



Benthic foraminifers and siliceous sponge spicules assemblages in the Quaternary rhodolith rich sediments from Pontine Archipelago shelf

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ABSTRACT - The bottom samples (Quaternary in age) of two cores (CS1 and Caro1) collected at 60 and 122 m water depth in the marine area near Ponza Island (Pontine Archipelago, Tyrrhenian Sea) are investigated. In particular, benthic foraminifers and siliceous sponge spicules are considered. The coralline red algae (pralines, boxworks and unattached branches) are abundant in both samples and, particularly, in the CS1 bottom as well as the benthic foraminifers. The siliceous sponge spicules also are very diversified and abundant in the CS1 bottom sample, while in the Caro1 bottom they are rare and fragmented. Benthic foraminiferal assemblage of two samples is dominated by *Asterigerinata mamilla* and *Lobatula lobatula*, typical epiphytic species but also able to live on circalittoral detrital seafloors, adapting to an epifaunal lifestyle. Based on these data the bottom of the studied cores represents the upper circalittoral zone, within the present-day depth limit distribution of coralline red algae in the Pontine Archipelago (shallower than 100 m water depth).

Keywords: benthic foraminifers; siliceous sponge spicules; coralline red algae; paleoenvironmental reconstruction; Quaternary; Pontine Archipelago; Tyrrhenian Sea.

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1. INTRODUCTION

In non-tropical shelf areas (as the Western Mediterranean), the potential exists for extensive deposits of skeletal carbonate to accumulate on shelves (< 200 m depth) if the terrigenous input rate is low (Tropeano and Spalluto, 2006): lower than 10 mm per 1000 years according to Nelson (1988). Non-tropical carbonate sediments are composed almost entirely of heterozoan skeletal remains (sensu James, 1997) represented by, in particular, benthic foraminifers, bryozoans, bivalves, barnacles and coralline red algae, constituting the foramol lithofacies (Betzler et al., 1997).

The Mediterranean area is normally affected by terrigenous sedimentation derived from fluvial inputs and erosional coastal processes, nonetheless examples of recent shelf carbonate production are present (Pérès and Picard, 1964; Carannante et al., 1988; Milker et al., 2009). Present-day carbonate sedimentation along the northern shores of the central Mediterranean Sea appears to be linked to either karstic coastal regions or small islands. The prevailing carbonate nature of the exposed rocks or the scarcity or absence of a drainage network permit the

development of foramol carbonate systems in shallow marine settings (Tropeano et al., 2003). In particular, in the Italian seas carbonate deposition occurs in the southern Adriatic Sea, Cagliari Bay (Sardinia), Adventure Bank (southwestern Sicily), Gulf of Naples and Pontine Archipelago (Colantoni et al., 1985; Corselli et al., 1994; Basso, 1998; Toscano and Sorgente, 2002; Lecca et al., 2005; Toscano et al., 2006; Tropeano and Spalluto, 2006; Brandano and Civitelli, 2007; Bracchi and Basso, 2012).

Several studies investigated temperate carbonate shelf of the Pontine Archipelago (Tyrrhenian Sea), focusing on sedimentary characteristics (Brandano and Civitelli, 2007) and biogenic facies characterised by benthic foraminifers (Frezza et al., 2005, 2010) or coralline red algae (Basso, 1998; Bracchi and Basso, 2012).

The Pontine Archipelago is characterised by a mixed siliciclastic-carbonate sedimentation in the infralittoral and in the lower circalittoral zones (Brandano and Civitelli, 2007). In the infralittoral zone, erosional processes on the rocky shoreline produce lithoclasts and volcanoclastic deposits that are reworked by wave-induced near-shore currents (e.g., longshore currents, rip currents). In the

lower circalittoral zone the prolific production by photic biota (coralline red algae) ends, while skeletal remains of the aphotic environment mix with pelagic sediments characterised by low carbonate content (Brandano and Civitelli, 2007). On the shelf, the sedimentation is mainly intrabasinal and made up of foraminifers, bryozoans, molluscs, echinoderms and coralline algae, and forms a thin carbonate veneer on the volcanic substrate. About benthic foraminifers, Frezza et al. (2005, 2010) recognised three recent assemblages: the shallowest assemblage (20-150 m water depth) is dominated by epiphytic taxa such as *Asterigerinata mamilla*, *Lobatula lobatula* and *Rosalina bradyi*, which also can live as epifauna on biodetrital circalittoral sediments; the *Cassidulina carinata* assemblage is reported at intermediate depths (100-250 m water depth); finally, the deepest assemblage is dominated by *Uvigerina mediterranea* and *Bulimina marginata* (200-380 m water depth). The rhodolith morphologies and their distribution around the Pontine Islands were investigated by Basso (1998), which distinguished three groups: the unattached, monospecific branches, the small compact "pralines" and the vacuolar "boxwork". More recently, Bracchi and Basso (2012) have identified two carbonate facies between 40 and 100 m water depth: the "calcareous algae facies" (40-70 m water depth) and the "carbonate matrix facies" (70-100 m water depth). In the stratigraphic perspective, Basso et al. (2006) have found a relationship between rhodolith facies and Holocene sea-level rise in four cores recovered at the Pontine Archipelago shelf break.

In the framework of a project on the Quaternary paleoenvironmental evolution of the Pontine Archipelago the goal of this study is to assess the paleoenvironment represented by the bottom samples, Quaternary in age, from two cores collected near Ponza Island by means of the benthic foraminiferal assemblages. This is realisable using the information on benthic foraminifers derived from previous studies, the knowledge on their distribution in the Recent sediments and the analysis of the test morphologies. Moreover, a first analysis of the siliceous sponge spicules, which are abundant in one of the two examined samples, is presented in order to investigate their potential paleoenvironmental significance.

2. STUDY AREA

Ponza Island is located in the western sector of the Pontine volcanic Archipelago, in the Central Tyrrhenian Sea (Fig. 1A), about 30 km off the Gulf of Gaeta (Latium, Italy). Pontine Archipelago is a typical example of Mediterranean Islands as far as climate, oceanography and environments. It consists of five major islands and may be divided into the Western (Ponza, Palmarola and Zannone) and the Eastern (Ventotene and Santo Stefano) Pontine Islands. The Western Archipelago represents the emergent part of the continental Tyrrhenian shelf (De Rita et al., 1986; Bellucci et al., 1999). The structural framework of the shelf is deeply influenced by the Plio-Pleistocene tectonic evolution of the Tyrrhenian basin.

During the Lower Pliocene a tectonic phase caused a simultaneous uprising of the area and the generation, by progradational processes, of a sedimentary platform (De Rita et al., 1986). These islands mainly consist of submarine volcanic products and subordinate subaerial volcanites. The beginning of volcanism can be dated back to Pliocene (De Rita et al., 1986; Bellucci et al., 1999). Volcanic rocks of Ponza Island consist of submarine rhyolites and subaerial trachyte and comendite lavas (Conte and Dolfi, 2002). Most of the Plio-Pleistocene rhyolitic rocks are the result of a hyaloclastic fragmentation occurred during extrusion of the acidic magma under sea water.

The geological setting lead to the formation of a narrow (2-8 km wide) and steep continental shelf, which surrounds the whole archipelago. The shelf break is well defined and lies at water depth of 105-160 m; the deepest shelf break is due to erosive processes at heads of canyon and gullies in the SW part of the shelf. In this area the continental slope, which connect the shelf to the Vavilov Abyssal Plain (at about 3600 m water depth), is extremely steep and characterised by huge instability phenomena that cause the cannibalisation of the whole margin so that only less than 5% of the seafloor is not affected by some sort of instability (Chiocci et al., 2003). Ponza Island is elongated N-S for about 7 km and is separated from Palmarola by an asymmetric channel also directed N-S. The coastline, mainly characterised by cliffs interrupted by small pocket-beaches, is affected by intense erosional processes causing a strong retreatment of cliffs and beaches. The Ponza Island stands on a structural high of the continental shelf, at the border of the continental slope. The morphology of continental shelf around Ponza is regular, with a low progradational gradient (< 1%). Chiocci and Orlando (1996) have found through the Pontine Archipelago a lowstand terrace now located at a depth of 100-150 m that could be linked to episodes of maximum energy (storms along the coast) during the last glacial period. This is confirmed by the occurrence of high percentages of glauconitised tests of shallow-water benthic foraminifers (e.g., *Elphidium*, *Lobatula* and *Asterigerinata*; Frezza et al., 2005, 2010), which may be related to the marine lowstand, during the Last Glacial Maximum (Corselli et al., 1994).

In general, the sediment supply from the continent is low, so carbonate sediment may become predominant (Martorelli et al., 2002). In the infralittoral zone, erosional processes on the rocky shoreline produce reworked volcanoclastic deposits; in the upper circalittoral zone, sediments are principally bioclastic, consisting of coralline red algae, foraminifers, bryozoans, molluscs and echinoderms. In the lower circalittoral zone, the sediment is composed of skeletal grains and planktonic foraminifers (Brandano and Civitelli, 2007). In addition, vegetated bottoms, mainly with *Posidonia oceanica*, occur at shallow water depths and extend down to 38-40 m water depth (Ardizzone and Belluscio, 1996; Frezza et al., 2011; Mateu-Vicens et al., 2012).

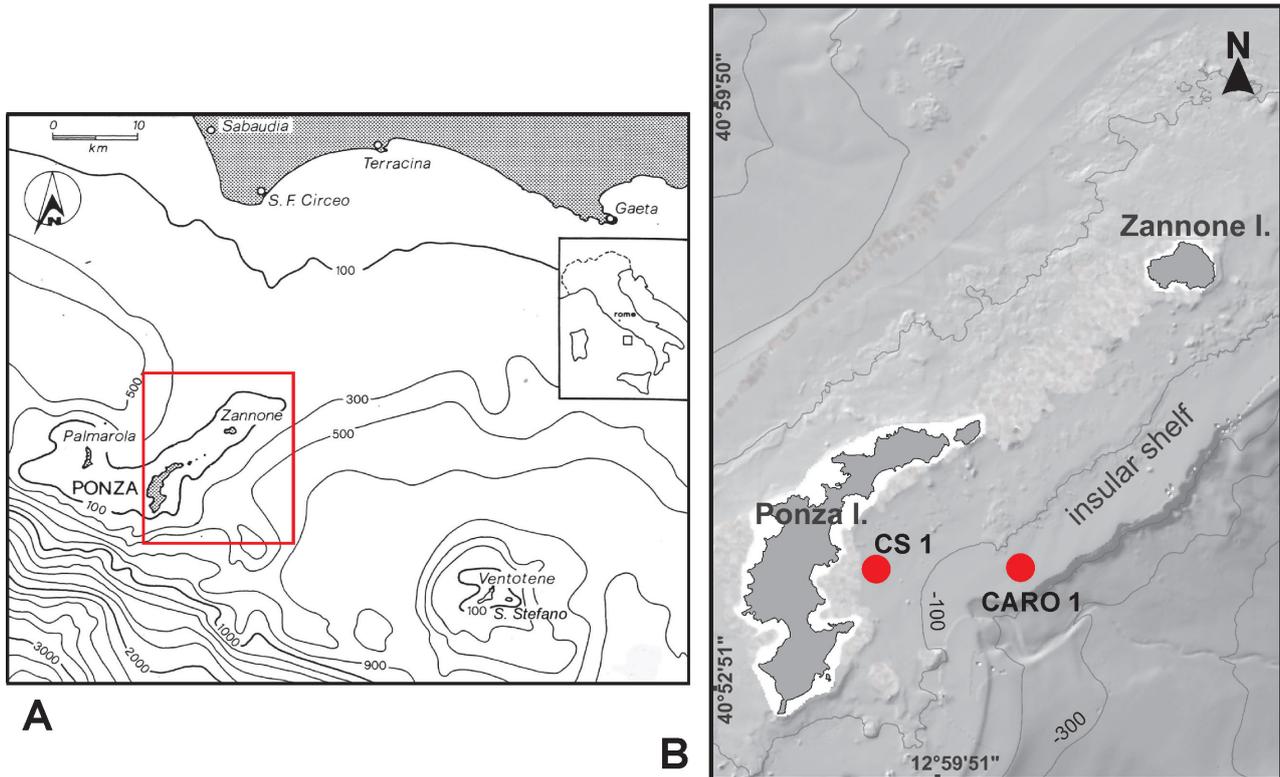


Fig. 1 - A) Pontine Archipelago and sampling area. B) Location map of the studied cores.

3. MATERIALS AND METHODS

Two cores were collected by a gravity corer, during the cruises “Urania 2001” and “Urania 2004” carried out by R/V Urania. They were recovered at 60 (CS1) and 122 m wd (Caro1), in the marine area near Ponza Island (Fig. 1B) and are 218 and 69 cm long respectively. The lithological description of the cores was carried out at the time of cores sampling. A total of 32 samples (consisting of a 1 cm thick sediment slice) were collected generally every 10 cm: 25 samples from the core CS1 and 7 from the core Caro1. In this study only the bottom samples of each core (rich in coralline red algae fragments) were considered for micropaleontological analysis: sample at -218 cm for CS1 and sample at -69 cm for Caro1. At present there are no available ^{14}C AMS datings; however mainly for the deepest core (Caro1), the sharp transition from coarser to finer lithology suggests that the its bottom was deposited during a lowstand phase. The top 15 cm correspond to the highstand phase occurring along the Tyrrhenian margin at 6000 years ago. On the contrary for CS1 core the homogeneity of the lithology and the shallower depth of the core do not allow to distinguish different depositional phases. It is probably that this core intercepted only the Holocene portion of the succession. On the other hand, radiocarbon datings on the bottoms of four cores collected in the Pontine Archipelago between 111 and 157 water depth (85-89 cm long) show a Holocene age (Basso et al., 2006).

In the laboratory, the sediment was wet-sieved through 125 μm , and then dried at 60 $^{\circ}\text{C}$. As the sediment is

generally abundant, washing residues were split with a microsplitter and at least 300 benthic foraminifers with well-preserved tests from each sample were handpicked and counted using a binocular microscope. Moreover, all the coralline red algal fragments present in the sample aliquot utilised for benthic foraminiferal counting were classified according to the terminology based on morphological variability (Basso, 1998, 2012): unattached branches, pralines and boxwork rhodoliths. The absolute abundance of red algae fragments was expressed as fragments/g of dry sediment.

Benthic foraminifers were classified at genus level according to Loeblich and Tappan (1987). Their species identification was also based on Cimerman and Langer (1991), Sgarrella and Moncharmont Zei (1993) and Fiorini and Vaiani (2001). To delineate in detail the assemblage structure, the following parameters were calculated for each sample: the α -Fisher index (Fisher et al., 1943) which is a relationship between the number of species and the number of specimens in each assemblage; the Shannon index (Murray, 1991, 2006), which takes into account both the number of species and the distribution of individuals among species, and is commonly used as an index of diversity; and the percentage of dominance (Walton, 1964), that is the highest percentage abundance of foraminiferal species in a sample. The diversity indices were calculated by using the PAST (version 2.16) - Palaeontological Statistics data analysis package (Hammer et al., 2001). The faunal density was expressed as specimens/g of dry sediment. Considering the abundance of epiphytic (epifaunal)

foraminifers in the analysed samples, foraminiferal species were classified following the criteria adopted by Langer (1993) as modified by Mateu-Vicens et al. (2014). These last authors suggested to assign all the symbiont-bearing taxa (such as *Amphistegina*, *Peneroplis* or *Sorites*) to the new morphotype SB. As result, a new morphotype classification should be considered according to Mateu-Vicens et al. (2014): A* and D*, including the morphotypes A and D of Langer (1993) without symbiont-bearing species; B* and C* are maintained as the original morphotypes B and C of Langer (1993); and finally, SB, that includes all symbiont-bearing taxa.

Sponge spicules were handpicked from the wet-sieved 125 µm residue of the sample from the two cores, whereas no specimens have been found in the 63 µm granulometric fraction. All representatives morphotypes of spicules found in the sediment of the CS1 bottom sample were mounted on stubs and investigated using a FEI-Quanta 400 Scanning Electron Microscope (SEM, at Dipartimento di Scienze della Terra, SAPIENZA Università di Roma) and, finally, identified by comparison with spicules of Recent sponges (Hooper and van Soest, 2002).

4. RESULTS

4.1. Lithology and sediment composition

The lithology of the core CS1 is represented mainly by coarse to fine clayey sands (Fig. 2). From the bottom (-218 cm) to -176 cm coarse sands, rich in bioclasts (e.g., rhodoliths), were found. From -176 to the top, fine clayey sands are present, with a level of coarse bioclastic sand between -160 and -154 cm. The bottom sample (-218 cm) is characterised by coarse sand containing rhodolith fragments centimetres in size. The sediment shows a siliciclastic composition consisting of small volcanic clasts and quartz grains, both angular and rounded. The abundant bioclastic fraction is made up of coralline red algae, siliceous sponge spicules, gastropod shells and fragments, often with traces of colour, bivalve fragments, plates and spines of spatangoids, chelae of crabs, tubes of annelids and encrusting bryozoans. Among molluscs, trochids and tellinids are the most frequent. Microfauna is abundant, mainly constituted by foraminifers and, subordinately, ostracods. The coralline red algae are very abundant (116.4 fragments for g of dry sediment), with 54 fragments collected during the foraminiferal counting: 38 unattached branches, 9 pralines (one > 1 cm) and 7 boxworks (one > 1 cm). Fruticose branches are both well preserved and eroded. Bioerosion traces are rare, some specimens are encrusted by foraminifers.

The core Caro1 consists of coarse sands at the base passing upward into more fine and clayey sands (Fig. 2). From the bottom (-69 cm) to -55 cm coarse sands are present with abundant rhodoliths; to -34 cm, silty sands are found showing abundant bioclasts (e.g., rhodoliths and molluscs). Successively, between -34 and -15 cm a coarse sand, with abundant bioclasts (e.g., bivalves,

rhodoliths and bryozoans), is present. Finally, to the top fine sand rich in small bioclastic fragments was found. The bottom sample (-69 cm) is characterised by sand containing rhodolith fragments. The sediment is made of carbonate lithoclasts and altered bioclasts (e.g., coralline algae), with sparse quartz grains. The bioclastic fraction consists of coralline algal fragments, gastropod and bivalve fragments, erected bryozoans, echinoid spines and test fragments (mainly from spatangoids), sponge spicules, crab chelae and tubes of annelids. Among the molluscs, pectinids are the most frequent. The abundant microfauna consists of foraminifers and subordinately ostracods. Thirty coralline algae fragments were counted in the sediment aliquot, in which 300 benthic foraminifers were found: 28 unattached branches, 1 praline (= 1.5 cm) and 1 boxwork (> 2 cm). On the whole, the coralline abundance is equal to 57.9 fragments/g of dry sediment.

4.2. Benthic foraminifers

In the bottom of core CS1, 41 species belonging to 26 genera of benthic foraminifers were identified. Perforate hyaline and porcelaneous species show similar abundances: 51.6 and 46.8%, respectively (Fig. 3); agglutinated taxa are subordinate (1.6%). Six species show a relative abundance higher than 5%, while only *Asterigerinata mamilla* and *Quinqueloculina stelligera* reach frequencies higher than 10%. The α -Fisher index is 12.66, while the Shannon index is 3.02; the dominance value is 19.4%. The faunal density show a value of 668.1 specimens/g of dry sediment. The benthic foraminiferal assemblages is characterised by the dominance of *A. mamilla* (19.4%) and *Q. stelligera* (10.3%), with *Lobatula lobatula* (6.8%), *Rosalina bradyi* (5.8%), *Cycloforina tenuicollis* (5.5%) and *Quinqueloculina berthelotiana* (5.5%) as accompanying taxa (Fig. 4). The analysis of epiphytic morphotypes reveals a dominance of the D* (43.9%) and B* (41.3%) groups. The morphotypes A* (characterised by permanently attached forms) and C* (motile species) are subordinate (6.5 and 6.8%, respectively), while the symbiont-bearing foraminifers of SB group are absent (Fig. 5).

The sample collected at the bottom of Caro1 showed the presence of 53 species and 35 genera of benthic foraminifers. Perforate hyaline species dominate the foraminiferal assemblage with a percentage of 64.2%. Porcelaneous (27.4%) and agglutinated (8.4%) foraminiferal species are subordinate (Fig. 3). Among the recognised taxa, three species exceed the 5% of the assemblage and only *L. lobatula* shows percentages higher than 10%. The α -Fisher index is higher than in CS1 bottom (18.39), as well as the Shannon index (3.28). The percentage of dominance reaches the same value of the bottom of CS1 core. The faunal density shows a value of 598.5 specimens/g of dry sediment. Benthic foraminiferal assemblage is dominated by *L. lobatula* (19.4%), with *A. mamilla* (9.7%) and *Miliolinella subrotunda* (9.7%). No other species reaches percentages higher than 5% (Fig. 4). The non permanent-attached forms of morphotype B*

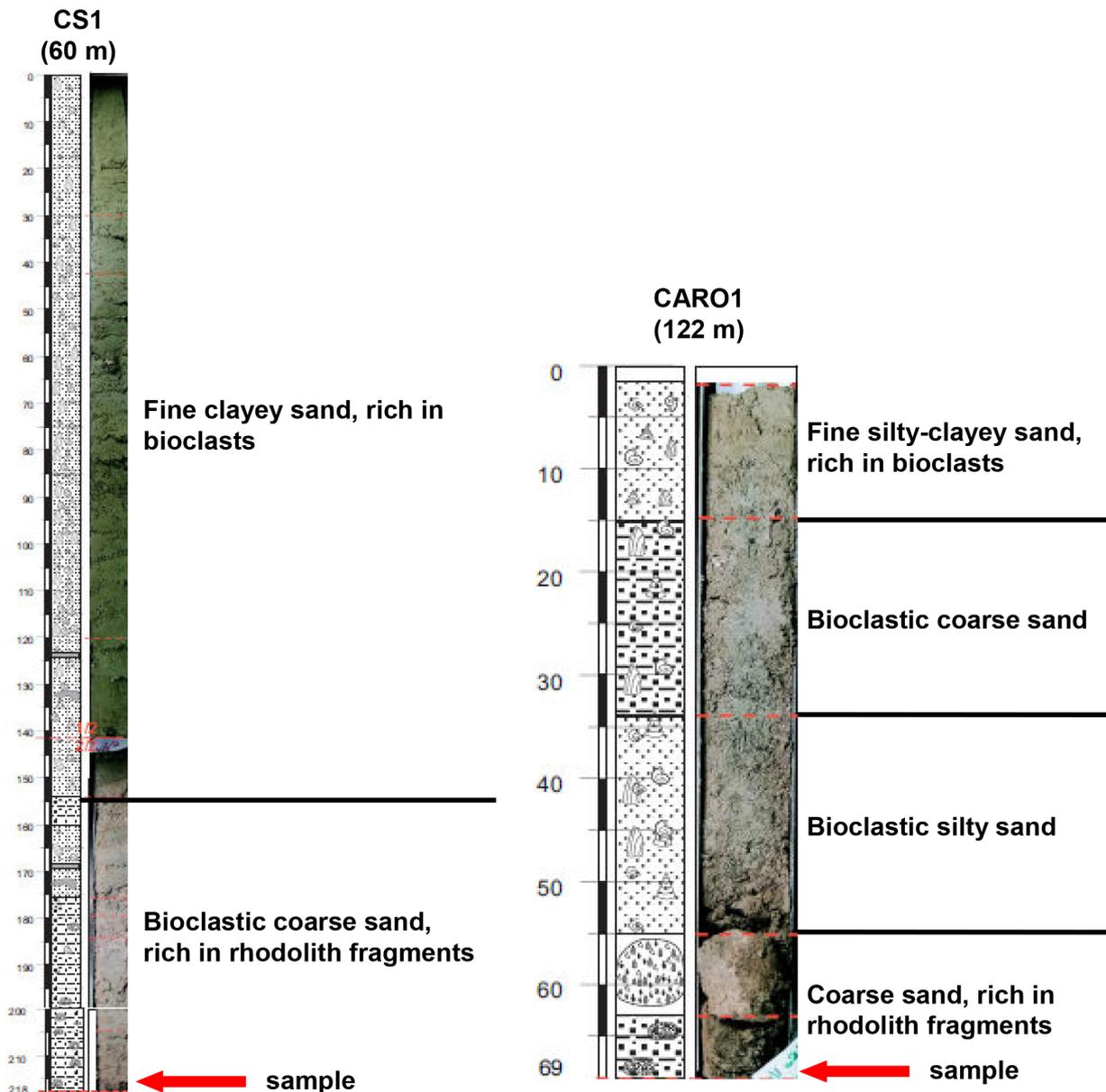


Fig. 2 - Lithological sketch of the studied cores (the red arrows indicate the samples investigated in this study).

(43.2%) dominate the assemblage, but also morphotype D* reaches high frequencies (34.8%). The morphotypes A* and C* are present with relatively low percentages (7.4 and 5.8%, respectively). In this sample also the symbiont-bearing foraminifers are not present (Fig. 5). However, the presence of infaunal benthic foraminifers (e.g., *Bolivina* spp., *Cassidulina* spp. and *Fissurina* spp.) is significant (8.7%).

The absolute and relative abundances of the detected foraminiferal species in both samples are reported in Table 1, whereas many of the more characteristic taxa are illustrated in Figure 6. The summary data concerning benthic foraminiferal assemblages and coralline red algae are included in Table 2.

4.3 Siliceous sponge spicules

In the bottom of core CS1, the siliceous sponge spicules are very abundant. Most of the long rays are broken, but shorter rays are always preserved. On the contrary, in the bottom sample of core Caro1, spicules are rare and fragmented.

Megascleres types of the bottom sample of core CS1 are, in order of frequency: oxeas, calthrops, dichotriaenes, triaenes and mesotriaenes/triods (Fig. 7). All the spicules are referable to demosponges, whose spicular components, tetraaxial and monaxial, are loose (except lithistids).

Oxeas: the gently curved shape prevails in specimens longer more than 2 mm (Fig. 7.1-7.2); straight specimens

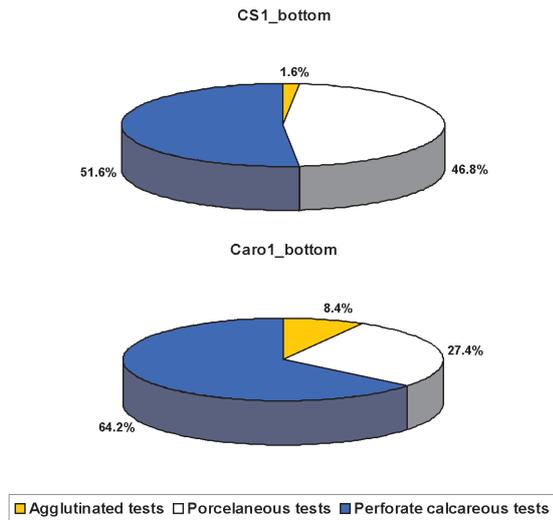


Fig. 3 - Test type composition of foraminiferal assemblages.

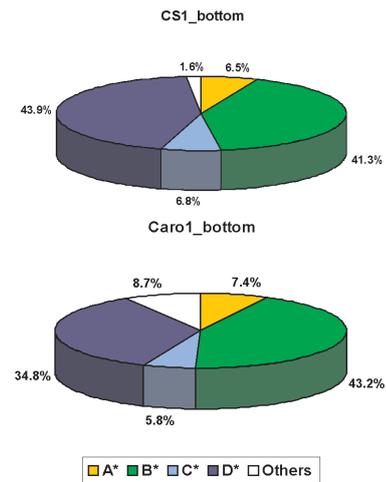


Fig. 5 - Morphotype distribution of epiphytic foraminifera found in the two analysed samples (morphotypes according to Mateu-Vicens et al., 2014).

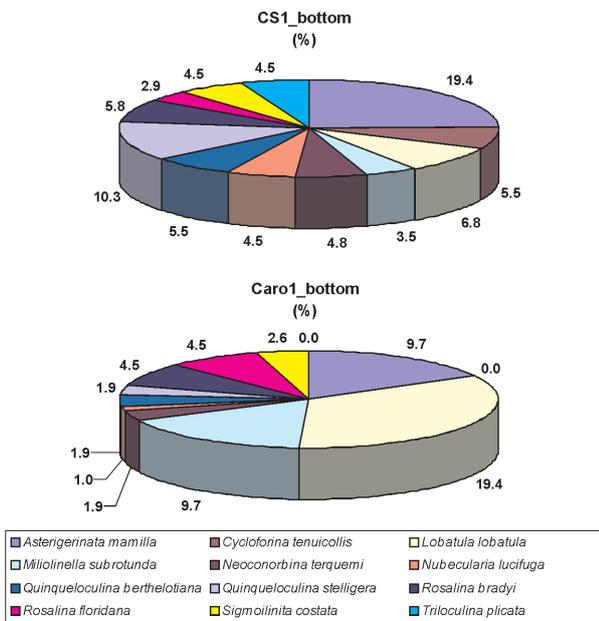


Fig. 4 - More abundant benthic foraminiferal taxa present in the two analysed samples.

(Fig. 7.4) are more rare; the shorter spicules (less than 1 mm) are straight (Fig. 7.3).

Calthrops: the short-shafted triaenes of calthrop-type are common. The morphotype with equal-sized, conical-straight cladi, with variable dimensions and short rhabd is the most frequent (Fig. 7.16); calthrops with unequal sized cladi, curved or with sub-rounded (Fig. 7.17) or rounded terminations (Fig. 7.18) are rare.

Dichotriaenes: both short and long-shafted morphotypes are frequent; the first type (dichocalthrop, considered a modification of calthrop by Van Soest et al., 2010) has short, large protoclads, never longer than clads, and very short rhabds (Fig. 7.14-7.15). Clads are slightly irregular and unequal. The long-shafted dichotrienes (mesotriaenes)

have rabs longer than 500 µm and protoclads and clads are short (Fig. 7.11-7.12).

Triaenes: the rabdome, in complete specimens, is usually long and the cladome has a small diameter. Plagiotriaenes (Fig. 7.5-7.6) and orthotriaenes (Fig. 7.7, 7.10) are frequent, anatriaenes (Fig. 7.8) rare.

Dioids: the rabdome is long; clads short; rare (Fig. 7.9).

Mesotriaenes/triders: short-shafted mesotrienes with irregular tetrafurcate massive clads (Fig. 7.13); they are rare.

In the Caro1 bottom sample, possible fragmented fragoxeas, calthrops and dichocalthrops have been found.

5. DISCUSSION

Sediments of the two studied bottom cores are rich in rhodolith fragments; in particular CS1 bottom sample shows a double content of rhodolith fragments per g of dry sediment and greater foraminiferal content (faunal density) than the Caro1 bottom sample.

In both samples, abundant unattached branches, pralines and rhodolith boxworks were identified. The pralines and rhodolith boxworks present in the Caro1 bottom reach larger size (over 2 cm) than CS1 bottom sample. These rhodolith sizes are consistent with the red algal particles present in the modern sediments of Pontine Archipelago: 1-3 cm according to Bracchi and Basso (2012). These authors described a “calcareous algae facies” between 40 and 70 m wd, constituted by a gravelly sand in which coralline red algae represent the most abundant group with percentages higher than 65%. Basso (1998) has found a maximum abundance of living coralline algae from 60 to 70 m wd, still around the Pontine Islands. Moreover, Brandano and Civitelli (2007) recognise an “unattached coralline algal branches gravel” facies between 50 and 112 m wd.

Benthic foraminiferal assemblage is characterised by the dominance of *Asterigerinata mamilla* and *Quinqueloculina stelligera* in the CS1 bottom and of *Lobatula lobatula* in the Caro1 bottom (Fig. 4). The diversity indices of these assemblages show values similar to recent foraminiferal associations recognised in the Pontine Archipelago at water depth lower than 100 m (α -Fisher: 4.2-20.8; Shannon: 2.17-3.70; Frezza et al., 2010), indicating normal marine environments with a good species diversity (better in Caro1 than in CS1 samples).

Epifaunal foraminifers as *A. mamilla* and *L. lobatula*, often associated to miliolids, dominate the assemblages of the two samples: similar foraminiferal assemblages dominated by *A. mamilla*, *L. lobatula* and *Rosalina bradyi* are typical of Recent Mediterranean infralittoral vegetated bottoms (e.g., Langer, 1988, 1993; Langer et al., 1998; Frezza et al., 2005, 2010, 2011; Mateu-Vicens et al., 2010, 2014; Benedetti and Frezza, 2016). Nevertheless, these taxa are described also as epifaunal suspension feeders, living permanently or temporarily attached to coarse substrates, such as bioclastic sands and gravels (Murray, 2006; Milker et al., 2009). In particular, *A. mamilla* was reported as very abundant from the infralittoral zone, especially on vegetated seabed (Jorissen, 1987; Langer, 1988, 1993; Coppa et al., 1994; Frezza et al., 2011), but also from circalittoral detrital bottoms (Jorissen, 1988; Sgarrella and Moncharmont Zei, 1993; Moulfi-El-Houari et al., 1999; Frezza et al., 2005, 2010; Ferraro et al., 2012). *Lobatula lobatula* shows a similar distribution in the Mediterranean area: it is abundant from infralittoral zone, especially on *Posidonia* meadows (Sgarrella and Barra, 1984; Jorissen, 1988; Langer, 1988; Vénec-Peyré and Le Calvez, 1988; Coppa et al., 1994; Frezza and Carboni, 2009; Frezza et al., 2011; Buosi et al., 2012; Benedetti and Frezza, 2016), but it is present also from circalittoral detrital bottoms (Sgarrella and Moncharmont Zei, 1993; Frezza et al., 2005, 2010). *Quinqueloculina stelligera* is frequent in the infralittoral zone, mainly on sandy or vegetated bottoms (Langer, 1993; Sgarrella and Moncharmont Zei, 1993; Frezza et al., 2005) but, in general, all miliolids are commonly described as linked to a vegetated seafloor (Ribes and Gracia, 1991; Langer, 1993).

Morphotype B* (including *A. mamilla* and *L. lobatula*) is very abundant in both analysed samples, but they are dominant in the Caro1 bottom. Species belonging to morphotype B* have been found on different phytal substrates and its species often constitute the major portion of epiphytic foraminiferal assemblages (Langer, 1993; Frezza et al., 2011; Mateu-Vicens et al., 2014). These species are generally motile, but temporarily attach their shell to the substrate with organic material. Their flat umbilical surface is well-adapted to smooth substrates (Langer, 1993; Mateu-Vicens et al., 2014). Morphotype D* (miliolids and agglutinated foraminifers) also is abundant in the two bottom samples. This group includes many opportunistic species with short life spans that are

particularly adapted to nutrient-rich environments, such as *P. oceanica* rhizomes (Langer, 1993; Mateu-Vicens et al., 2014). On the other hand, it usually attains abundances greater than 20% (Langer, 1993; Mateu-Vicens et al., 2010, 2014; Frezza et al., 2011).

Morphotype A* (permanently attached forms as *Nubecularia lucifuga* and *Planorbulina mediterraneensis*) and C* (mainly *Elphidium* spp.) are poorly represented in the analysed samples; they are generally associated with stable, undisturbed *P. oceanica* meadows (Mateu-Vicens et al., 2014). Finally, symbiont-bearing taxa (SB group) are completely absent. Their distribution in the Western Mediterranean is restricted (Murray, 2006), being controlled by light penetration and temperature (Hallock, 1999). In general, high abundances of symbiont-bearing foraminifers testify very good environmental conditions in shallow and oligotrophic waters (Blanc-Vernet, 1988; Langer et al., 1998; Hyams-Kaphzan et al., 2008 and references therein; Mateu-Vicens et al., 2014). Consequently, the lack of the symbiont-bearing foraminifers may be linked to non-optimal environmental conditions, in terms of lighting and trophism of the waters. This hypothesis can be confirmed by the presence (particularly in the Caro1 bottom sample) of infaunal taxa as *Bolivina* spp., *Cassidulina* spp. and *Melonis* spp. that are more disturbance tolerant, generally indicative of low-oxygen concentrations (Bernhard and Sen Gupta, 2002).

In the Recent sediments of Pontine Archipelago, benthic foraminiferal assemblages dominated by epifaunal taxa were described both in the infralittoral vegetated seabed (Frezza et al., 2011) and in the biodetrital circalittoral sediments (Frezza et al., 2005, 2010). Benthic foraminiferal communities found in the *Posidonia* prairies near Ponza Island are characterised by the dominance of *L. lobatula* and *R. bradyi*, but also by high abundances of a symbiont-bearing species as *Peneroplis pertusus* in the shallowest samples. In the circalittoral zone of the Pontine Archipelago Frezza et al. (2005, 2010) described a benthic foraminiferal assemblage dominated by epifaunal taxa (*A. mamilla*, *L. lobatula* and *R. bradyi*) on coarse biodetrital sediments.

The possible correlation of the loose sponge spicules associations in marine sediments and that of the living sponges has been investigated by some authors, both on Cenozoic (Pisera et al., 2006; Frisone et al., 2014; Lukowiak et al., 2014), Quaternary (Martini and Locker, 1990) and Recent sediments (Inoue, 1984; Lukowiak et al., 2013; Lukowiak, 2016).

In modern siliceous demosponges, oxeas occur commonly, both as accessory and main components. Calthrops and short-shafted mesotriaenes (dichotriaenes) are mainly found in the representatives of the two astrophorid families of Pachastrellidae and Calthropellidae, usually as the unique megasclere-types (Hooper and Van Soest, 2002; Maldonado, 2002). Few genera of three tetractinellid families (the spirophorid Tetillidae and the astrophorid Geodiidae and Ancorinidae) contain calthrops

Benthic foraminiferal species	Mateau-Vicens et al. (2014) morphotypes	Caro1 bottom		CS1 bottom	
		specimens	%	specimens	%
<i>Adelosina cliarensis</i>	D*	3	1.0	3	1.0
<i>Adelosina dubia</i>	D*	1	0.3	0	0.0
<i>Adelosina pulchella</i>	D*	0	0.0	1	0.3
<i>Affinetrina planciana</i>	D*	3	1.0	3	1.0
<i>Ammonia parkinsoniana</i>	B*	1	0.3	0	0.0
<i>Angulogerina angulosa</i>		1	0.3	0	0.0
<i>Asterigerinata mamilla</i>	B*	30	9.7	60	19.4
<i>Asterigerinata planorbis</i>	B*	3	1.0	0	0.0
<i>Bigenerina nodosaria</i>	D*	1	0.3	0	0.0
<i>Bolivina aenariensis</i>		0	0.0	1	0.3
<i>Bolivina difformis</i>		3	1.0	0	0.0
<i>Bolivina pseudoplicata</i>		3	1.0	0	0.0
<i>Bulimina elongata</i>		0	0.0	1	0.3
<i>Cassidulina carinata</i>		3	1.0	0	0.0
<i>Cassidulina crassa</i>		5	1.6	0	0.0
<i>Cibicidoides pseudoungerianus</i>	B*	1	0.3	0	0.0
<i>Connemarella rudis</i>	D*	11	3.5	2	0.6
<i>Conorbella patelliformis</i>	B*	1	0.3	3	1.0
<i>Cornuspira involvens</i>	D*	2	0.6	1	0.3
<i>Cycloforina contorta</i>	D*	0	0.0	5	1.6
<i>Cycloforina tenuicollis</i>	D*	0	0.0	17	5.5
<i>Elphidium aculeatum</i>	C*	2	0.6	0	0.0
<i>Elphidium advenum</i>	C*	0	0.0	2	0.6
<i>Elphidium complanatum</i>	C*	6	1.9	0	0.0
<i>Elphidium crispum</i>	C*	5	1.6	2	0.6
<i>Elphidium macellum</i>	C*	0	0.0	6	1.9
<i>Elphidium maioricense</i>	C*	0	0.0	1	0.3
<i>Elphidium pulvereum</i>	C*	0	0.0	8	2.6
<i>Elphidium translucens</i>	C*	5	1.6	1	0.3
<i>Fissurina cucullata</i>		3	1.0	0	0.0
<i>Fissurina orbignyana</i>		3	1.0	1	0.3
<i>Gavelinopsis praegeri</i>	B*	2	0.6	0	0.0
<i>Haynesina depressula</i>	C*	0	0.0	1	0.3
<i>Lachlanella undulata</i>	D*	6	1.9	0	0.0
<i>Lobatula lobatula</i>	B*	60	19.4	21	6.8
<i>Melonis barleeanus</i>		1	0.3	0	0.0

Tab. 1 - Absolute and relative abundances of the detected benthic foraminiferal species.

Benthic foraminiferal species	Mateau-Vicens et al. (2014) morphotypes	Caro1 bottom		CS1 bottom	
		specimens	%	specimens	%
<i>Melonis pompilioides</i>		3	1.0	0	0.0
<i>Miliolinella elongata</i>	D*	0	0.0	2	0.6
<i>Miliolinella semicostata</i>	D*	1	0.3	0	0.0
<i>Miliolinella subrotunda</i>	D*	30	9.7	11	3.5
<i>Miniacina miniacea</i>	A*	1	0.3	0	0.0
<i>Neoconorbina terquemi</i>	B*	6	1.9	15	4.8
<i>Nubecularia lucifuga</i>	A*	3	1.0	14	4.5
<i>Planorbulina acervalis</i>	A*	1	0.3	0	0.0
<i>Planorbulina mediterraneensis</i>	A*	8	2.6	6	1.9
<i>Pseudotriloculina laevigata</i>	D*	3	1.0	0	0.0
<i>Pseudotriloculina oblonga</i>	D*	1	0.3	0	0.0
<i>Quinqueloculina berthelotiana</i>	D*	6	1.9	17	5.5
<i>Quinqueloculina bosciana</i>	D*	0	0.0	1	0.3
<i>Quinqueloculina parvula</i>	D*	1	0.3	0	0.0
<i>Quinqueloculina seminulum</i>	D*	0	0.0	1	0.3
<i>Quinqueloculina stalkerii</i>	D*	0	0.0	2	0.6
<i>Quinqueloculina stelligera</i>	D*	6	1.9	32	10.3
<i>Quinqueloculina subpolygona</i>	D*	3	1.0	0	0.0
<i>Quinqueloculina ungeriana</i>	D*	5	1.6	5	1.6
<i>Reussella spinulosa</i>		1	0.3	1	0.3
<i>Rosalina bradyi</i>	B*	14	4.5	18	5.8
<i>Rosalina floridana</i>	B*	14	4.5	9	2.9
<i>Rosalina globularis</i>	B*	0	0.0	2	0.6
<i>Sigmoilinita costata</i>	D*	8	2.6	14	4.5
<i>Siphonaperta irregularis</i>	D*	0	0.0	1	0.3
<i>Spaerogypsina globula</i>	A*	1	0.3	0	0.0
<i>Spirillina vivipara</i>	A*	9	2.9	0	0.0
<i>Spiroloculina excavata</i>	D*	2	0.6	1	0.3
<i>Spiroloculina ornata</i>	D*	1	0.3	0	0.0
<i>Spiroplectinella wrighti</i>	D*	6	1.9	0	0.0
<i>Textularia bocki</i>	D*	8	2.6	3	1.0
<i>Tretomphalus concinnus</i>	B*	2	0.6	0	0.0
<i>Triloculina plicata</i>	D*	0	0.0	14	4.5
<i>Uvigerina mediterranea</i>		1	0.3	1	0.3
Counted foraminifers		310		310	

Tab. 1 - Continued ...

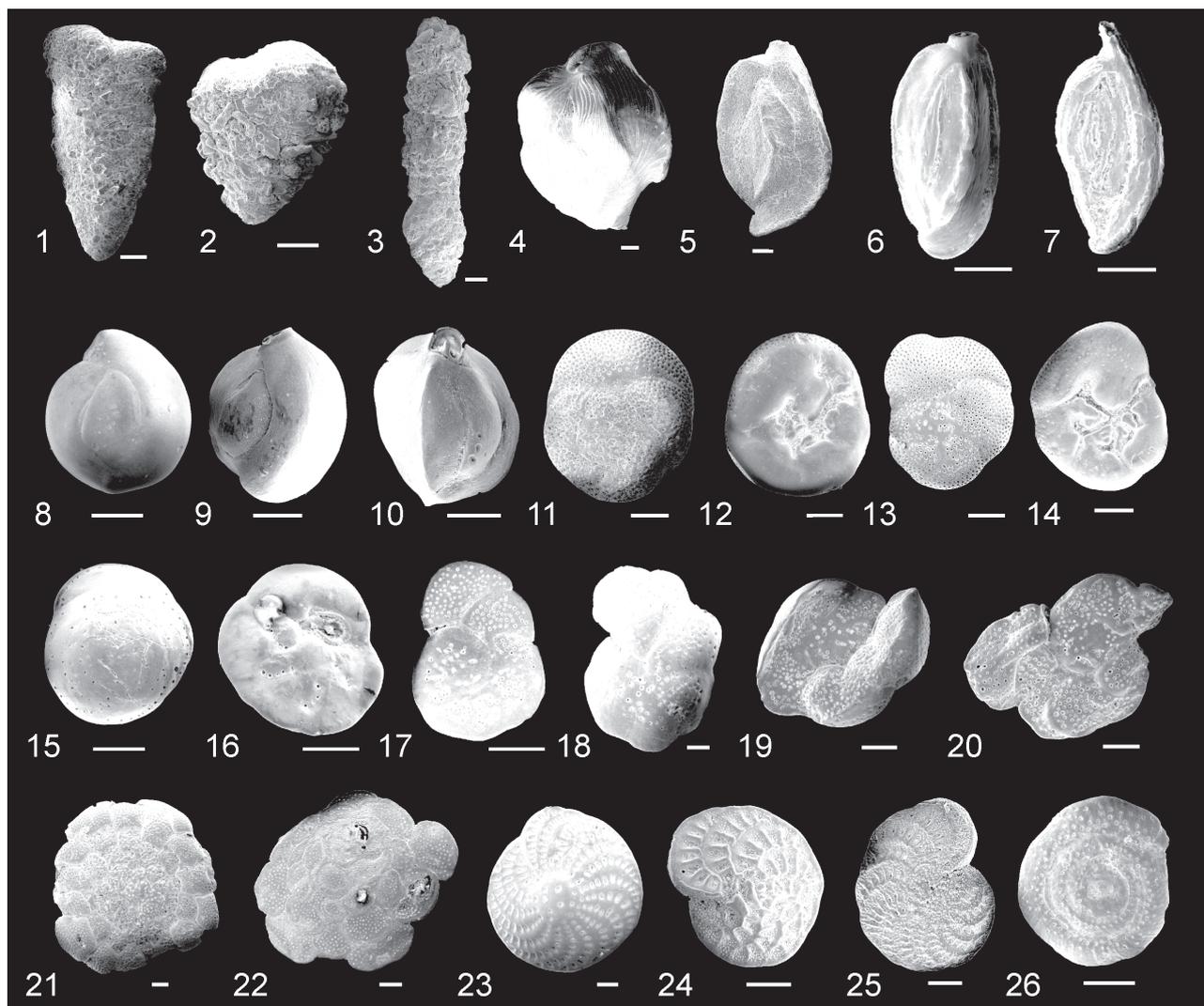


Fig. 6 - Scanning electron micrographs of more significant benthic foraminiferal species recognised in the two bottom cores from Pontine Archipelago. Scale bar = 100 μm : 1. *Spiroplectinella wrighti*, side view, Caro1 bottom; 2. *Textularia bocki*, side view, Caro1 bottom; 3. *Bigenerina nodosaria*, side view, Caro1 bottom; 4. *Lachlanella undulata*, side view, Caro1 bottom; 5. *Quinqueloculina berthelotiana*, side view, Caro1 bottom; 6. *Quinqueloculina stelligera*, side view, Caro1 bottom; 7. *Sigmoinilita costata*, side view, Caro1 bottom; 8. *Miliolinella subrotunda*, side view, Caro1 bottom; 9-10. *Triloculina plicata*, CS1 bottom: 9. side view; 10. apertural view; 11-12. *Rosalina bradyi*, Caro1 bottom: 11. spiral view; 12. umbilical view; 13-14. *Rosalina floridana*, CS1 bottom: 13. spiral view; 14. umbilical view; 15-16. *Asterigerinata mamilla*, Caro1 bottom: 15. spiral view; 16. umbilical view; 17-20. *Lobatula lobatula*, Caro1 bottom: 17. spiral view; 18. umbilical view; 19-20. spiral view of irregular specimens; 21-22. *Planorbulina mediterraneensis*, CS1 bottom: 21. dorsal side; 22. attached side; 23. *Elphidium crispum*, side view, Caro1 bottom; 24. *Elphidium macellum*, side view, CS1 bottom; 25. *Elphidium pulvereum*, side view, CS1 bottom; 26. *Spirillina vivipara*, side view, Caro1 bottom.

or dichotriaenes, but less numerous and accompanied by oxeas and triaenes (Van Soest et al., 2010); short-shafted dichotriaenes are present also in Lithistids (Pisera et al., 2006). Even if a certain variability in shape of calthrocs and dichocalthrocs in the same species and individuals is relatively common (Van Soest et al., 2010), the short-protoclad massive dichotriaenes present in the examined sample resemble those of the pachastrellid genus *Dercitus* and its sub-genus *Stoeba*. *Dercitus* is a world-wide taxon, frequent in the western Mediterranean area mainly with the species *Dercitus (Stoeba) plicatus*, with a wide depth range down 100 m wd (Pulitzer-Finali, 1983). Mesotriders and irregularly shaped mesotriaenes with

nearly symmetrical rabdomes, shorter than the clads, are typical of the problematic monotypic genus *Brachiaster*, known from Philippine waters, recently attributed to Pachastrellidae (Maldonado, 2002); mesotriaenes with tetrafurcate clads (and protoclads longer than those of *Brachiaster*) are present also in the pachastrellid genus *Triptolemma*, present in the Mediterranean Sea with the species *T. simplex*, growing within various demosponges (Sarà, 1959).

Orthotriaenes and plagiotriaenes are common as ectosomal triaenes of the astrophorid family of Ancorinidae.

The megasclere assemblage of the CS1 bottom

		Caro1 bottom	CS1 bottom
		%	%
Benthic foraminifers			
Counted foraminifers		310	310
Species		53	41
Fisher_α Index		18.39	12.66
Shannon_H Index		3.28	3.02
Dominance (%)		19.4	19.4
Faunal density (specimens/g)		598.5	668.1
Agglutinated tests		8.4	1.6
Porcelaneous tests		27.4	46.8
Perforate hyaline tests		64.2	51.6
Mateau-Vicens et al. (2014)	A*	7.4	6.5
morphotypes	SB	0.0	0.0
	B*	43.2	41.3
	C*	5.8	6.8
	D*	34.8	43.9
	Others	8.7	1.6
Coralline red algae			
boxworks (> 3,5 mm)		1	7
pralines (> 3,5 mm)		1	9
fragments (> 3,5 mm)		13	18
fragments (< 3,5 mm)		15	20
Coralline abundance (fragments/g)		57.9	116.4
Dry sediment weight (g)		0.518	0.464

Tab. 2 - Summary data regarding foraminifers and coralline red algae.

sample indicates a well developed living community of astrophorid demosponges, probably accompanied by other demosponge taxa, as presumed from the “parasitic” habitat of *Triptolemma*. Although pachastrellids and ancorinids have a wide depth range, in western Mediterranean Sea they are common in the coralligenous environment (Bertolino et al., 2013, 2014).

Even if most of microscleres have not been retained by > 63 μm sieve, microscleres produced by modern representatives of the astrophorid families are mainly of various types of asters (sterraster, euaster, streptasters, sanidasters), microrabds and microxeas (Hooper and

Van Soest, 2002), some of which have dimensions > 63 μm. Nevertheless, a selective post-mortem dispersal of microscleres has to be considered, whereas the selective dissolution of the microscleres in undersaturated marine waters seems excluded by the perfect state of preservation of the megascleres.

6. CONCLUSIONS

The Quaternary sediments of the bottom samples of two cores (CS1 and Caro1) are rich in rhodoliths and the benthic foraminiferal assemblages are dominated by

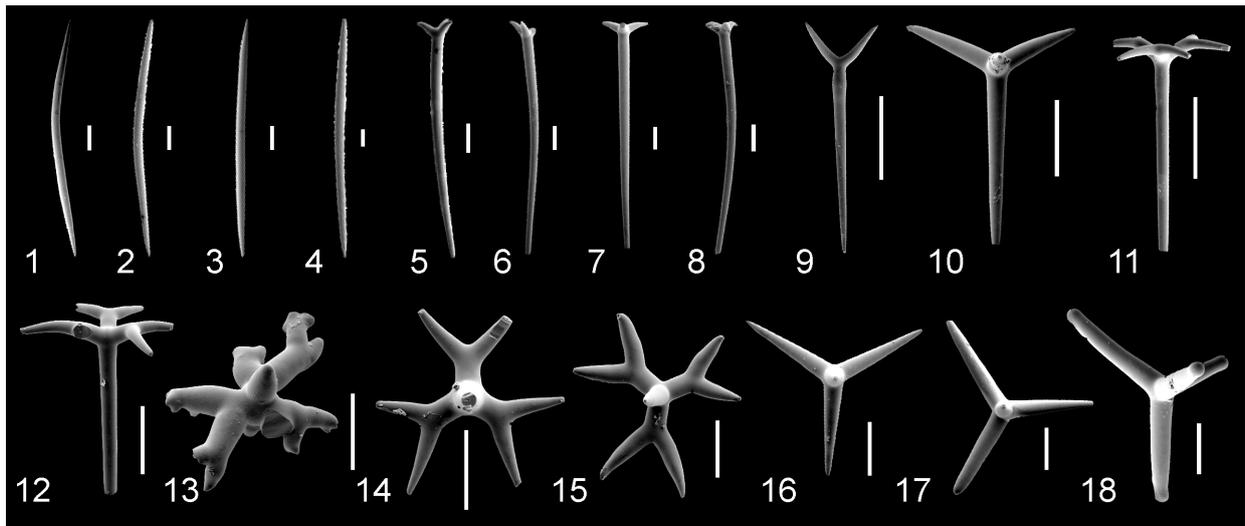


Fig. 7 - Scanning electron micrographs of the demospone spicules (Astrophorida) recognised in the CS1 bottom sample from Pontine Archipelago. Scale bar = 200 μm : 1-4. oxeas; 5-6. triaenes (plagiotriaenes); 7. triaenes (orthotriaenes); 8. triaenes (anatriaene); 9. diaen; 10. triaenes (orthotriaenes); 11-12. long-shafted dichotriaenes; 13. mesotriaene; 14-15. short-shafted dichotriaenes; 16-18. calthrops.

Asterigerinata mamilla and *Lobatula lobatula* (without symbiont-bearing species). In the Recent sediments of Pontine Archipelago, the rhodolith facies is present from 40 to 100 m wd (Basso, 1998; Brandano and Civitelli, 2007; Bracchi and Basso, 2012), bathymetries in which benthic foraminiferal assemblages are dominated by *A. mamilla* and *L. lobatula*, and barren in symbiont-bearing taxa.

Different abundance in sponge spicules in the two examined samples evidence some differences in the depositional environment. The scarce presence of spicules and their bad preservation in the Caro1 bottom sample could be explained by their washing out by bottom-currents; however, the relative abundance of well preserved delicate specimens of erect bryozoans and infaunal foraminifers in the latter sample indicates that the water movement was enough weak. Moreover, the different sediment composition (richness in quartz grains and in non-carbonate clasts in CS1; richness in carbonate clasts in Caro1) indicate different sources of terrigenous clasts.

In conclusion, the base of the two cores CS1 and Caro1 was deposited within the present-day depth limit of the distribution of living coralline red algae in the Pontine Archipelago (shallower than 100 m wd), but nearly the lower limit. The most superficial part of the bathymetric range of the rhodolith facies can be excluded for the absence of symbiont-bearing foraminifers, whereas the similarity with the upper circalittoral recent foraminiferal assemblages (Frezza et al., 2005, 2010), allow us to hypothesise the lower part of the range, therefore the upper circalittoral zone.

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