Trace fossil assemblages in rhodoliths from the Middle Miocene of Mt. Camposauro (Longano Formation, Southern Apennines, Italy)

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SUMMARY - Trace fossil assemblages in rhodoliths from the Middle Miocene of Mt. Camposauro (Longano Formation, Southern Apennines, Italy) - There are few taphonomic studies on both recent and fossil rhodoliths. In this paper, trace fossils within rhodoliths produced by boring organisms are studied in detail with respect to their morphologies, their taxonomy as well as position within the rhodoliths. The studied samples originate from a rhodolith floatstone from the Vitulano area of the Camposauro Mountain (Southern Apennines, Italy). These rhodoliths are characterised by common trace fossils. The morphology and size parameters as well as the taxonomic make-up of the coralline algae which construct the rhodoliths are analyzed. The taxonomy of the traces was determined as far as possible following a detailed description of their size and morphology. The traces are represented by macroborers (six ichnogenera) and by other undetermined microborings. The macroborers can be ascribed to the genera Gastrochaenolites, Entobia, Meandropolydora, Trypanites, Uniglobites, (?Caulostrepsis) and were caused by sponges, bivalves, polychaete and/or barnacles. The microborings were produced by bacteria, fungi, algae and/or sponges. Important differences exist in the position and dominance of different ichnotaxa in different parts of the rhodoliths. Furthermore, the boreholes are filled by various types of sediments as well as by calcite cement. Variations of ichnotaxa distribution as well as borehole filling sediments are used to interpret the environment of deposition of the rhodoliths.

RIASSUNTO - Tracce fossili all’interno di depositi a rodoliti del Miocene medio del M. Camposauro (Formazione di Longano, Appennino Meridionale, Italia) - Nell’area di Vitulano (Monte Camposauro, Appennino Meridionale, Italia) affiorano dei depositi miocenici caratterizzati da un floatstone ricco in rodoliti all’interno di una matrice emipelagica marnosa, che giacciono in paracordanza su sedimenti cretacici. Tali depositi possono essere riferiti a quelli noti in letteratura con il nome di Marne ad Orbulina. I rodoliti generalmente non sono presenti all’interno delle sopraccitate emipelagiti e possono essere pertanto considerati come una componente peculiare caratteristica di tale area. Essi sono distribuiti uniformemente nella matrice e mostrano al loro interno una ricca icnocoenosi. Questo lavoro, partendo da un’analisi preliminare dei caratteri dei rodoliti (come la forma, le morfologie di crescita, le componenti biotiche), si focalizza sull’icnocoenosi presente al loro interno al fine di definire i caratteri dei boring, la loro distribuzione, il grado di preservazione e le possibili relazioni che essi hanno con le morfologie di crescita delle corallinacee all’interno dei quali si sviluppano. Tale studio rappresenta una delle prime analisi tafonomiche di associazioni a rodoliti. I caratteri peculiari dei rodoliti eccezionalmente rinvenuti nelle Marne ad Orbulina nell’area di Vitulano offrono una grande opportunità di descrivere le icnocoenosi che si sviluppano all’interno dei depositi a corallinacee tipici degli ambienti di acqua bassa durante il Miocene inferiore e medio in Appennino Meridionale.

Key words: rhodoliths, borings, trace fossils, Miocene, Southern Apennines, Italy
Parole chiave: rodoliti, borings, tracce fossili, Miocene, Appennino Meridionale, Italia

1. INTRODUCTION

Boring and encrusting organisms are widely developed in both fossil and modern marine environments characterised by firm- and hard- substrates. Fossil assemblages in hard substrates often preserve the encrusting elements of the original biocoenosis. Non-sessile faunal elements, including the boring components are generally missing due to various taphonomic processes such as abrasion, fragmentation, disarticulation, dissolution and predation. Nevertheless, the presence of boring organisms can be often deduced from the occurrence of trace fossils (e.g. Bromley 1994; Perry 1996; Pickerill et al. 1998; Taylor & Wilson 2003). The ichnocoenoses produced by borers within hard carbonate substrate, in fact, rally show a good preservation potential, although later processes, such as abrasion, can remove and erode the outermost part of the colonised surface.

There are many examples from the literature which describe how destruction of substrates by boring organisms influences sedimentation rates in carbonate environments (e.g. Bromley 1978; Macintyre 1984; Pleydell & Jones 1988; Fursich et al. 1994; Perry 1996). Studies carried out on modern environments (e.g. Bromley & D’Alessandro 1990) show that the distribution and diversity of borings is highly dependent on environmental and ecological factors. The investigation of hard substrate ichnocoenoses represents, therefore, an important and useful tool for palaeoenvironmental and palaeoecological interpretations (Kidwell et al. 2001; Staff et al. 2002;

The occurrence and ecology of trace fossil assemblages in hard substrates dominated by coralline red algae assemblages have been very scarcely investigated (e.g. Stee neck, 1985; Piller & Rasser, 1996). Bioerosion characterising coralline assemblages have been associated with grazing activity (mostly fishes and echinoids) and with the activities of infaunal borers (e.g. fungi, cyanobacteria, chlorophytes, rhodophytes, sponges, bivalves and worms; May et al. 1982; Hutchings 1986; Ghirardelli 2002). All these biological activities deeply influence the development and the preservation potentiality of coralline communities (e.g. Nebelsick & Bassi 2000). A better understanding of the boring-related biological processes that contribute to colonise, transport and/or degrade rhodoliths may represent an important contribution to the palaeoenvironmental and palaeoecological interpretation of coralline algal dominated deposits. The development of an integrated approach based on rhodolith characteristics and related borings could contribute to the understanding of fossil sedimentary successions characterised by coralline red algae assemblages.

Data and remarks reported in this paper evidence how variation of environmental parameters (e.g. changing in depths of formation of the rhodoliths) can be deduced not only on rhodolith characters (e.g. shape, growth form, taxonomy) but also from the ichnofaunal assemblages.

2. GEOGRAPHICAL AND GEOLOGICAL SETTING

Miocene shallow water carbonates characterised by coralline red algae, bryozoans, echinoderms and bivalves widely crop out in Central and Southern Apennines (Italy). These sediments, known in literature as the “Calcarei a Brio zoi e Litotammini” (Bryozoan and Lithotamnium Limestones, BLL, Accardi et al. 1967; “formazione di Cusano”, FC, Selli 1957) represent the oldest evidence of the Miocene transgressive phase in the Central and Southern Apennines. These deposits are locally (e.g. eastern Matese Mountains and eastern Mt. Camposauro area) overlaid by hemipelagic deposits known as the Orbulina marls. The Orbulina marls in the Camposauro area is represented by the “Formazione di Longano” (FL, Selli 1957). The boundary between the BLL and FL can be gradual or abrupt. In the latter case, the transition is characterised by a 10-35 cm thick rudstone rich in rhodoliths, bryozoans, intraclasts and phosphatic grains (Carannante & Simone 1996). The BLL generally consist of rhodalg deposits (sensu Carannante et al. 1988) and are dominated by bryozoans, rhodoliths, bivalves (mainly pectinids and oysters), echinoids and benthic foraminifers. Planktonic foraminifers, barnacles and ser pulids are uncommon, while green algae, gastropods, brachiopods and heterotopic corals are very rare.

In south-eastern Matese Mountains the base of the FL is Serravallian in age (Lirer et al. 2005). In the Vitulano area (eastern Mt. Camposauro), the FC and FL are represented by a marly floatstone with common rhodoliths and abundant planktonic foraminifers. These hemipelagic deposits directly overlie Cretaceous sediments. Rare carbonate intraclasts are associated with rhodoliths within the floatstone. Finer grains are mainly composed by planktonic foraminifers and secondarily by miliolids, cibicids, amphisteginids, fish teeth, carbonate clasts and phosphatic grains. Some authors attribute the formation of these fractures wedges to pre- and syn-Miocene tectonic activity (e.g. D’Argenio 1967).

3. MATERIALS AND METHODS

The marly horizon rich in planktonic foraminifers and scattered rhodoliths was sampled in the Guria Quarry, Vitulano area (Southern Apennines, Southern Italy; Fig. 1). The studied horizon represents an exceptional deposition of the Orbulina marls that lay directly on Cretaceous carbonate sediments. Fifty-four rhodoliths characterising the hemipelagic marly floatstones were collected. The sampling was representative of the heterogeneous size of the rhodolith assemblage. Rhodolith characters were collected and studied both in situ and in the laboratory. Two marly matrix samples were also analysed. One dry-peel and at least two thin sections (generally 7.5 x 11 cm in size) were obtained from each sample in order to perform a semi-quantitative estimation of biotic components. Rhodoliths sphericity was calculated plotting the three main diameters (longest L, intermediate I, shortest s; Sneed & Folk 1958) in a triangular diagram (TRI-PLOT software; Graham & Midgley 2000).

The taxonomic identification at family and subfamily level of coralline assemblages is based on Woelker ling (1988), Verheiji (1993) and Braga et al. (1993). Coralline algal growth-form terminology follows Woelker ling et al. (1993). A semi-qualitative analysis of coralline growth forms was performed for each rhodolith. Polished surfaces and thin section of rhodoliths were analysed to characterise the trace fossil assemblages recorded within rhodoliths. Cross section analysis carried out in randomly chosen thin section square surfaces of 1 cm in length-side were also performed in order to obtain a representati ve percentage of boring cover. Washed samples were ob tained from sediment matrix samples in order to characte-
rize the planktonic foraminiferal assemblage and biostratigraphy of these deposits.

4. RHODOLITHS

Rhodoliths represent the dominant components within the studied Orbulina marly floatstone horizon. Subordinately, rare carbonate clasts of Cretaceous and Middle Miocene age are present. Within the rhodoliths, skeletal components such as bryozoans and encrusting foraminifers (e.g. acervulinids and Miniacina Galloway) occur. Rare echinoids, solitary corals, barnacles, bivalves, benthic foraminifers (e.g. Amphistegina D’Orbigny, Operculina D’Orbigny, Sphaerogypsina Galloway, Gypsina Carter, Elphidium De Montfort, textularids, rotalids, miliolids, cibicids) and planktonic foraminifers are also present. The coralline red algal assemblage is characterised by Melobesioideae (>50% of the total coralline assemblage) and Mastophoroideae (from 35 to 40%). Rare Lithophyloideae and Sporolithaceae are also present.

Most of the studied rhodoliths consist of more than one coralline family/subfamily member. Maximum rhodolith diameter (L) ranges from 4.0 to 13.1 cm, the intermediate size (I) ranges from 3.3 to 11.9 cm and the minimum size (s) from 2.0 to 9.6 cm. Despite of the heterogeneous size, rhodolith shape is homogeneous and is mainly sub-spheroidal (Fig. 2a). Three rhodolith growth-stages have been recognised, each of which representing different environmental setting in which the rhodoliths grew. Within these rhodolith growth-stages, coralline thalli show a variation in abrasion rate. The inner and intermediate rhodolith growth-stages are, in fact, characterised by a very high abrasion which becomes more superficial on the outer rhodolith part where coralline branches and thin crusts developed, suggesting occasional rhodolith overturning. Such differences in the taphonomic signature influence the fossil trace preservation.

5. BORINGS

Several types of boring traces were recorded within the Vitulano rhodoliths (Figs 2b, 2c). These traces can be distinguished as macro- and micro-borings based of their...
<table>
<thead>
<tr>
<th>boring shape</th>
<th>ichnogenera</th>
<th>associated borers</th>
<th>chamber diameter (mm)</th>
<th>maximum depth reached from the original surface</th>
<th>filling matrix</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>r-b-e f r-b-e-f w/p c m g</td>
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<tr>
<td>Macroboring</td>
<td></td>
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<tr>
<td>single chamber, straight, elliptical</td>
<td><em>Gastrochaenolites</em></td>
<td>bivalves</td>
<td>0.3-1.9</td>
<td>0.8-72</td>
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<td></td>
<td>Single or multiple rounded, irregular chambers connected with narrow apertures</td>
<td><em>Entobia</em></td>
<td>sponges</td>
<td>1.8-8.9</td>
<td>6.5-14.2</td>
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<td></td>
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<td></td>
<td>cylindrical, straight, bended or helicoidally arranged chamber with constant diameter</td>
<td><em>Trypanites, Meandropolydora, Caulostrepsis (?)</em></td>
<td>polychaete, barnacles</td>
<td>0.3-1.7</td>
<td>1.3-13.4</td>
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<tr>
<td>Microboring</td>
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<tr>
<td></td>
<td>cylindrical, straight chamber with constant diameter perpendicular to surface</td>
<td>(?)</td>
<td>algae, fungi, bacteria, sponges</td>
<td>0.01-0.04</td>
<td>1.5-4.9</td>
</tr>
<tr>
<td></td>
<td>network of very contorted and sinuous, cylindrical micro-galleries</td>
<td>(?)</td>
<td>algae, fungi, bacteria, sponges</td>
<td>0.01-0.03</td>
<td>0.07-0.19</td>
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<tr>
<td></td>
<td>branched network of micro-galleries with irregular diameter</td>
<td>(?)</td>
<td>algae, fungi, bacteria, sponges</td>
<td>0.02-0.04</td>
<td>1.4-5.3</td>
</tr>
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Tab. 1 - Boring and related shape, size range, thickness of bored substrate, possible borers and textures of fill cements within the studied rhodoliths. r= red algal fragments; b= bryozoan fragments; e= echinoid fragments; f= planktonic foraminifers; m= mudstone; w/p= wackestone/packstone; c= calcite cement; g= geopetal structures.

Tab. 1 - Tipologie di boring e relative morfologia, taglia, profondità dalla superficie del substrato perforato, possibili borers e matrice di riempimento. r= frammenti di alghe corallinacee; b= frammenti di briozoi; e= frammenti di echinidi; f= foraminiferi planctonici; m= mudstone; w/p= wackestone/packstone; c= cemento calcitico; g= strutture geopetali.
in addition the occurrence of bivalve shells that sometime coincide in shape with these bioerosions contribute to strengthen this hypothesis.

5.1.2. Single or multiple-chamber boring with irregular, rounded inter-connected chambers (Pl. 1, 3-5)

This trace consists of single or multiple chambers, 2-8.9 mm in width, with an irregular rounded or polygonal shape. Each chamber is connected to the surface or with other chambers through narrow apertures ranging in diameter from 0.3 to 2.1 mm. Short to elongate sinuous or straight apophyses, and canals often branch off from the chambers. Multi-chambered networks can be referred to the ichnogenus *Entobia* Bronn. The high heterogeneity of shape and size of chambers, canals and apophyses (where present) suggest the presence of more than one *Entobia* species (e.g. Bromley & D’Alessandro 1984). Similar single chambered borings can be attributed to the ichnogenus *Uniglobites* Pleydell & Jones. The chamber diameter is from 2 to 8.9 mm (Fig. 3b). They are rare in the inner and outer part and very common in the intermediate part of the rhodoliths (Tab. 2). The infilling sediment consists of coralline algal, bryozoan, echinoderm wackestone/packstone and coralline algal, bryozoan, echinoderm and planktonic foraminifer wackestone/packstone. Geopetal structures are present. Similar boring patterns are widely described from both fossil and recent environments (e.g. Bromley & D’Alessandro 1987; Pleydell & Jones 1988; Perry 1996) and their development is generally attributed to the sponges.

5.1.3. Straight or winding tubular chambers (Pl. 1, 6-9)

These trace fossils are characterised by cylindrical tubes, perpendicular, slightly- or strongly-angled to the bored surface. The tunnel diameter is constant and the termination is generally rounded. The chambers can be straight or sinuous or meandering. Straight tunnels are mainly perpendicular to the surface, while winding ones can develop freely in all directions within the red algal thalli. The diameter of straight galleries ranges from 0.6 to 1.7 mm and their length can exceed 1 cm. These borings can be referred to the ichnogenus *Trypanites* Mägdefrau 1932. Ekdale et al. (1984) attributed the formation of these borings principally to polychaetes and barnacles. The diameter of the winding, irregularly convoluted and meandering galleries varies from 0.3 to 0.8 mm. The diameter may be enlarged where the galleries bend. These tunnels can be referred to the ichnogenera *Meandropolydora* Voigt 1965 and *Caulostrepsis* Clarke 1908 (see also Bromley & D’Alessandro 1983). Some of these tubular borings may, however, be referred to *Entobia* due to the difficulties of recognising the exact morphology of the galleries in two dimensions. The diameter of the galleries ranges from 0.3 to 1.7 mm (Fig. 3c). They are common in the inner part, very frequent in the intermediate and rare in the outer part of the rhodoliths (Tab. 2) and they are filled by a variety of sediment.
of sediments including coralline, bryozoan and echinoderm wackestone/packstone, muddy carbonates as well as calcite cements. Geopetal structures can be present.

5.2. Microborings

5.2.1. Wedge-shaped micro-borings (Pl. 1, 10-12)

Micro-tunnels with a straight axis perpendicular to the surface characterised by a wedge shaped chamber; the chamber section is circular and its diameter decreases from the surface to the deeper part. The maximum recorded length is up to 500 µm. The diameters range from 0.01 to 0.04 mm (Fig. 3d). They are rare in the inner part and common in the intermediate and outer parts of the rhodoliths (Tab. 2). They are filled by calcite cement. Similar micro-borings have been associated in the literature to the action of boring bacteria, fungi, algae and sponges (e.g. May et al. 1982; Ghirardelli 2002).

5.2.2. Branched micro-borings (Pl. 1, 13)

These borings consist of branched micro-galleries characterised by a slightly irregular diameter. In most cases, these tunnels converge in a triple-point creating a Y-shaped pattern. Secondary thinner tunnels branching off from the main...
axis are sometimes present. These tunnels only develop in coralline thallus surface down to a depth of 0.5 mm. The diameters of the traces range from 0.01 to 0.025 mm (Fig. 3e). These micro-borings are very rare in the inner part and common in the intermediate and outer parts of the rhodoliths (Tab. 2). They are filled by calcite cement. Similar micro-patterns have been associated in the literature to the action of boring bacteria, fungi, algae and/or sponges (Ghirardelli 2002).

5.2.3. Winding micro-borings (Pl. 1, 14)

Complex network of winding and meandering micro-tunnels developing very close to the substrate surface. The cross section of galleries is rounded. The diameter of these micro-borings ranges from 0.02 to 0.04 mm. The diameter is generally higher at tunnel junctions (Fig. 3f). These borings are frequent, but restricted to the outer part of the rhodoliths (Tab. 2). They are filled by calcite cement. The developing of these sinuous traces can possibly be attributed to the action of boring bacteria, fungi, algae and/or sponges.

6. DISCUSSION

Bioerosion activity related to hard-grounds, rocky shorelines and reefs has been mainly studied in carbonate environments (e.g. Goreau & Hartman 1963; Neumann 1966; Goldring & Kazmierczak 1974; MacGeachy & Stearn 1976; Warme 1977; Bromley 1978; Risk & MacGeachy 1978; Fürsich 1979; Highsmith 1981; Palmer 1982; Kleemann 1992, Perry 1996). The relationship between boring-types and environmental conditions has also been widely documented for both fossil and modern environments (e.g. Bromley & D’Alessandro 1990; Perry & Bertling 2000; Pari et al. 2002). Very little attention has been paid, however, to the interaction and relationship between boring activity and rhodolith development (e.g. Steneck 1985). In spite of boring abundance, the palaeoecological role played by borers in rhodolith-bearing sediments rich in rhodoliths has been never clearly developed. Little attention has been paid to their potential as palaeoenvironmental and palaeoecological indicators for rhodolith assemblages.

The ichnocoenoses that characterise the Vitulano rhodoliths are mainly represented by Gastrochaenolites, Uniglobites, Entobia, Trypanites, Meandropolydora and (?)Caulostrepsis. Undetermined micro-borings were also observed. Most of the borings were recorded on the inner and intermediate rhodolith growth stages while fewer borings were found in the outer part of the rhodoliths (Tab. 2).

The nucleus of the rhodoliths is characterised by abraded coralline thalli with frequent bivalve-related borings such as Gastrochaenolites, common tubular tunnels (Trypanites, Meandropolydora, (?)Caulostrepsis, rare micro-borings and Entobia.

The intermediate growth stage still consists of abraded thalli with common borings such as Gastrochaenolites, Uniglobites, Entobia, Trypanites, Meandropolydora, (?)Caulostrepsis and by other micro-borings. In correspondence of this rhodolith growth stage the higher ichnogeneric diversity is recorded. This high diversity contrasts with the very scarce and poorly diversified boring association present in the outer part of the rhodoliths. Here the ichnocoenosis is almost restricted to micro-borings (Tab. 2). Additionally, abrasion of the coralline thalli is very rare.

The bore-holes in the inner parts of the rhodoliths are dominated by a coarse grained packstone/wackestone rich in coralline algae, bryozoans, foraminifer and bivalve fragments. The bore-holes in the outer parts of the rhodoliths are characterised by an infilling of sediment consisting of a mixed composition ranging from a coralline algal, bryozoan and echi- noderms packed/wackestone to a planktonic foraminiferal packstone/wackestone. When a planktonic foraminiferal packstone/wackestone is present within the borings, it differs from the enclosing Orbulina marls in colour (reddish-greyish within borings; greyish-greenish in the Orbulina marls) and composition of the matrix (carbonate matrix within the borings and marls in the Orbulina marls).

Bromley & D’Alessandro (1990) in comparing Recent and Plio-Pleistocene deep and shallow water bioerosion recorded an evident correspondence between ichnocoenoses and bathymetry. The authors reported that the ichnogenera Trypanites, Caulostrepsis and Meandropolydora are abundant in the infralittoral zone and become less common till rare moving down to the circalittoral and the bathyal zones. They also observed that Gastrochaenolites is present only in the infralittoral, while the ichnogenus Entobia can be present from the infralittoral to the bathyal. Entobia can provide information concerning depth only at the species level. The ichnocoenosis variation from infralittoral to bathyal zone reported by Bromley & D’Alessandro (1990) can be compared with that recorded within the Vitulano rhodoliths moving from the inner to the outer growth-stages of the rhodoliths (Tab. 2). Consequently, the changing in ichnocoenosis composition in the studied samples can be interpreted as an environmental deepening of the rhodoliths during the last phases of their growth history. The studied ichnocoenoses along with other taphonomic signatures (e.g. high coralline thallassal and boring abrasion, coralline and bryozoan fragment packstone as boring-filling matrix) in correspondence of the inner and intermediate rhodolith growth stage suggest that the rhodoliths were nucleated and grew in a shallow high-energy environment similar to those described for BLL (e.g. Catenacci et al. 1982; Barbera et al. 1980). In addition, the taphonomic parameters of the last rhodolith growth stage (e.g. decrease in ichnogene- ric diversity, planktonic foraminifer wackestone filling matrix, absent abrasion) lead to hypothesize that these rhodoliths gradually moved into the deeper water environment where the Orbulina marls were depositing. Here the rhodoliths continued to grow till their final burial; coralline growth in this deeper environment is testified by the fine-grained sediment rich in planktonic foraminifers trapped within the outer algal thin crusts.

The presence of fossil traces (borings) within the BLL
Trace fossil assemblages in rhodoliths from the Middle Miocene of Mt. Camposauro
sedimentary succession has been commonly reported in the literature (e.g. Catenacci 1974; Barbera et al. 1978; Barbera et al. 1980; Carannante 1982; Carannante & Simone 1996; Brandano & Corda 2002; Corda & Brandano 2003; Civitelli & Brandano 2005). A detailed analyses focusing on the ichnocoenosis has only been carried out with respect to the unconformity between BLL and the underlying sediments (e.g. Catenacci et al. 1982). Catenacci et al. (1982) described the boring association along the unconformity between the BLL and the underlying Cretaceous/Paleogene sediments outcropping in the M. Maiella area (Central Apennines, Italy). These authors reported the presence of several borings produced by bivalves, polychaetes and sponges and grouped them into four ichnospies belonging to the genera Entobia and Trypanites sensu Bromley (1972). The same unconformity had been studied in the Pietroariva area (Matese Mountains, Southern Apennines, Italy) by Barbera et al. (1980) with similar results. The bio- and ichno-coenosis integrated with sedimentological aspects has allowed the BLL to be interpreted as shallow water sediments deposited in an open platform setting. These deposits gradually passed into the deeper and partially heteropic Orbula marls (Barbera et al. 1980). The ichnocoenoses observed in the early and intermediate rhodolith growth stages of the Vitulano rhodoliths are comparable to those described by Catenacci et al. (1982) and by Barbera et al. (1980). The lower ichnogeneric diversity mentioned by these authors is presumably due to different taxonomic interpretation of the borings from that of the present investigation. An example is given by the elliptical bivalve borings which were attributed to the ichnogenus Trypanites by Catenacci et al. (1982) and Barbera et al. (1980), while in this study they are ascribed to the genus Gastrochaenolites. The ichnocoenoses characterising the last rhodolith growth stage which is clearly dominated by micro-borings cannot be compared to any other previously described Miocene boring association in this area.

7. CONCLUDING REMARKS

A taphonomic analysis of the Vitulano rhodolith assemblage present within the Orbula marls deposits allows the recognition of an ichnocoenosis represented by six ichnogenera ascribed to sponges, bivalves, polychaetes and barnacles. Other microborings referable to bacteria, fungi, algae and sponges were also identified. Boring distribution changes moving from the core to the outermost part of rhodoliths. The early and intermediate rhodolith growth stages are characterised by the ichnogenera Gastrochaenolites, Uniglobsites, Entobia, Trypanites, Meandropolydora, Caulostrep~s~ and by other micro-borings. The outer growth stage clearly shows a decrease in trace fossil diversity as low-diversity micro-borings (possibly related to algae, fungi, bacteria and/or sponges) dominate the ichnocoenosis.

Among the identified ichnogenera, Gastrochaenolites and Meandropolydora are known to be typical of very shallow water environments. The diversity of ichnotaxa is greater in shallow than in deep water (Bromley & D’Alessandro 1990; Bromley 1994). Furthermore, shallow water boring assemblages are known to be made up of several approximate-
ly equally abundant types, while in deeper water a few ichnospecies dominate (Bromley & D’Alessandro 1990; Bromley 1994).

The identified variations in studied ichnocoenoses assemblies within each rhodolith suggest a deepening of rhodolith assemblages during their development and growth. Rhodoliths show high abrasion in the inner and intermediate growth stages due to the frequent overturning in high energy environmental conditions. In the external part of the rhodolith, thallus abrasion is very weak as a consequence of a decrease in water turbulence. This hydrodynamic gradient suggests that rhodoliths were subjected to a transport towards deeper environments during their growth. This transport is confirmed by boring-filling matrix: borings in the inner part of the rhodoliths are filled mainly by abraded fragments of coralline algae, bryozoans and echinoids. Towards the outer part, the borings are filled by a sediment which gradually becomes richer in planktonic foraminifers and muddy matrix.

This study (A) documents a well exposed example of the poorly known ichnocoenoses that occur in Miocene rhodolith assemblages and (B) represents an original contribution to the understanding of borings in developing palaeoecological and palaeoenvironmental interpretations of rhodolith-dominated deposits. In particular it contributes, as it scarcely has been done before in previous works, to estimate, using both trace fossils and the associated filling matrix, variations in water depth of the environment in which rhodolith communities developed. Indeed, in the literature, authors have only rarely described examples of borings present inside rhodoliths referred to different depths; however, no examples of rhodoliths containing highly diversified ichnocoenoses which indicate different depths have been reported.

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