

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 emipelagitica marnosa, che giacciono in paracordanza su sedimenti cretaci. 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 sopracitate 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 icnocenosi. Questo lavoro, partendo da un'analisi preliminare dei caratteri dei rodoliti (come la forma, le morfologie di crescita, le componenti biotiche), si focalizza sull'icnocenosi 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 icnocenosi che si sviluppavano 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, gene-

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; Fürsich *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;

Taylor & Wilson 2003; Yesares-García & Aguirre 2004). Actualistic analyses have been used to study the preservation potential of organisms in various present-day shallow water settings (e.g. Feige & Fürsich 1991). Special attention has been paid in literature to the ichnocoenoses developed in coral reef systems with respect to their ecological significance (e.g. Goreau & Hartman 1963; Hein & Risk 1975; MacGeachy & Stearn 1976; MacGeachy 1977; Hutchings 1986; Pisera 1987; Hutchings *et al.* 1992; Kiene & Hutchings 1994; Perry 1996, 2000; Perry & Bertling 2000; Benner *et al.* 2004).

The occurrence and ecology of trace fossil assemblages in hard substrates dominated by coralline red algae assemblages have been very scarcely investigated (e.g. Ste-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 Briozoi e Litotamni” (Bryozoan and Lithotamnium Limestones, BLL, Accordi *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 rudsto-

ne rich in rhodoliths, bryozoans, intraclasts and phosphatic grains (Carannante & Simone 1996). The BLL generally consist of rhodalgal 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 serpulids are uncommon, while green algae, gastropods, brachiopods and ahermatipic 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, cibicides, 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 Woelkerling (1988), Verheiji (1993) and Braga *et al.* (1993). Coralline algal growth-form terminology follows Woelkerling *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 representative percentage of boring cover. Washed samples were obtained from sediment matrix samples in order to characterise

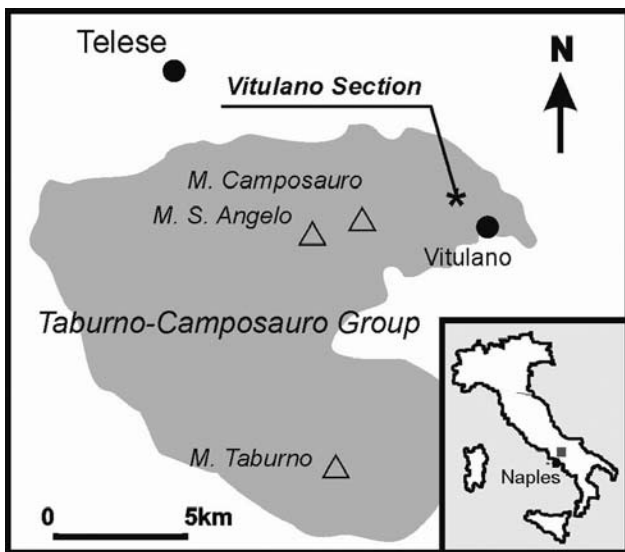


Fig. 1 - Study area showing the location of the Cava Guria (Guria Quarry) in which the studied *Orbulina* marls occur.
 Fig. 1 - Area di studio e localizzazione dei depositi di Marne ad *Orbulina* presi in esame, affioranti in corrispondenza della Cava Guria (Vitulano, Monte Camposauro).

size 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 forami-

nifers (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, rotaliids, 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 Lithophylloideae 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

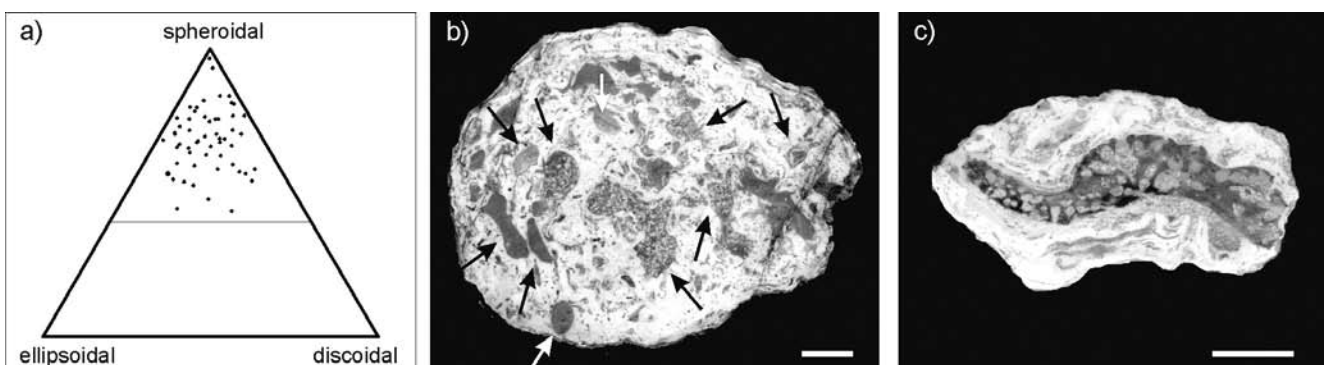


Fig. 2 - a. Rhodolith shape in the studied Vitulano outcrop. b. Rhodolith cross section (sample CASV32) where borings are visible in darker fill sediments. White arrows denote bivalve-related borings; black arrows indicate borings referable to the ichnogenus *Entobia*. c. Example of rhodolith (sample CASV42) with a nucleus composed by an oyster shell deeply bioeroded by *Entobia*. All scale bars correspond to 1 cm.
 Fig. 2 - a. Diagramma triangolare rappresentante il grado di sfericità dei rodoliti analizzati. b. Sezione di uno dei rodoliti analizzati (campione CASV32) in cui i numerosi boring presenti sono messi in risalto dal colore più scuro della matrice al loro interno. Le frecce bianche indicano le bioerosioni subellittiche prodotte da bivalvi; le frecce nere indicano numerose cavità attribuite all'ichnogenere *Entobia*. c. Esempio di rodolite (sample CASV42) il cui nucleo è costituito da una valva di ostreide caratterizzata da numerosi boring attribuibili all'ichnogenere *Entobia*. Entrambe le scale bar indicano lo spessore di 1 cm.

Tab. 2 - Distribution and abundance of borings within the studied rhodoliths. Thickness of the lines suggests relative abundance. Interm. = intermediate.

Tab. 2 - Distribuzione ed abbondanza dei boring all'interno dei rodoliti. Lo spessore della linea è funzione dell'abbondanza relativa dei boring. Interm. = intermediale.

	boring shape	possible borers	rhodolith growth stage		
			inner	interm.	outer
Macro-boring	<i>Gastrochaenolites</i>	bivalves	[thick bar in inner stage]		
	<i>Entobia</i>	sponges	[thick bar in interm. stage]		
	<i>Trypanites</i> , <i>Meandropolydora</i> (?) <i>Caulostrepsis</i>	polychaete, barnacles	[thick bar in interm. stage]		
Micro-boring	cylindrical, straight, wedge-shaped chamber	algae, fungi, bacteria, sponges	[thick bar in interm. stage]		
	network of very contorted and sinuous, cylindrical galleries	algae, fungi, bacteria, sponges	[thick bar in interm. stage]		
	branched network of micro-galleries	algae, fungi, bacteria, sponges	[thick bar in interm. stage]		

size. The two-dimensional analyses performed on thin sections and acetate dry peels allowed the description of the fossil traces only at genus level. Sometimes the attribution to a specific ichno-genus was problematic. The description, dimensions (Tab. 1), position and abundance within the rhodolith (Tab. 2), as well as presence of infilling sediment matrix nature were noted for each type of boring.

5.1. Macro-borings

5.1.1. Elliptical, flask-like and sac-like borings (Pl. 1, 1-2)

These traces consist of elliptical, flask-like and sack-like borings with a rounded cross section and the main axis generally perpendicular to the eroded surface. The aperture, at the top of the boring is very rarely preserved due to abrasion. The aperture is sub-rounded in cross section and its diameter is shorter than the main chamber. Two main groups of these traces can be distinguished on the base of chamber size (Fig. 3a); both smaller and larger borings can be referred to the ichnogenus *Gastrochaenolites* Leymerie 1842. The chamber diameter range from 3 to 6.5 mm and from 1.2 to 1.4 cm (Fig. 3a); no chambers with diameter comprises between 1.4 and 3 cm have been recorded. They are very common in the inner and middle part of the rhodoliths and only very rarely in the outer part (Tab. 2). The infilling sediment consists of coralline algae, bryozoan and echinoderm and/or planktonic foraminiferal wackestone/packstone. The comparison of the geometry of these fossil traces with modern borings suggests that they were produced by bivalves;

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 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

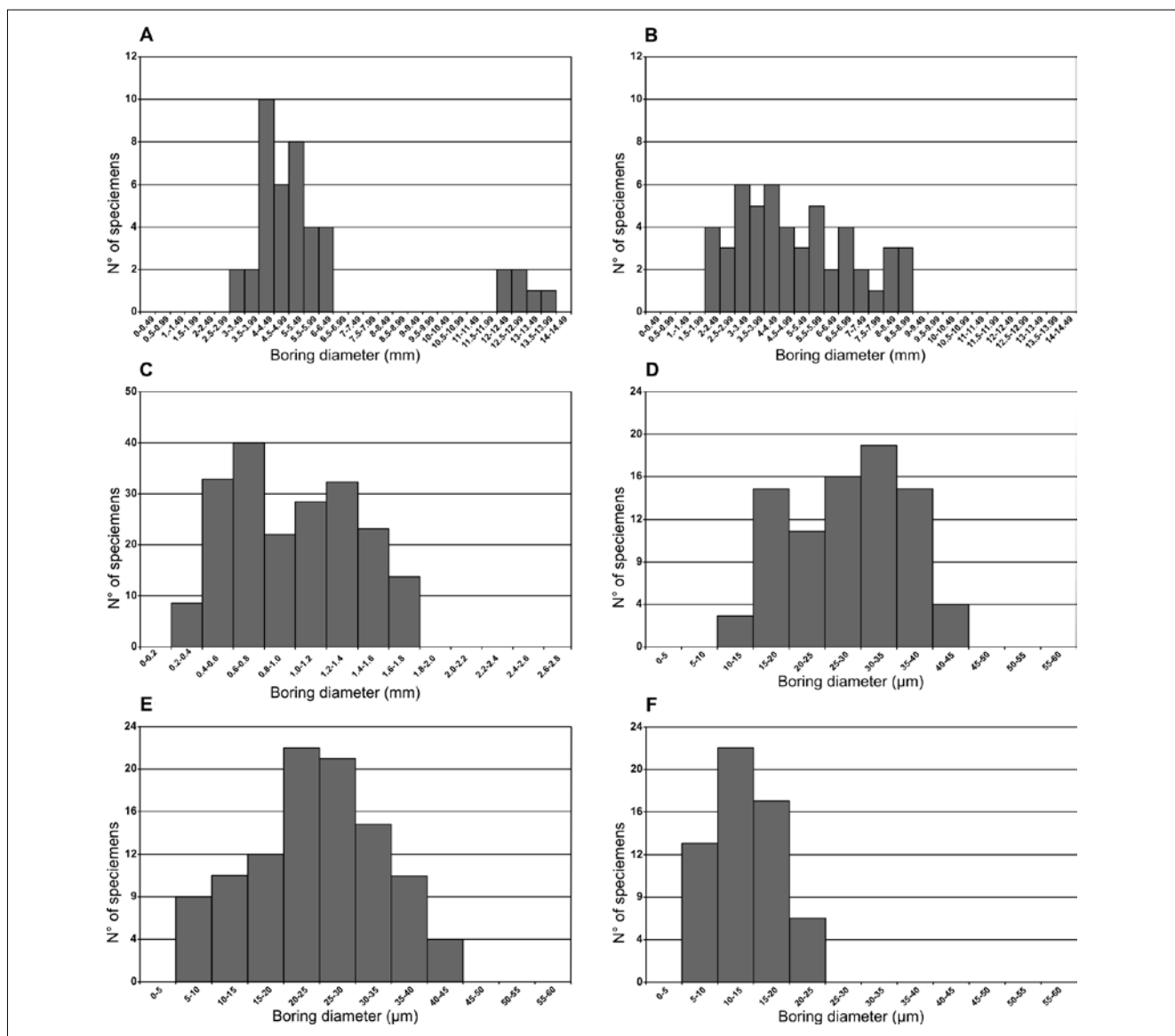


Fig. 3 - Histograms showing the variability of chamber diameter of recorded boring-groups (see Chapter 5). A. bivalve-related elliptical, flask-like and sac-like borings; B. single or multiple-chamber boring with irregular, rounded inter-connected chambers (*Entobia*); C. straight or winding tubular chambers; D. wedge-shaped micro-borings; E. branched micro-borings; F. winding microborings.

Fig. 3 - Istogrammi rappresentanti la variabilità del diametro delle camere dei boring all'interno di ciascuno dei gruppi morfologici di tracce fossili riconosciuti (si veda Cap. 5). A. Boring ellissoidali o dalla forma a "fiasco" prodotti da bivalvi; B. camere singole o multiple di forma irregolare, tondeggianti, connesse tra di loro (*Entobia*); C. camere tubulari rettilinee o meandranti; D. micro-boring con morfologia a cuneo; E. micro-boring ramificati; F. micro-boring sinuosi o meandranti.

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 have been mainly studied in carbonate environments (e.g. Goreau & Hartman 1963; Neumann 1966; Goding & Kazmierczak 1974; MacGeachy & Stearn 1976; Warne 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*.

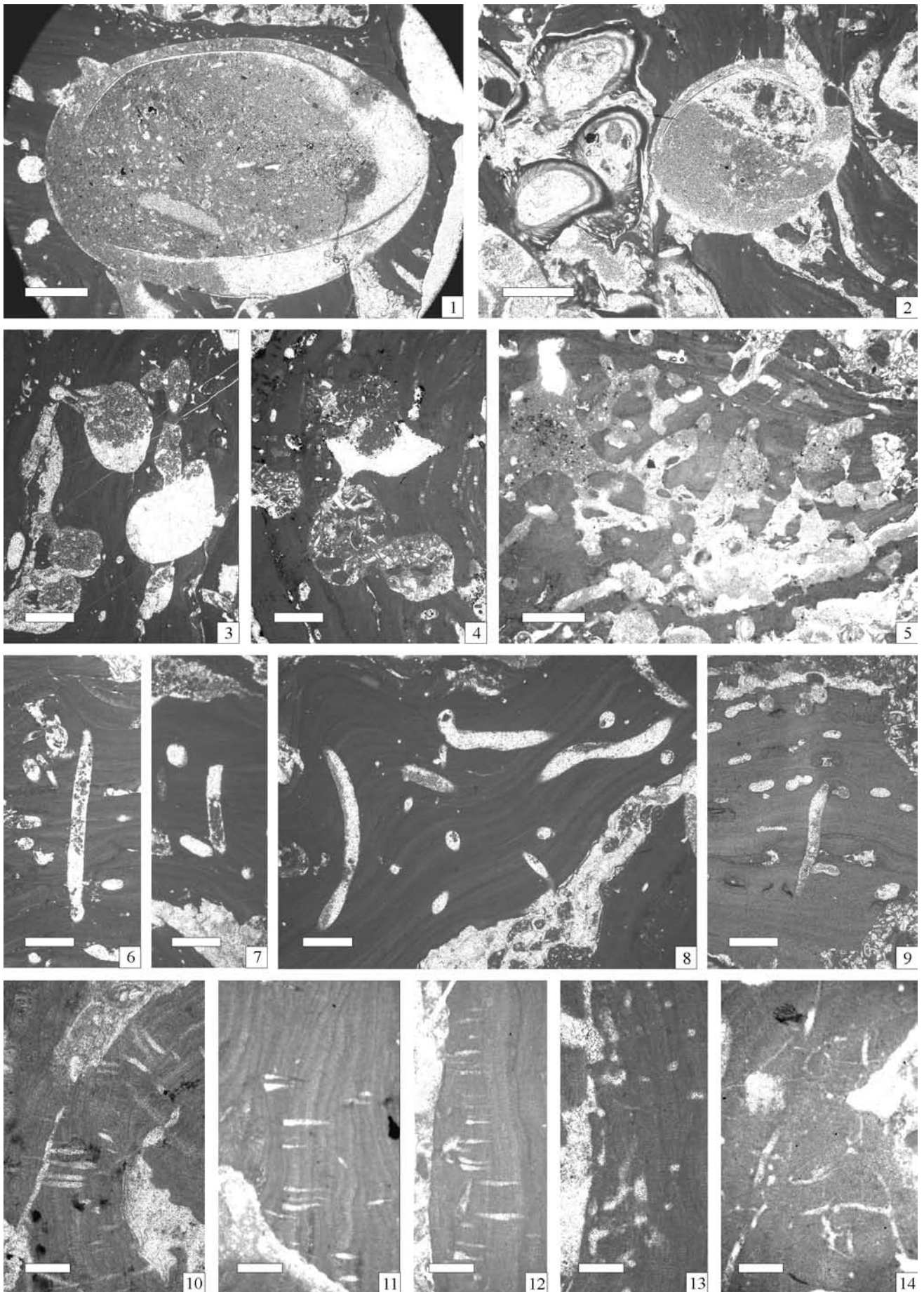
The intermediate growth stage still consists of abraded thalli with common borings such as *Gastrochaenolites*, *Uniglobites*, *Entobia*, *Trypanites*, *Meandropolydora*, (?)*Caulo-*

strepsis and by other micro-borings. In correspondence of this rhodolith growth stage the higher ichnogenic 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 echinoderm packstone/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 thallial 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 ichnogenic 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



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 ichnospecies belonging to the genera *Entobia* and *Trypanites sensu* Bromley (1972). The same unconformity had been studied in the Pietrarroia 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 *Orbulina* 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 *Orbulina* 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*, *Uniglobites*, *Entobia*, *Trypanites*, *Meandropolydora*, (?)*Caulostrep-sis* 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-

← Pl. 1 - 1. *Gastrochaenolites* specimen containing valves of its producer; bivalve shells approximately coincide in shape with the cavity (sample CASV7). 2. *Gastrochaenolites* specimen within coralline thallus; serpulids encrusted corallines after bivalve-related cavity development as shown by their shape which slightly follows the boring outline (sample CASV36). 3. Irregular chambers of sponge-related borings referable to the ichnogenus *Entobia*; the original matrix filling the bore hole was partially replaced by calcite cement (sample CASV22). 4. Sponge-related borings referable to the ichnogenus *Entobia* (sample CASV10). 5. Complex network produced by *Entobia* (sample CASV25); 6-7. Tubular straight chambers referable to *Trypanites*; calcite cement generally replaces the original boring-filling matrix (sample CASV2). 8. Slightly winding tubular chambers possibly referable to the ichnogenus *Caulostrep-sis* (sample CASV3). 9. Undetermined gently curved tubular chamber; the two dimensional analysis through thin sections often does not allow to undoubtedly determine borings at genus level (sample CASV9). 10-12. Networks of parallel wedge-shaped micro-borings that developed perpendicularly to coralline surfaces (10-11, sample CASV1; 12, sample CASV35). 13. Complex network of winding and meandering micro-tunnels developing very close to the surface of the eroded substrate (sample CASV11). 14. Branched micro-galleries that often converge in a triple-point creating a Y-shaped pattern (sample CASV8). Scale bars: 1-9, 1 mm; 10-14, 0.25 mm.

Tav. 1 - 1. *Gastrochaenolites* sviluppatosi all'interno del tallo di corallinacee; al suo interno sono ancora visibili le valve disarticolate dell'organismo che lo ha prodotto (campione CASV7). 2. *Gastrochaenolites* all'interno di corallinacee; i serpulidi hanno colonizzato il rodolite successivamente all'azione dei borers come evidenziato dalla forma dei serpulidi stessi che segue quella del boring (campione CASV36). 3. Camere di forma piuttosto irregolare attribuibili all'ichnogenere *Entobia*; la matrice originaria è stata sostituita parzialmente da cemento calcitico (campione CASV22). 4. Boring prodotti da spugne carenti e attribuibili a *Entobia* (campione CASV10). 5. Complesso sistema di bioerosioni prodotte da spugne carenti e attribuibili a *Entobia* (campione CASV25). 6-7. Boring tubulari perpendicolari alla superficie del rodolite appartenenti all'ichnogenere *Trypanites*; il cemento calcitico in genere sostituisce parzialmente o totalmente la matrice originaria che riempiva gli esemplari di *Trypanites* (campione CASV2). 8. Camere tubulari leggermente ricurve probabilmente attribuibili all'ichnogenere *Caulostrep-sis* (campione CASV3). 9. Camera tubulare di affinità incerta caratterizzata da deboli curvature; l'analisi bi-dimensionale delle icnocoenosi attraverso lo studio di sezioni sottili spesso non permette di caratterizzare a livello generico le bioerosioni presenti (campione CASV9). 10-12. Network di micro-boring cuneiformi paralleli tra loro e perpendicolari alla superficie del rodolite (10-11, campione CASV1; 12, CASV35). 13. Sistema di micro-tunnel sinuosi e meandranti (campione CASV11). 14. Micro-gallerie ramificate che convergono spesso in punti tripli generando dei pattern a forma di Y (campione CASV8). Scala: 1-9, 1 mm; 10-14, 0,25 mm.

ly equally abundant types, while in deeper water a few ichnospecies dominate (Bromley & D'Alessandro 1990; Bromley 1994).

The identified variations in studied ichnocoenoses assemblages 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 the potential 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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