding the presence and representation of some forms are admissible.

The association of the bioerosive structures described in the Baix Llobregat and Alt Empordà outcrops, with dominance of *Gastrochaenolites lapidicus* and *G. torpedo*, abundance of *Entobia* ichnospp. and a significant presence of *Caulostrepsis* ichnosp., *Meandropolydora* ichnosp. and *Trypanites* ichnosp. is characteristic of shallow marine environments (Bromley and D'Alessandro, 1990; Bromley and Asgaard, 1993), and reveals very and shallow facies and very clear waters.

Following Bromley and Asgaard (1993), at the present time *Gastrochaenolites torpedo* and *G. lapidicus* are produced nowadays in the Mediterranean by *Lithophaga lithophaga* and *Gastrochaena dubia*, two species restricted to very shallow environments (0-10 m depth in the case of *L. lithophaga*). Moreover, these authors remark the necessity of a very low or null rate of sedimentation to permit the development of the individuals.

In one of the Empordà outcrops (Viladamat), a zonation between borings of bivalves (in the upper part of the outcrop) and sponges (2 m below) is observed. This phenomenon is not identified in any other of the studied outcrops, except maybe in the case of Sant Mori-Sant Miquel. Unknowing the sponge ichnospecies concerned, any paleobatimetric inference is hazardous, but *Entobia* possibly indicates a zone deeper than that with *Gastrochaenolites* and bowl-shaped pits. Martinell and Domènech (1986) attributed the bowl-shaped pits to bioerosive activity of regular echinoids. Great similarity can be found between these pits and the traces of recent *Paracentrotus lividus*. Today, such borings are found at depths between 0 and 10 m in the Mediterranean, with a maximum presence between 0 and 2 m (Martinell, 1981). Considering also the abundance of *Gastrochaenolites torpedo* and *G. lapidicus* in the same point, it seems clear that the upper bioerosion horizon of Viladamat would correspond to a very shallow environment, between 0 and 2 m depth.

The material studied in the Els Olivets outcrop (Alt Empordà basin) reveals two phases of bioerosion, the first affecting only the pebbles, and the second the conglomerate, matrix and encrusters. These phases are related to two possible oscillations of the marine level, not identifiable by other means (Martinell and Domènech, 1986). This outcrop represents the uppermost Pliocene in the area and it is the only site where the oscillation has been recorded.

The bioerosive activity in the Pliocene of the Baix Ebre is scarce, because the rather restricted conditions, but *G. torpedo* is abundant.

In the Baix Ebre basin, *Entobia* traces on the pebbles appear enlarged by the activity of herbivorous gastropods. At the present time, this phenomenon may be observed at numerous points on the Mediterranean coast. In these cases, individuals of the very expanded species *Littorina neritoides* and *L. punctata* installed themselves inside the small perforations made by sponges, where they gnaw at the encrusted algae on which they feed (personal observations). *L. neritoides* live high in the rocky shores and even in the splash zone, which is never submerged. That could indicate that the deposition of the pebbles affected both by sponge perforations and activity of gastropods were deposited in a really very shallow depth.

Due to the extensive stratigraphic distribution of the ichnogenus *Trypanites* (Cambrian-Recent) (Warme, 1975; Kobluck *et al.*, 1978), Frey and Seilacher (1980) chose it to define the shallow ichnofacies in hard substrate. In the Pliocene basins studied the most representative ichnotaxa of these environments are, in first place, *Gastrochaenolites* and, secondly, *Entobia*, which appears in a lesser proportion. This association is found in many other Neogene outcrops in the Mediterranean and the Atlantic, both at the East coast (Portugal and Maroc, for example) and the West (Venezuela, for example) (personal observations). The same may also be said concerning the Pleistocene and the Holocene. Also, the bibliographical references for this age and areas mention both these ichnogenera as the most representatives (Bromley and Asgaard, 1993, etc.). We consider therefore that emphasis must be given to the ichnocoenosis *Gastrochaenolites-Entobia* when characterizing the shallow environments of hard substrate of a Neogene age.

CONCLUSIONS

At a regional level, the three basins correspond to shallow facies, with some little paleogeographical differences.

The presence of bioerosive activity upon different hard substrates uncomformably upperlied by Pliocene sediments permits us to characterize the ancient rocky shore (paleocliffs) active during this period in these basins.

The three basins present very similar bioerosive characteristics, but some differences exist. In the Baix

Ebre Pliocene bioerosion is scarce, only present in the conglomerates of Sant Onofre (where *Gastrochaenolites torpedo* is locally abundant), and in the outcropping paleocliff. In the Baix Llobregat basin bioerosion is better represented, with the association of *G. lapidicus* and *G. torpedo*, abundance of *Entobia* and a significant presence of *Caulostrepsis, Meandropolydora* and *Trypanites*. In the Empordà basin, a great variety of ichnotaxa appear, including those mentioned in the other basins and some exclusive ones such as the echinoid pits and *Centrichnus eccentricus*.

The presence and abundance of *Gastrochaenolites lapidicus, G. torpedo* and *Entobia* ichnospp. in the outcrops of Baix Llobregat and Alt Empordà reveal a depositional environwent of very shallow conditions and very clear waters (Table 2).

The conglomerates studied in Els Olivets outcrop (Alt Empordà basin) reveal two phases of bioerosion, the first one affecting only the former unconsolidated pebbles, and the second affecting the conglomerates on the whole (pebbles, matrix and encrusters). These two phases are related to two possible oscillations of the marine level.

Emphasis is given to the the extensive presence of the *Gastrochaenolites-Entobia* ichnocoenosis in Neogene rocky shores, characterizing many shallow environments of hard substrate.

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BIBLIOGRAPHY

Agustí, J., Domènech, R., Julià, R. and Martinell, J. 1990. Evolution of the Neogene basin of Empordà (NE Spain). *Paleontologia i Evolució*, Mem. esp. **2**, 251-267.

Aigner, T. 1983. A Pliocene cliff-line around the Giza Pyramids Plateau, Egypt. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **42**, 313-322.

Arasa, A. 1990. El Terciario del Baix Ebre: Aportaciones estratigráficas y sedimentológicas. *Acta Geologica Hispanica*, **25**, 271-287.

Bottjer, D. J. and Ausich, W. I. 1986. Phanerozoic development of tiering in soft substrata suspension-feeding communities. *Paleobiology*, **12**, 400-420.

Boucot, A. J. 1981. *Principles of Benthic Marine Paleoecology*. Academic Press, New York, 1-463.

Bromley, R. G. and Asgaard, U. 1993. Endolithic community replacement on a Pliocene rocky coast. *Ichnos*, **2**, 93-116.

Bromley, R. G. and D'Alessandro, A. 1987. Ichnological study of shallow marine endolithic sponges from the Italian coast. *Rivista Italiana di Paleontologia e Stratigrafia*, **95**, 279-314.

Bromley, R. G. and D'Alessandro, A. 1990. Comparative analysis of bioerosion in deep and shallow water, Pliocene to Recent, Mediterranean Sea. *Ichnos*, **1**, 43-49.

Bromley, R. G. and Martinell, J. 1991. *Centrichnus*, new ichnogenus for centrically patterned attachment scars on skeletal substrates. *Bulletin of the Geological Society of Denmark*, **38**, 243-252.

Clauzon, G., Martinell, J., Aguilar, J.-P. et Suc, J.-P. 1990. Les basins catalans espagnols. *In: Livret-Guide des Excursions (Roussillon, Penedès et Baix Llobregat)*, Regional Committee on Mediterranean Neogene Stratigraphy, 47-73.

Donville, B. 1973. Ages Potassium-Argon des vulcanites du Haut Ampurdan (NE de l'Espagne). Implications stratigraphiques. *Comptes Rendus de l'Academie des Sciences de Paris*, **276 D**, 2497-2500.

Frey, R. W. and Seilacher, A. 1980. Uniformity in marine invertebrate ichnology. *Lethaia*, **13**, 183-207.

Gibert, J. M.ª de y Martinell, J. 1992. Principales estructuras biogénicas en el Plioceno marino de la Cuenca del Baix Llobregat (Catalunya). *Geogaceta*, **12**, 104-106.

Hoffman, A. and Martinell, J. 1984. Prey selection by naticid gastropods in the Pliocene of Empordà (Northeast Spain). *Neues Jahrbuch Geologie Paläontologie*, **7**, 393-399.

Johnson, M. E. 1988. Why are ancient rocky shores so uncommon? *Journal of Geology*, **96**, 469-480.

Kelly, S. R. A. and Bromley, R. G. 1984. Ichnological nomenclature of clavate borings. *Palaeontology*, **27**, 783-807.

Kitchell, J. A., Boggs, C. H., Rice, J. A., Kitchell, J. F., Hoffman, A. and Martinell, J. 1986. Anomalies in naticid predatory behavior: a critique and experimental observations. *Malacologia*, **27**, 291-298.

Kobluk, D. R., James, N. P. and Pemberton, G. 1978. Initial diversification of macroboring ichnofossils and exploitation of the macroboring niche in the lower Paleozoic. *Paleobiology*, **4**, 163-170.

Martinell, J. 1981. Actividad erosiva de *Paracentrotus lividus* (Lmk.) (Echinodermata, Echinoidea) en el litoral gerundense. *Oecologia aquatica*, **5**, 219-225.

Martinell, J. 1982a. Borings produced by presumed brachiopods from l'Empordà (Catalunya). *Butlletí de la Institució Catalana d'Història Natural*, **46** (Geologia 3), 135-139.

Martinell, J. 1982b. Echinoid bioerosion on the Pliocene materials from N. E. Spain. *Geobios*, **15**, 249-253.

Martinell, J. 1988. An overview of the marine N. E. Spanish Pliocene. *Géologie Méditerranéenne*, XV (4), 227-233.

Martinell, J. y Domènech, R. 1984. Malacofauna del Plioceno de Sant Onofre (Baix Ebre, Tarragona). *Iberus*, **5**, 1-27.

Martinell, J. y Domènech, R. 1987. Actividad bioerosiva en el Plioceno del Empordà (Catalunya). *Paleontologia i Evolució*, **20**, 247-251.

Martinell, J. y Marquina, M. J. 1980. Señales de depredación en los Gastropoda procedentes de un yacimiento pliocénico de Molins de Rei (Barcelona). Implicaciones paleoecológicas. *Acta Geologica Hispanica*, XIII, 125-128.

Martinell, J., Marquina, M. J. y Domènech, J. 1982. Moluscos y Crustáceos: una relación traumática. Evidencias en el Plioceno catalán. *Acta Geologica Hispanica*, XVII, 11-19.

Matías, I. 1990. *Els nanofòssils calcaris del Pliocè de la Mediterrània nord-occidental*. Doctoral Thesis, Universitat de Barcelona, 1-241.

Warme, J. E. 1975. Borings as trace fossils, and the processes of marine bioerosion. *In: The study of trace fossils* (Frey, R. W., Ed.), Springer-Verlag, New York, 181-227.

Watkins, S. R. 1990. Paleoecology of a Pliocene Rocky Shoreline, Salton Trough Region, California. *Palaios*, **5**, 167-175.

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