

Recent foraminiferal assemblages near Ponza Island (Central Tyrrhenian Sea, Italy)

Virgilio FREZZA, Maria Gabriella CARBONI & Ruggero MATTEUCCI

V. Frezza, Dipartimento di Scienze della Terra, Università di Roma "La Sapienza", Piazzale A. Moro 5, I-00185 Roma, Italy;
virgilio.frezza@uniroma1.it

M.G. Carboni, Dipartimento di Scienze della Terra, Università di Roma "La Sapienza", Piazzale A. Moro 5, I-00185 Roma, Italy;
gabriella.carboni@uniroma1.it

R. Matteucci, Dipartimento di Scienze della Terra, Università di Roma "La Sapienza", Piazzale A. Moro 5, I-00185 Roma, Italy;
ruggero.matteucci@uniroma1.it

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ABSTRACT - Ponza Island is located in the western sector of the Pontine volcanic Archipelago, on a structural high of the continental Tyrrhenian shelf. This preliminary study is comprised in a broad interdisciplinary project, aimed to know and describe the sea bottom of the Pontine Archipelago. On the whole, 22 grab samples, collected for micropaleontological analyses East to Ponza during the cruise of spring 2001, have been studied. Sampling stations range from 20 to 380 m water depth and are located on four transects, having the NW/SE direction. Among these, one transect comprises 12 stations, whereas the others are constituted by 2 to 4 stations. A total of 300 benthic foraminifera with well-preserved tests from each sample were separated and classified, from $>125 \mu\text{m}$ size fraction. All benthic foraminifera with broken and old tests (tests with yellow/brown walls and filled by glauconite) were interpreted as reworked and/or displaced. These tests were collected and counted; planktonic foraminifera were contemporaneously counted and identified. Moreover, all the other bioclastic components of sediment (bivalves, bryozoans, coralline algae, gastropods, ostracods, pteropods, spines of echinoids and spicules of sponges) were counted in each aliquot of samples, in order to better describe the bioclastic facies. In absence of significant sources of terrestrial sediments, organic fraction is generally prevalent; benthic foraminifera always dominate bioclastic component, except in two samples. A total of 199 species, belonging to 91 genera, have been recognised. The data set, containing relative abundance of 16 common taxa of benthic foraminifera, was used to perform the multivariate analysis (Hierarchical Cluster Analysis and Principal Cluster Analysis). The output of Q-mode HCA singles out three main clusters, corresponding to three distinct foraminiferal assemblages: 1) *Rosalina bradyi* and *Asterigerinata mamilla* assemblage (depth: 20-87 m, inner continental shelf with *Posidonia oceanica* meadows), with *Lobatula lobatula*, *Spirillina vivipara*, *Tretomphalus concinnus* and *miliolids*. This biofacies corresponds to the infralittoral-upper circalittoral zone and is dominated by benthic foraminiferal tests with, sometimes, rhodoliths. High values of broken tests may be related to action of wave motion. $P/(P+B)$ ratio is very low; 2) *Cassidulina carinata* assemblage (depth: 79-202 m, outer continental shelf and upper slope), comprising *Bolivina difformis* and *Textularia bocki*. This biofacies corresponds to the circalittoral zone and presents high percentage of old glauconitic of shallow water taxa. They are probably related to sea level stillstand conditions during Late Quaternary. The $P/(P+B)$ ratio increases and, among planktonic species, *Globigerinoides ruber*, *Globigerina bulloides*, *Globorotalia inflata* and *G. truncatulinoides* are present; 3) *Uvigerina mediterranea* assemblage (depth: 250-380 m, continental slope), with *Bulimina marginata*, *Cassidulina crassa*, *Hyalinea balthica* and *Melonis pompilioides*. This biofacies corresponds to the upper epibathyal zone, and is characterised by bioclastic sediment with abundant benthic and planktonic foraminifera, pteropods and spicules of sponges. $P/(P+B)$ ratio shows the highest values.

RIASSUNTO - [Associazioni a foraminiferi recenti nei pressi dell'isola di Ponza (Mar Tirreno Centrale, Italia)] - L'isola di Ponza è situata nel Mar Tirreno centrale, a circa 30 km dalla costa del Lazio (Golfo di Gaeta), su un alto strutturale, al limite della scarpata continentale. Più precisamente, Ponza, insieme alle isole di Palmarola e Zannone, si trova nel settore occidentale dell'arcipelago delle isole Pontine. Queste sono costituite dai prodotti delle eruzioni vulcaniche, sia sottomarine che subaeree che, a partire dal Pliocene, hanno interessato l'area. Dal punto di vista sedimentologico, mancando apporti dal continente, tutta l'area è soggetta ad una prevalente sedimentazione bioclastica (gusci di foraminiferi, briozoi, molluschi, frammenti di echinodermi e alghe coralline, spicole di spugne), mentre la frazione terrigena, comunque subordinata, è costituita da frammenti di origine vulcanica. L'intero arcipelago è oggetto di un ampio progetto interdisciplinare (supportato dal Servizio Geologico), volto alla ricostruzione della distribuzione dei sedimenti e dell'evoluzione della piattaforma continentale dell'area, durante il Quaternario. Lo scopo di questo studio micropaleontologico è la descrizione delle associazioni a foraminiferi bentonici e della loro distribuzione, nel settore a sud-est di Ponza. Sono stati analizzati 22 campioni superficiali di sedimento, prelevati tramite benna, durante una campagna oceanografica svoltasi nella primavera del 2001. Si tratta di campioni ubicati a profondità variabili tra 20 e 380 m, lungo quattro transetti, di cui il più ampio ne comprende 12. Al momento del campionamento il sedimento è stato trattato con una soluzione di etanolo e Rosa Bengala (un colorante biologico), per poter distinguere i foraminiferi viventi. Per ogni campione sono stati contati e classificati almeno 300 foraminiferi bentonici (con guscio ben conservato) della frazione $>125 \mu\text{m}$. Visto il basso numero di foraminiferi con guscio colorato (e quindi viventi al momento del campionamento), il conteggio è stato effettuato considerando l'associazione totale. I foraminiferi con gusci rotti o alterati (colorati di giallo-bruno o glauconitizzati) sono stati contati e considerati come rimaneggiati o trasportati. Inoltre, per poter meglio descrivere le biofacies, sono stati conteggiati anche tutti i foraminiferi planctonici e gli altri componenti bioclastici (bivalvi, briozoi, rodoliti, gasteropodi, ostracodi, pteropodi, radioli di echinoidi e spicole di spugne) presenti nell'aliquota di sedimento comprendente i 300 bentonici. I dati riguardanti questi ultimi, sono stati trattati statisticamente, tramite la Hierarchical Cluster Analysis (HCA) e la Principal Component Analysis (PCA). Sono state classificate 199 specie di foraminiferi bentonici (appartenenti a 91 generi), ma per l'analisi statistica sono stati considerati solo i 16 taxa con un'abbondanza superiore al 10%. Dalla HCA sono stati individuati tre clusters, corrispondenti a tre distinte associazioni di foraminiferi bentonici: 1) associazione a *Rosalina bradyi* e *Asterigerinata mamilla* (profondità: 20-87 m; piattaforma continentale interna, con fondali a *Posidonia oceanica*), comprendente anche altre specie tipiche di ambiente vegetato, come *Lobatula lobatula*, *Spirillina vivipara*, *Tretomphalus concinnus* e *Miliolacea*. Questa biofacies corrisponde a un ambiente infralitorale-circalitorale superiore ed è dominata dai foraminiferi bentonici con la presenza, talvolta, di alghe calcaree (rodoliti). Le alte percentuali

di gusci di foraminiferi bentonici rotti possono essere imputate all'azione del moto ondoso, mentre il rapporto plancton/(plancton+benthos) è molto basso; 2) associazione a *Cassidulina carinata* (profondità: 79-202 m; piattaforma continentale esterna e scarpata superiore), comprendente anche *Bolivina difformis* e *Textularia bocki*. Questa biofacies corrisponde al piano circalitorale e presenta alte percentuali di gusci alterati o glauconitizzati, appartenenti a taxa infralitorali (*Elphidium*, *Lobatula* e *Asterigerinata*). Questi gusci, molto probabilmente, indicano condizioni di basso stazionamento del livello marino (correlabili con fasi fredde), durante il tardo Quaternario. Il rapporto plancton/(plancton+benthos) cresce sensibilmente e, tra le specie planctoniche, si trovano *Globigerinoides ruber*, *Globigerina bulloides*, *Globorotalia inflata* e *G. truncatulinoides*; 3) associazione a *Uvigerina mediterranea* (profondità: 250-380 m; scarpata continentale), con *Bulimina marginata*, *Cassidulina crassa*, *Hyalinea balthica* e *Melonis pompilioides*. Tale biofacies, corrispondente al piano epibatiale superiore, è caratterizzata da una frazione bioclastica, costituita prevalentemente da foraminiferi bentonici e planctonici, pteropodi e spicole di spugna. Il rapporto plancton/(plancton+benthos) presenta i valori più elevati.

INTRODUCTION

Ponza Island is located in the western sector of the Pontine volcanic Archipelago, in the Central Tyrrhenian Sea (Fig. 1), about 30 km from the Gulf of Gaeta (Latium, Italy). It stands on a structural high of the continental shelf, at the border of the continental slope. 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 & 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) 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 is mainly characterised by cliffs interrupted by small pocket-beaches; the main beaches (longer than 100 m) are: Chiaia di Luna, Frontone and M. Rosa. Almost all the coastline is affected by intense erosional processes causing a strong retreatment of cliffs and beaches. This strong erosion is a consequence of the low resistance and high alterability of pontian lithology. The morphology of continental shelf around Ponza is regular, with a low progradational gradient (< 1%). This flat area represents the top of a prograding wedge formed during the Last Glacial Maximum (Chiocci & Orlando, 1996).

In this area sediment supply from the continent is low, so carbonate sediment may become predominant (Martorelli et al., 2002). The substrate is characterised mainly by sand and, secondly, by rock. The distribution of these two facies is strongly related to the distribution of rocky coasts and beaches. In addition, the vegetated bottom, mainly with *Posidonia oceanica*, is also present. Finer sediments (mud) were found on the continental slope only (below 120-150 m). Generally, the coarse fraction is mainly made up of biogenic clasts, whereas the terrigenous fraction is subordinated, including volcanic clasts: sanidine, biotite, volcanic glass and volcanic rock fragments (Martorelli et al., 2002). On the shelf, the sedimentation is mainly intrabasinal and made up of the rest of different benthic communities (foraminifera, bryozoans, molluscs, echinoderms and coralline algae), that form a thin carbonate blankets on the volcanic substrate.

The marine conditions of this area are controlled by prevailing westerly and northwesterly winds, but

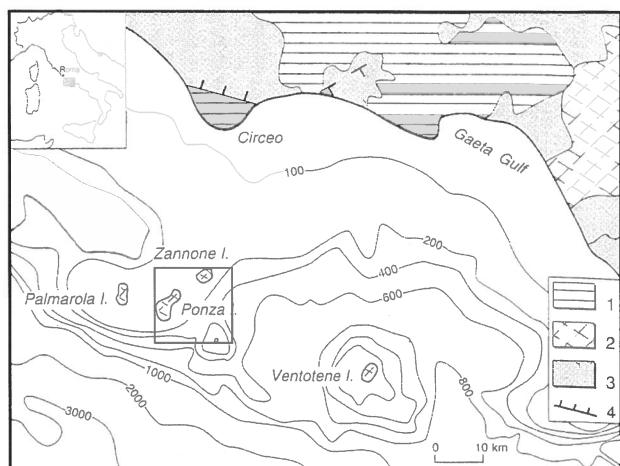


Fig. 1 - Pontine archipelago and mainland coast (after Chiocci & Orlando, 1996, modified). Legend: 1 - Neritic carbonate sediments (Middle Triassic-Paleogene); 2 - volcanic rocks (Pleistocene); 3 - continental and subordinate marine deposits (Holocene-Late Pleistocene). The sampling area is evidenced by a square.

the most violent storms come from east, during autumn and winter (Basso, 1998).

This research is comprised in a broad interdisciplinary project, aimed to reconstruct the sediment distribution and shelf evolution of the Pontine Archipelago, during Late Quaternary. Since 1997, the research has consisted in a morphoacoustic, seismostratigraphic, sedimentological, palaeontological, minero-petrographical characterization of the continental shelf deposits and rock outcrops for a submarine geological mapping, funded by the Geological Survey of Italy (Martorelli et al., 2002). For this purpose, a large amount of different kinds of data was collected (side scan sonar records, seismic profiles, several grab samples and rock samples, gravity cores and ROV films plus multibeam).

Benthic foraminifera are found in most environments and are the most important components of modern and ancient benthic communities. As foraminiferal distribution is controlled by physical, chemical and ecological parameters of the substrate and water (depth, salinity, oxygen and organic carbon content, sediment grain size), their assemblages can be used as indicators of (palaeo)environmental modifications. Consequently, the study of these assemblages will not only allow to define present habitats, but will also can give a contribution for the reconstruction of the past evolution of the shelf.

The Mediterranean Sea represents an important field area in the history of foraminiferal studies. Currently, the number of studies dealing with the superficial distribution of benthic foraminifera in the Tyrrhenian Sea is limited (Moncharmont Zei, 1962, 1964; Giammarino & Tedeschi, 1974; Parisi, 1981; Sgarrella & Barra, 1985; Sgarrella et al., 1985; Belfiore et al., 1987; Coppa, 1987; Langer, 1988; Coppa, 1991; Langer, 1993; Sgarrella & Moncharmont Zei, 1993; Bellotti et al., 1994; Coppa et al., 1994; Carboni et al., 2000, 2004).

The aim of this study is a preliminary description of benthic foraminiferal assemblages and their distribution patterns, in the southeastern part of Ponza platform. In this paper, it will be possible to establish a relationship between water depth, type of sediment and foraminiferal spatial distribution.

MATERIALS AND METHODS

A total of 22 grab samples collected east to Ponza, in April-May 2001, have been analysed. Sampling stations range from 20 to 380 m water depth and are located on four transects, having the NW/SE direction, between Ponza and Zannone islands and Botte Rock. Among these, transect II comprises 12 stations, the others by no more than 4 stations (Fig. 2). Samples were stored in ethanol-Rose Bengal solution to distinguish between living and dead foraminifera (Walton, 1952).

All the 22 samples were dried in oven at 60 °C. Subsequently, the samples were wet-sieved over 63 and 125 µm. The sediment retained in each sieve was dried at 60 °C and weighed; then, it were split by a

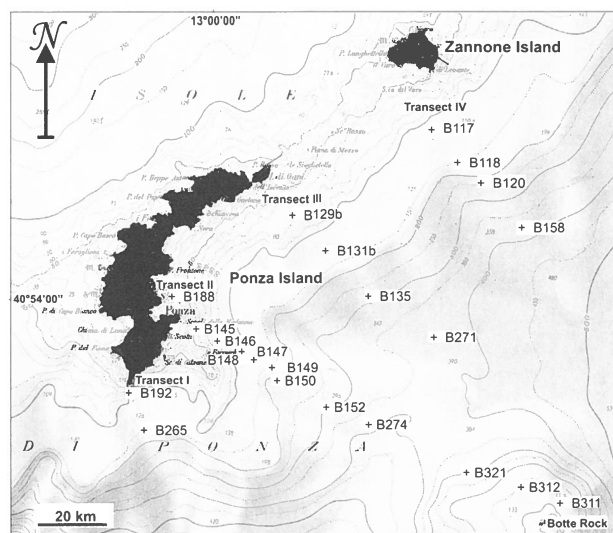


Fig. 2 - Geographic setting and location of the sampling sites.

microsplitter into small portions, to obtain an appropriate number of specimens, reflecting the original assemblage.

In this study we employ data from >125 µm size fraction: the smaller fraction (juvenile specimens) was eliminated from counting, but a proper taxonomic identification of the entire split aliquots was allowed.

At least 300 benthic foraminifera with well-preserved tests from each sample were separated and counted using a binocular microscope. All benthic foraminifera with broken and old tests (tests with yellow/brown halls and filled by glauconite) were interpreted as reworked and/or displaced. These tests were collected and counted. Planktonic foraminifera in each sample were contemporaneously counted and identified. The quantitative analysis was carried out on the total assemblage (living + dead foraminifera), because the percentage of living foraminifera (Rose Bengal stained) was very low. The total assemblage, which represents the mean environmental conditions over the year, according to Scott & Medioli (1980), was utilised for statistical data processing, whereas living specimens were considered indicative of species that are very probably autochthonous.

Moreover, all other bioclastic components of sediment (bivalves, bryozoans, coralline algae, gastropods, ostracods, pteropods, spines of echinoids, spicules of sponges) in each aliquot of samples were counted to describe better the bioclastic facies.

Benthic and planktonic foraminifera were identified according to Loeblich & Tappan (1987). Moreover, identification of benthic foraminifera was also based on AGIP (1982), Cimerman & Langer (1991), Sgarrella & Moncharmont Zei (1993), and Fiorini & Vaiani (2001). Concerning *Melonis* genus we followed Bergamin et al. (1997). A faunal reference list with all the cited benthic species is given in the Appendix.

Multivariate statistical analyses (Q-mode and R-mode Hierarchical Cluster Analysis and R-mode Principal Component Analysis) were performed using

Species or groups of species	Included species
<i>Textularia</i> spp.	<i>T. bocki</i> , <i>T. pseudorugosa</i> , <i>T. sagittula</i>
<i>Connemarella rudis</i>	
<i>Spirillina vivipara</i>	
<i>Adelosina</i> spp.	<i>A. cliarensis</i> , <i>A. duthiersi</i> , <i>A. intricata</i> , <i>A. italica</i> , <i>A. mediterraneensis</i> , <i>A. partschi</i> , <i>Adelosina</i> sp.
<i>Quinqueloculina</i> spp.	<i>Q. berthelotiana</i> , <i>Q. bidentata</i> , <i>Q. bosciana</i> , <i>Q. disparilis</i> , <i>Q. jugosa</i> , <i>Q. laevigata</i> , <i>Q. limbata</i> , <i>Q. neapolitana</i> , <i>Q. nodulosa</i> , <i>Q. padana</i> , <i>Q. seminulum</i> , <i>Q. stalker</i> , <i>Q. stelligera</i> , <i>Q. undulata</i> , <i>Q. viennensis</i>
<i>Lenticulina</i> spp.	<i>L. calcar</i> , <i>L. orbicularis</i> , <i>L. rotulata</i> , <i>L. stellata</i>
<i>Cassidulina</i> spp.	<i>C. crassa</i> , <i>C. carinata</i>
<i>Bulimina</i> spp.	<i>B. costata</i> , <i>B. elongata</i> , <i>B. etnea</i> , <i>B. inflata</i> , <i>B. marginata</i>
<i>Uvigerina mediterranea</i>	
<i>Neonorbina</i> spp.	<i>N. posidonicola</i> , <i>N. terquemi</i> , <i>N. cf. terquemi</i>
<i>Rosalina bradyi</i>	
<i>Hyalinea balthica</i>	
<i>Lobatula lobatula</i>	
<i>Asterigerinata mamilla</i>	
<i>Melonis</i> spp.	<i>M. barleanum</i> , <i>M. pompilioides</i>
<i>Elphidium</i> spp.	<i>E. aculeatum</i> , <i>E. advenum</i> , <i>E. complanatum</i> , <i>E. crispum</i> , <i>E. decipiens</i> , <i>E. excavatum</i> , <i>E. granosum</i> , <i>E. incertum</i> , <i>E. jensen</i> , <i>E. macellum</i> , <i>E. maioricensis</i> , <i>E. pulvereum</i> , <i>E. translucens</i>

Tab. 1 - List of the benthic foraminifera used for statistical analyses.

the SPSS (10.1) statistical software. Only species or genera (some species have been grouped) more abundant than 10% in at least one sample were considered to create a matrix of data for the statistical analyses. Infrequent occurring taxa (<10% relative abundance) were omitted as they have insignificant effect on the formation of the major groups (Kovach, 1987, 1989). Consequently, 7 species and 9 groups were used for the statistical treatment; the list of species groups utilised for analysis is reported in Tab. 1. Distance of HCA is given in percentage by Pearson correlation, whereas the similarities of the new fused clusters were calculated by adopting the Average Linkage method (within group) (Pielou, 1984; Parker & Arnold, 1999). The HCA classified the samples into associations (clusters), where each cluster includes a group of species with a similar spatial distribution pattern (Samir et al., 2003).

To delineate in detail the assemblage structure, the following parameters were calculated: the Fisher α -Index (Fisher et al., 1943; Murray, 1973) that is a relationship between the number of species and the number of specimens in each assemblage; the Percentage of Dominance (Walton, 1964) that is the highest percentage abundance of foraminiferal species in a sample; and the P/(P+B) ratio.

RESULTS

Bioclastic fraction

In absence of significant sources of terrestrial sediments, the biogenic fraction (bryozoans, echinoderms, foraminifera, molluscs, ostracods, spicules of sponges and coralline algae) is generally prevalent. Tab. 2 shows the main bioclastic components

in each sample. Benthic foraminifera dominate the bioclastic component in all samples, except sample B311 (135 m), in which spicules of sponges prevail, and sample 274 (380 m), in which planktonic foraminifera dominate. In the shallowest samples (20-50 m water depth), benthic foraminifera are very abundant, and many leaves and fibres of *Posidonia oceanica* (Rose Bengal stained) are present. Other components of the bioclastic fraction are very rare. Between 80 and 90 m water depth, calcareous red algae (rhodoliths) are locally widespread. Between 100 and 200 m, except for benthic and planktonic foraminifera, spicules of sponges and bryozoans are the main components. Finally, between 200 and 380 m, planktonic foraminifera, pteropods and spicules of sponges are locally abundant.

In Tab. 2 the distribution of well-preserved, broken and old benthic foraminifera and of identified planktonic foraminifera on the 22 samples is also shown. Well-preserved benthic foraminifera tests dominate all samples, except for the deepest one (B274, 380 m water depth), where planktonic foraminifera dominate. Well-preserved benthic tests show the higher values (mean 81.8%) in the shallower samples (between 20 and 90 m water depth), whereas they decrease as far as 200 m (60.8%) and between 250 and 380 m (52.3%). Broken benthic tests show the same trend, decreasing with water depth: 14.3% from 20 to 90 m, 9.9% as far as 200 m and 6.4% below 250 m. Old tests (or glauconitic tests) are very few in the shallowest samples (0-8%), increasing between 100 and 200 m (mean 12.2%), and decreasing below 250 m (4.8%). The highest percentages of glauconitic tests (8-24%) is recorded between 150-200 m water depth. The percentage of planktonic foraminifera is very low at water depth shallower than 90 m (0-4.6%), and increases offshore with percentages of 26.9-48.3% between 160 and 380 m.

Samples	Locality	Depth (m)	Longitude	Latitude	Number of benthic forams tests				Planktonic forams	Species Number	Fisher Index	% Dominance	P/(P+B)%	Principal bioclastic components
					Well-preserved	R.B. stained	Broken	Old						
B188	East Ponza	20			302	32	54			49	16.6	20.9	0	Benthic forams (and <i>P. oceanica</i>)
B145	East Ponza	54			318	11	72		13	50	16.7	11.6	3.9	Benthic forams (<i>P. oceanica</i>)
B129BIS	East Ponza	79			308		30	30	8	18	4.2	27.6	2.5	Benthic forams, spines of spongia, spines of echinoids
B146	East Ponza	80			300		72		18	51	17.6	14.3	5.7	Benthic forams, rhodoliths
B192	South Ponza	87			300		42		5	57	20.9	12.3	1.6	Benthic forams, rhodoliths, bryozoans
B147	East Ponza	103			316		60	46	45	45	14.4	20.9	12.5	Benthic forams, planktonic forams
B117	South Zannone	119			312		42	120	15	53	18.3	19.9	15	Benthic forams
B131B	East Ponza	120			305	1	18	30	41	50	17.0	21.6	11.8	Benthic forams, spines of spongia, planktonic forams
B148	East Ponza	121			308		36	55	91	51	17.4	27.9	22.8	Benthic forams, planktonic forams
B311	Botte Rock	135			314		87	126	59	44	13.9	13.4	15.8	Spines of spongia, benthic forams, bryozoans, planktonic forams
B312	Botte Rock	145			305		42	70	188	60	22.4	10.5	38.1	Benthic forams, spines of spongia, planktonic forams
B265	South Ponza	150			303	1	72	42	45	55	19.7	13.2	12.9	Benthic forams, bryozoans, planktonic forams
B118	South Zannone	155			300		48	54	79	59	22.0	7.7	20.8	Benthic forams, spines of spongia, planktonic forams, bryozoans
B149	East Ponza	164			309		42	15	173	67	26.3	10.3	35.9	Benthic forams, planktonic forams
B150	East Ponza	202			312		72	114	162	64	24.4	7.7	34.2	Benthic forams, planktonic forams, pteropods
B120	South Zannone	250			300		27	1	155	47	15.6	11.3	34.1	Benthic forams, planktonic forams, pteropods, spines of spongia
B135	East Ponza	300			314		60	42	153	25	6.4	29.6	32.8	Benthic forams, planktonic forams, spines of spongia, pteropods
B152	East Ponza	300			300	2	16	13	162	56	20.3	11.3	35.1	Benthic forams, planktonic forams, pteropods
B321	Botte Rock	300			324		48	90	218	42	12.9	11.1	40.2	Benthic forams, planktonic forams, pteropods
B158	South Zannone	380			304		48		303	57	20.7	10.8	49.9	Benthic forams, planktonic forams, pteropods, spines of spongia
B271	East Ponza	380			300		60	54	239	22	5.5	41.3	44.3	Benthic forams, planktonic forams, pteropods, bivalves, spines of spongia
B274	East Ponza	380			307		13	13	311	54	19.0	14.3	50.3	Planktonic forams, benthic forams

Tab. 2 - Depth, location, number of tests (well-preserved, Rose Bengal stained, broken, old, planktonic), number of species, Fisher Index, Percentage of Dominance, P/(P+B) ratio, and principal bioclastic components of the samples.

Benthic foraminifera populations

199 benthic foraminifera species, belonging to 91 genera and 50 families, have been classified. Among them, 34 species showed a relative abundance higher than 5% in at least one sample.

Considering the total number of species in all samples, only *Cassidulina carinata*, *Elphidium crispum*, *Rosalina bradyi* and *Uvigerina mediterranea* can be considered dominant species (>20%). *Adelosina mediterraneensis*, *Asterigerinata mamilla*, *Bolivina difformis*, *Bulimina marginata*, *Cassidulina crassa*, *Connemarella rudis*, *Hyalinea balthica*, *Lobatula lobatula*, *Melonis pompilioides*, *Spirillina vivipara*, and *Textularia pseudorugosa* are considered common species (10-20%). The following species are classified as accessory species (5-10%): *Adelosina intricata*, *Ammolagena clavata*, *Amphicoryna scalaris*, *Bulimina costata*, *Cibicides refulgens*, *Clavulina crustata*, *Gavelinopsis praegeri*, *Globocassidulina subglobosa*, *Lenticulina calcar*, *L. rotulata*, *Melonis barleanum*, *Neoconorbina* cf. *terquemi*, *Nubecularia lucifuga*, *Planulina ariminensis*, *Reussella spinulosa*, *Spiroplectinella wrighti*, *Textularia bocki*, *Tretomphalus concinnus*, and *Uvigerina auberiana*. All other species occur in relative abundance lower than 5%, so they are considered to be rare or accidental species.

Among dominant, common and accessory species, only *Amphicoryna scalaris*, *Asterigerinata mamilla*, *Bulimina marginata*, *Cassidulina carinata*, *C. crassa*, *Gavelinopsis praegeri*, *Globocassidulina subglobosa*, *Lobatula lobatula*, *Melonis barleanum*, *M. pompilioides*, *Rosalina bradyi*, *Reussella spinulosa*, *Spirillina vivipara*, *Spiroplectinella wrighti*, *Textularia bocki*, *Tretomphalus concinnus*, and *Uvigerina*

mediterranea are represented in more than 50% of the samples.

The distribution of dominant species around the Ponza Island shows the following patterns:

the occurrence of *Cassidulina carinata* is directly related to water depth, with increasing trend until 121 m water depth (27.9%). In deeper sampling stations its abundance decreases;

Elphidium crispum is abundant only in one sample (79 m water depth), whereas it is rare in all other samples; it is absent below 164 m;

Rosalina bradyi occurs in higher percentages in water depth shallower than 90 m. Maximum values for this species (11-20.9%) occur between 20 and 87 m water depth. Below 100 m its relative abundance drops below 5%;

Uvigerina mediterranea is absent in all the samples shallower than 120 m water depth. It shows a distribution with values lower than 5% between 120 and 200 m, and it displays the highest percentages below 250 m, with the maximum of 41.3% at 380 m.

The α -Fisher index values ranges between 4.2 and 26.3, with the highest values between 145 and 202 m (Fig. 3a; Tab. 2). Percentage of dominance shows the reverse pattern compared to α -Fisher index, ranging between 7.7 and 41.3%. On the average, values comprised between 11.6 e 27.9% are found between 20 and 121 m, whereas lowest values are found between 145 and 250 m (Fig. 3b; Tab. 2).

Living individuals (Rose Bengal stained) of benthic foraminifera are very few; they are present in relevant percentage only in the samples B188 (20 m) and B145 (54 m): 10.6 and 3.5%, respectively. In these samples, living foraminifera show a strong correspondence with the dead assemblage, belonging to the most abundant

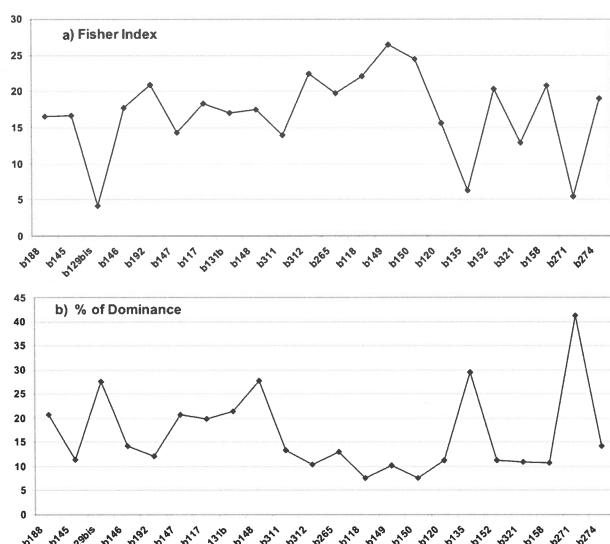


Fig. 3 - a) Variation of the Fisher Index values; b) Variation of the Percentage of Dominance. Samples ordering follows the water-depth.

species in total assemblages: *Spirillina vivipara* and *Rosalina bradyi*.

Statistical analysis

The R-mode cluster analysis (Fig. 4), applied to stations containing the 16 taxa with relative abundances higher than 10% (Tab. 1), groups taxa into two main clusters (A and B). Cluster (or assemblage) A can be

subdivided into two subclusters: A1 and A2. Cluster A1 comprises the taxa *Connemmarella rudis*, *Adelosina* spp., *Elphidium* spp., *Textularia* spp., *Melonis* spp. and *Cassidulina* spp.; cluster A2 with *Lenticulina* spp., *Uvigerina mediterranea*, *Hyalinea balthica* and *Bulimina* spp.; cluster B with *Spirillina vivipara*, *Rosalina bradyi*, *Quinqueloculina* spp., *Lobatula lobatula*, *Asterigerinata mamilla* and *Neoconorbina* spp.

The R-mode PCA output is plotted in Fig. 5. The first and the second component of PCA account for 30.8 and 25.2% of the variance, respectively. The groups of taxa singled out by the PCA may be referred to the assemblages of the R-mode cluster analysis (Fig. 4). Cluster A1 is not clearly related to the two components. However, it is characterised exclusively by positive values of component 2. Cluster A2 is loaded negatively by both the components. Taxa of cluster B plot positively on the first component and negatively on the second one.

The resulting dendrogram of Q-mode cluster analysis (Fig. 6) represents the grouping of samples according to the relative abundance of benthic foraminiferal species. The dendrogram singles out three main clusters: 1, 2 and 3. Cluster 1 groups 11 samples collected between 79 and 202 m water depth; cluster 2 (7 samples) can be found between 250 and 380 m water depth, whereas cluster 3 (4 samples) dominates at water depths generally between 20 and 87 m.

These clusters correspond to three distinct foraminiferal assemblages that may be viewed as foraminiferal biofacies and are interpreted as reflecting primarily different ecological conditions (Scott et al.,

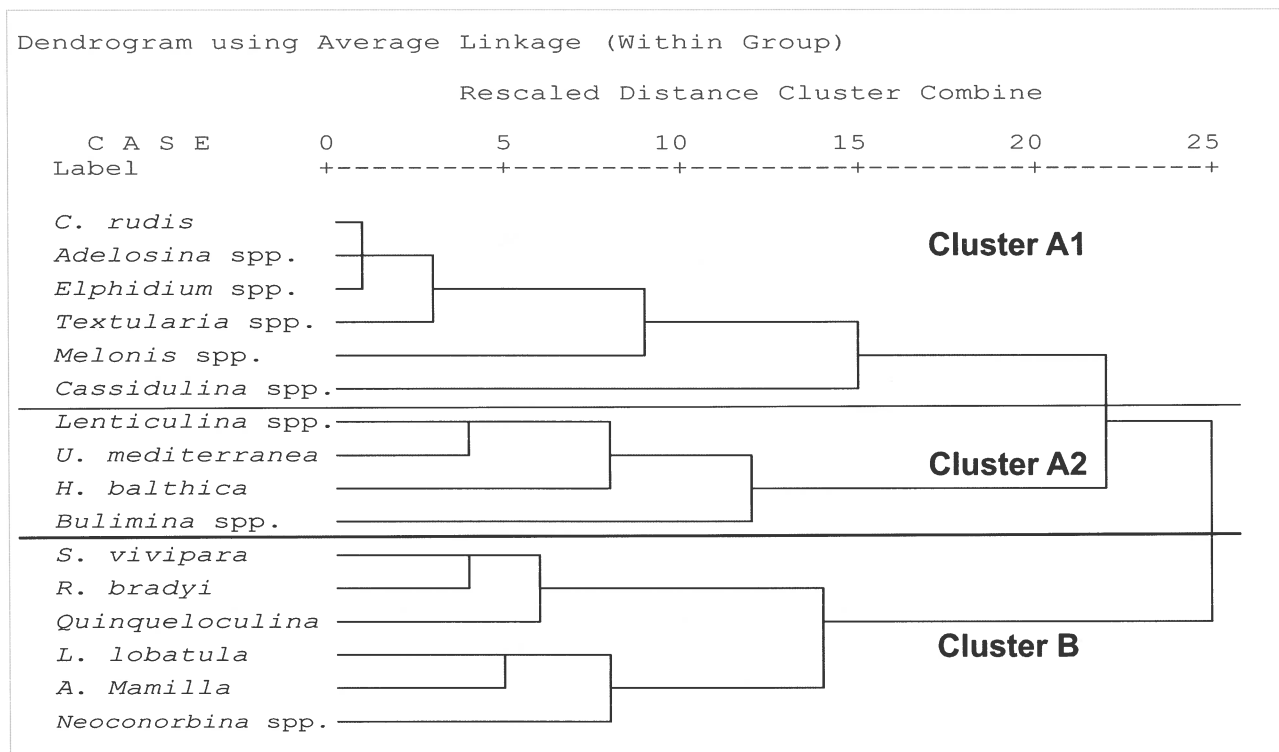


Fig. 4 - Dendrogram of R-mode cluster analysis of the taxa, based on the total abundance higher than 10%. Three main assemblages are evidenced.

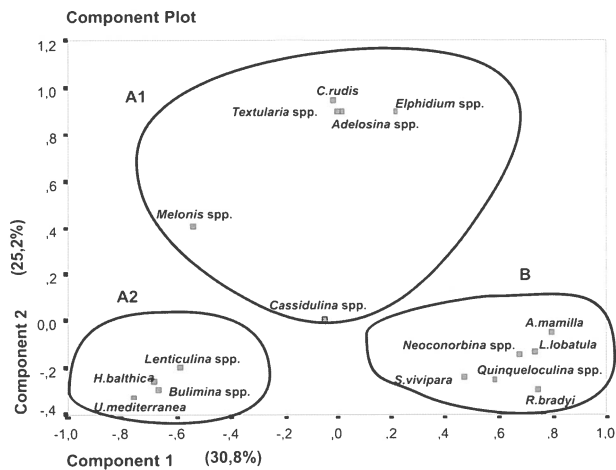


Fig. 5 - Bivariate plot of the taxa on the first and second principal components. The three clusters of R-mode cluster analysis are circled.

2001). A comparison of the distribution of these assemblages seems to be associated to bathymetry and probably to shelf morphology.

Planktonic foraminifera

Members of families Globorotaliidae, Candeinidae, Globigerinidae and Hastigerinidae represent planktonic species. A total of 23 species belonging to 9 genera are recognised. The most common species are *Globigerina bulloides*, *G. falconensis*, *Globigerinoides ruber*, *Globorotalia inflata* and *G. truncatulinoides*. These species prefer transitional conditions between warm and cold water, but in the Mediterranean Sea they proliferate, especially in winter, in the western sector of the basin. Only *Globigerinoides ruber* prefers warm waters; it is the best indicator of warm water in the Mediterranean basin (Bé & Tolderlund, 1971; Thunell, 1978; Pujol & Vergnaud Grazzini, 1995). P/(P+B) ratio shows the direct linkage to water depth: it is very low in shallower samples (20-87 m), comprised between 10 and 38% in the middle depth, whereas the highest values (33-50%) occur between 164 and 380 m water depth (Fig. 7; Tab. 2).

DISCUSSION

The Q-mode cluster analysis (Fig. 6) indicates a zonation of the Pontine shelf and slope into three segments.

Cluster 1 is found between approximately 80 and 200 m water depth. Benthic and planktonic foraminifera, spicules of sponges and branches of bryozoans constitute bioclastic skeletal fraction. Benthic foraminiferal assemblages are characterised by *Cassidulina carinata*, *Bolivina difformis*, and *Textularia bocki*. *Textularia pseudorugosa*, *Connemarella rudis*, *Adelosina mediterraneensis*, *Elphidium crispum*, *Lobatula lobatula* and *Asterigerinata mamilla* are other important taxa. These species were observed in other

Mediterranean areas: *Cassidulina carinata* is typical of circalittoral and bathyal muds with optimum from 70 to 700 m (Parker, 1958; Moncharmont Zei et al., 1981; Bizon & Bizon, 1984; Sgarrella & Moncharmont Zei, 1993; Carboni et al., 2004); *Bolivina difformis* is recorded deeper than 62 m (Parker, 1958; Blanc-Vernet, 1969; Parisi, 1981; Sgarrella & Moncharmont Zei, 1993); *Textularia bocki* is reported from the infralittoral and circalittoral zones (Cimerman & Langer, 1991; Yanko et al., 1994); *Textularia pseudorugosa* is mostly recorded in the coarse sediments from the infralittoral and circalittoral zones (Blanc-Vernet, 1969; Moncharmont Zei et al., 1981; Sgarrella & Moncharmont Zei, 1993; Moufî-El-Houari et al., 1999); *Connemarella rudis* is reported from the circalittoral detrital sediments (Blanc-Vernet, 1969; Blanc-Vernet et al., 1979; Moncharmont Zei et al., 1981; Sgarrella & Moncharmont Zei, 1993); *Adelosina mediterraneensis* is recorded between 10 and 100 m water depth (Blanc-Vernet, 1969; Sgarrella & Barra, 1985; Sgarrella et al., 1985; Sgarrella & Moncharmont Zei, 1993; Basso & Spezzaferri, 2000); *Elphidium crispum* occurs from infralittoral sand (D'Onofrio, 1969; Bellotti et al., 1994) and from circalittoral detritic sand (Jorissen, 1988; Sgarrella & Moncharmont Zei, 1993; Moufî-El-Houari et al., 1999); *Lobatula lobatula* is abundant from infralittoral zone, especially on *Posidonia* prairies (Blanc-Vernet, 1969; Blanc-Vernet et al., 1979; Sgarrella & Barra, 1985; Jorissen, 1988; Langer, 1988; Vénec-Peyré & Le Calvez, 1988; Coppa et al., 1994), but it is present also from circalittoral detritic bottoms (Sgarrella & Moncharmont Zei, 1993); *Asterigerinata mamilla* is very abundant from the infralittoral zone, especially on vegetated bottoms (Jorissen, 1987; Langer, 1988; 1993; Coppa et al., 1994) but also from circalittoral detritic bottoms (D'Onofrio, 1969; Jorissen, 1988; Sgarrella

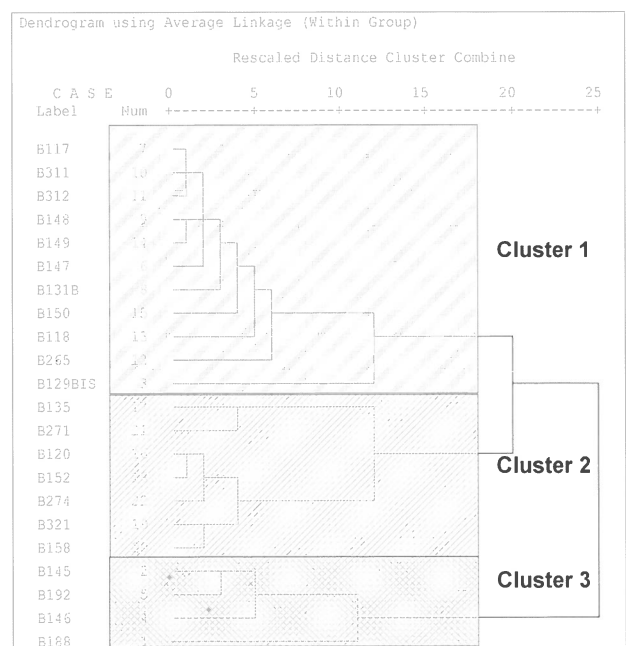


Fig. 6 - Dendrogram of Q-mode cluster analysis of the samples, based on the total abundance higher than 10%.

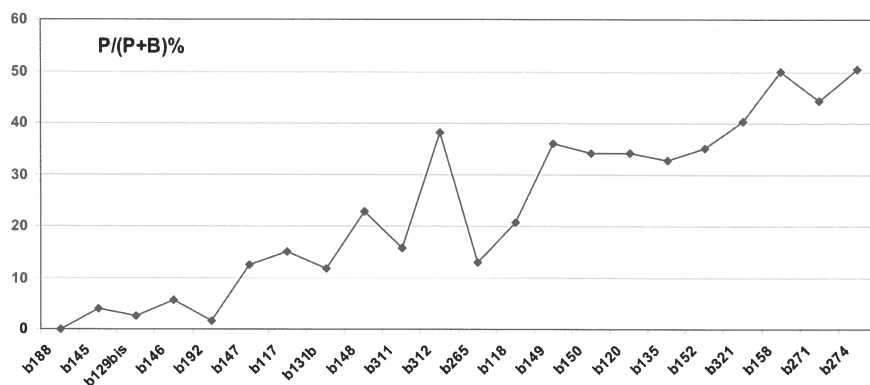


Fig. 7 - Variation of the P/(P+B) ratio values. Samples ordering follows the water-depth.

& Moncharmont Zei, 1993; Moufî-EI-Houari et al., 1999).

The α -Fisher index values of samples included in Cluster 1 range between 4.2 and 26.3, with a mean value of 18.2. The Dominance varies between 7.7 and 27.9% (mean 16.4%). The P/(P+B) ratio is on the average of 20%, ranging between 2.5 and 38.1%. Cluster 1 corresponds to circalittoral environment and can be compared with the *Cassidulina laevigata* assemblage described by Murray (1991) in the Mediterranean basin.

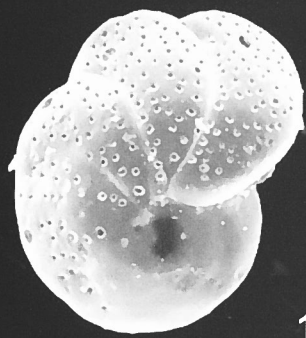
High percentage of old (glauconitic) benthic foraminifera tests are found in samples of cluster 1, at around 100-200 m water depth. Mainly, these tests belong to genera *Elphidium*, *Lobatula* and *Asterigerinata*, normally living at shallow water depths. They are probably related to events of displacement or to sea level lowstand during glacial peaks or during sea level rise. Chiocci & Orlando (1996) found through the Pontine Archipelago a lowstand terrace now located at a depth of 100-150 m. It could be linked to episodes of maximum energy (storms along the coast) during the last glacial period (Chiocci & Orlando, 1996). The fact that old tests are still exposed on the sea ground evidences very low sedimentation rates in the continental shelf (Mendes et al., 2004). This is confirmed by the occurrence of glauconite in these foraminiferal tests, a mineral deposit normally associated with periods of low sedimentation rates for sufficiently long times (Odin & Matter, 1981). According to Corselli et al. (1994), old shallow benthic assemblages may to be related to the marine lowstand, during the Last Glacial Maximum

(LGM). Moreover, the glauconitization may have produced after the LGM, during short still stands that interrupted the Early Holocene rapid sea-level rise (Corselli et al., 1994). On the other hand, in the Mediterranean Sea glauconitization occurred at different times during the older episodes of the Würm, too (Robert & Odin, 1975).

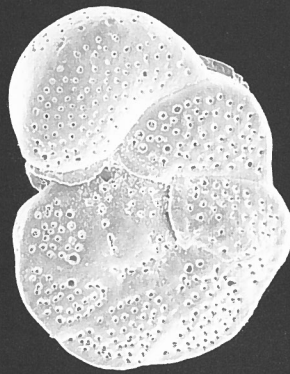
Cluster 2 is found between 250 and 380 m water depth. The bioclastic components of sediment is characterised by benthic and planktonic foraminifera, pteropods and spicules of sponges. This deep water assemblage is constituted by *Uvigerina mediterranea*, *Bulimina marginata*, and *Cassidulina crassa*. *Hyalinea balthica* and *Melonis pompilioides* are also present, with relevant percentages. *Uvigerina mediterranea* is very widespread, recorded from the circalittoral zone (50-70 m) downward, and very abundant in bathyal muds (Parker, 1958; Blanc-Vernet, 1969; Bizon & Bizon, 1984; Sgarrella & Barra, 1985; Sgarrella & Moncharmont Zei, 1993; Coppa et al., 1994; Carboni et al., 2004). *Bulimina marginata* is reported from the infralittoral zone (D'Onofrio, 1969; Bellotti et al., 1994), but it is frequent or abundant from circalittoral and bathyal muds (Blanc-Vernet, 1969; Moncharmont Zei et al., 1981; Jorissen, 1988; Sgarrella & Moncharmont Zei, 1993; Carboni et al., 2004). *Cassidulina crassa* is abundant from circalittoral and bathyal muds with the optimum between 120 and 650 m water depth (Parker, 1958; Sgarrella & Moncharmont Zei, 1993). *Hyalinea balthica* is typical of circalittoral and, especially, epibathyal muds, frequent between 90 and 500 m water depth (Parker, 1958; Blanc-Vernet, 1969; Blanc-Vernet et al.,

EXPLANATION OF PLATE 1

- Figs. 1-2 - *Lobatula lobatula* (x 100). 1) Ventral side. 2) Spiral side.
 Fig. 3 - *Rosalina bradyi* (x 100). Spiral side.
 Fig. 4 - *Asterigerinata mamilla* (x 100). Spiral side.
 Figs. 5-6 - *Neoconorbina terquemi* (x 100). 5) Spiral side. 6) Umbilical side.
 Fig. 7 - *Sigmoilinita costata* (x 150). Lateral view.
 Fig. 8 - *Spirillina vivipara* (x 200). Lateral view.
 Fig. 9 - *Elphidium complanatum* (x 150). Lateral view.
 Figs. 10-11 - *Planorbulina mediterraneensis* (x 100). 10) Free side (specimen attached on *Posidonia oceanica*). 11) Attached side.



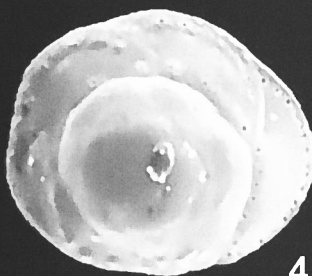
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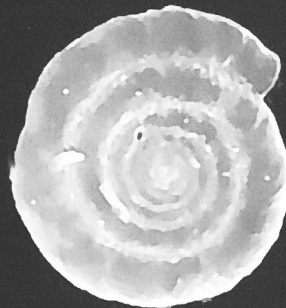
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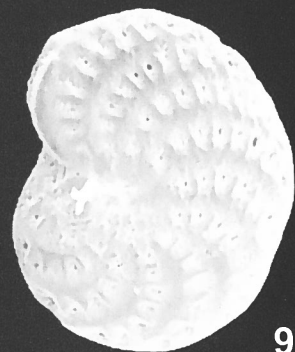
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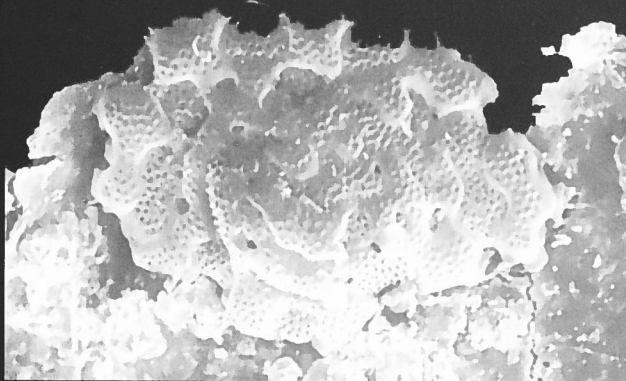
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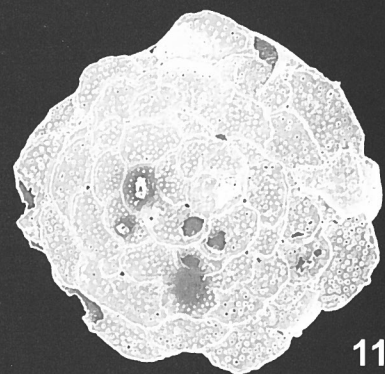
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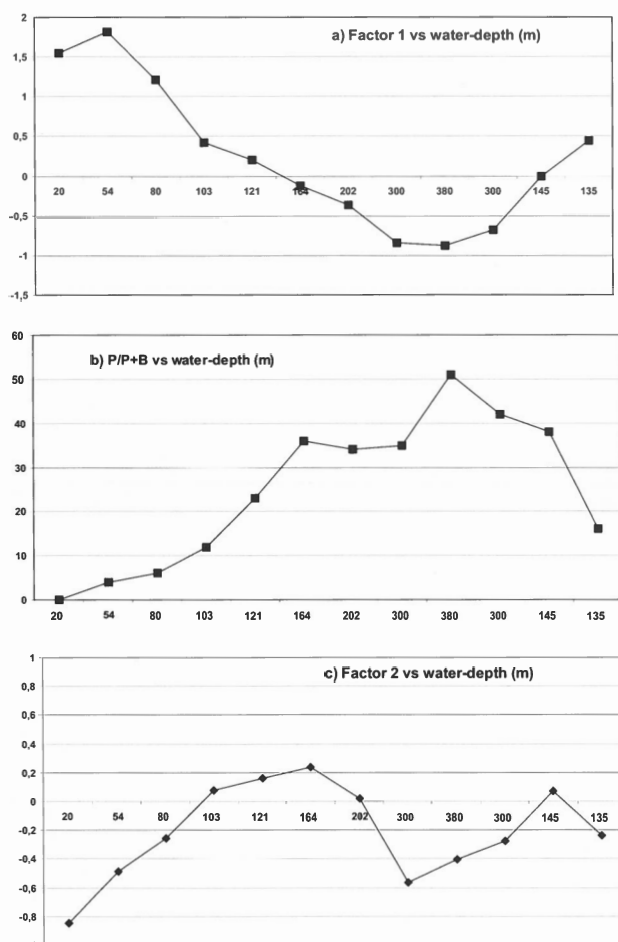


Fig. 8 – a) Factor 1 of Principal Component Analysis; b) P/(P+B) ratio; c) factor 2 of PCA related to depth, along the transect II.

1979; Bizon & Bizon, 1984; Sgarrella & Barra, 1985; Sgarrella & Moncharmont Zei, 1993; Coppa et al., 1994). *Melonis pompilioides* has its maximum abundance in circalittoral assemblages (Bergamin et al., 1997; Carboni et al., 2004).

The α -Fisher index of samples included in cluster 2 shows values comprised between 5.5 and 20.7; the mean value is 14.3. Percentage of dominance shows very high values: the mean is 18.5%, but values higher than 40% are present. The P/(P+B) ratio shows the highest values; these are comprised between 32.8 and

50.3% (mean 41%). This assemblage corresponds to upper epibathyal environment and shows a strong similarity with the *Uvigerina mediterranea* assemblage of Murray (1991).

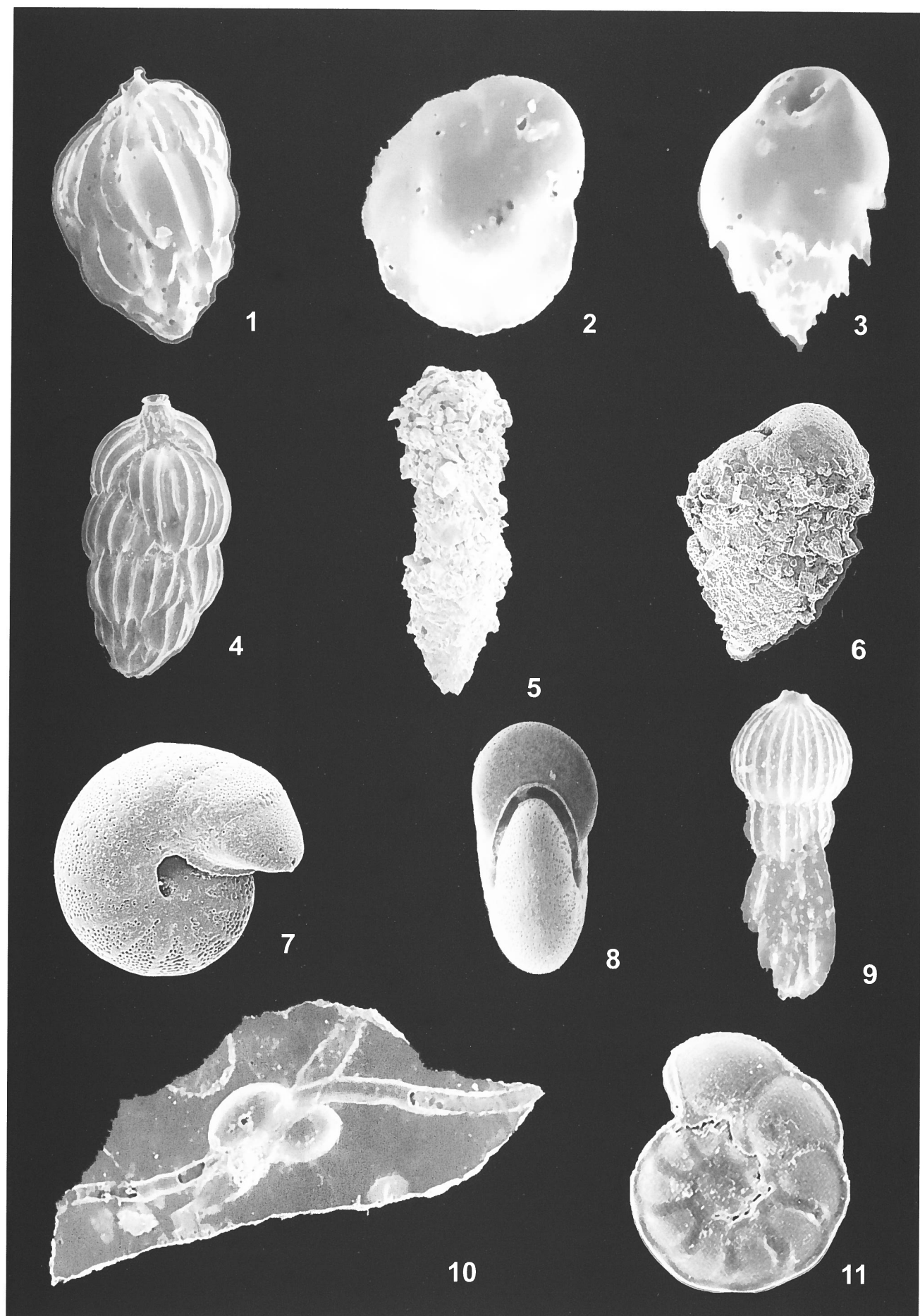
The shallowest foraminiferal assemblage (20-87 m water depth), corresponding to cluster 3, is composed of typical infralittoral species. This assemblage is characterised by *Rosalina bradyi*, *Asterigerinata mamilla*, *Lobatula lobatula*, *Spirillina vivipara*, *Tretomphalus concinnus*, and miliolids (mainly *Miliolinella subrotunda* and *Quinqueloculina stelligera*). These species are reported from infralittoral bottoms with vegetation cover, mostly *Posidonia*, and from detritic circalittoral bottoms (Parker, 1958; Blanc-Vernet, 1969; Moncharmont Zei et al., 1981; Sgarrella & Barra, 1985; Jorissen, 1987, 1988; Langer, 1988; Vénec-Peyré & Le Calvez, 1988; Langer, 1993; Sgarrella & Moncharmont Zei, 1993; Coppa et al., 1994; Moufif-El-Houari et al., 1999; Carboni et al., 2004).

In this assemblage the α -Fisher index is comprised between 16.6 and 20.8 (mean 17.9). The percentage of dominance shows a mean value of 15% (11.6-20.9%). The P/(P+B) ratio shows its lower values: 0-6%.

The highest values (up to 10.7%) of living foraminifera are present in this assemblage, between 20 and 54 m water depth, where leaves and fibres of living *Posidonia oceanica* are very abundant. The living assemblage presents a strong correspondence with the dead assemblage: mainly *Spirillina vivipara* and *Rosalina bradyi*. The assemblage points to an infralittoral environment. It is located near Ponza Island, mainly in the sea-grass bottom with *Posidonia oceanica*. This typical Mediterranean marine plant (Giraud, 1977) is normally restricted to the photic zone. Phanerogam meadows are today found in Pontine archipelago at depths between 15 and 35 m (Chiocci & Orlando, 1996), but their limit can be deeper than 50 m when the water is very transparent. In the samples B146 and B192 (80-90 m water depth) *Posidonia oceanica* meadows are absent, but this taxon may be related also to detritic bottoms, because the individuals may live attached on grains, too. In the deeper samples calcareous red algae (rhodoliths) are also present. Higher percentages (12-18%) of broken benthic foraminifera tests have been found between 20 and 90 m water depth; this could be related to occasional transport of shells caused by waves and tidal currents. Moreover, at these depths, old (glauconitic) tests are absent; on the other hand, in shallow environments,

EXPLANATION OF PLATE 2

- Figs. 1, 4 - *Uvigerina mediterranea* (x 100). Lateral view.
 Fig. 2 - *Cassidulina carinata* (x 100). Lateral view.
 Fig. 3 - *Bulimina marginata* (x 150). Lateral view.
 Fig. 5 - *Bigenenerina nodosaria* (x 150). Lateral view.
 Fig. 6 - *Textularia bocki* (x 100). Lateral view.
 Figs. 7-8 - *Melonis pompilioides* (x 100). 7) Lateral view. 8) Edge view.
 Fig. 9 - *Amphicoryna scalaris* (x 150). Lateral view.
 Fig. 10 - *Ammolagena clavata* (x 100). Lateral view (attached on bivalve shell).
 Fig. 11 - *Hyalinea balthica* (x 100). Lateral view.



the turbulent well-oxygenated waters are unfavourable to glauconitization (Odin & Matter, 1981).

Results from Q-mode cluster analysis (Fig. 6) are well supported by R-mode cluster analysis (Fig. 4), which distinguishes three different assemblages at identical location. Assemblage A1 of R-mode corresponds to cluster 1 of Q-mode, with the circalittoral taxa (*Connemmarella rudis*, *Adelosina* spp., *Elphidium* spp., *Textularia* spp., *Melonis* spp., and *Cassidulina* spp.); assemblage A2, which includes *Lenticulina* spp., *Uvigerina mediterranea*, *Hyalinea balthica* and *Bulimina* spp., is well correlated with cluster 2. Finally, assemblage B including epiphytic taxa (*Spirillina vivipara*, *Rosalina bradyi*, *Quinqueloculina* spp., *Lobatula lobatula*, *Asterigerinata mamilla* and *Neoconorbina* spp.) coincides completely with cluster 3.

In the PCA-diagram (Fig. 5), the first factor is loaded positively by the epiphytic taxa of assemblage B, whereas it is negatively loaded by *Lenticulina* spp., *Uvigerina mediterranea*, *Hyalinea balthica*, and *Bulimina* spp. (assemblage A2). These species are indicative of deep-water environments (circalittoral-bathyal zones), and often they have been reported as species tolerant to oxygen-depleted environments (Murray, 1991; Gooday, 1994; Kahio, 1994; Bernhard & Sen Gupta, 1999; Kahio, 1999; Van der Zwaan et al., 1999; Mendes et al., 2004). For this reason, the first factor appears negative for low oxygenated conditions and positive for well-oxygenated bottom. It seems to be indicative of changes in bottom water oxygenation, but it is also inversely related to water depth, with shallower taxa of group B (positive side) and deeper taxa of group A2 (negative taxa).

Plotting factor 1 scores (Fig. 8a) along transect II (the largest transect), it shows that positive values prevail in the infralittoral and circalittoral samples (20-145 m water depth), whereas negative values are present in the epibathyal ones (164-300 m water depth). Factor 1 shows a decreasing trend according to increasing water-depth and, consequently, factor 1 shows a negative correlation with P/(P+B) ratio (Fig. 8b). Negative values of factor 1 correspond to high percentages of P/(P+B) ratio whereas, on the contrary, positive values correspond to low percentages. Factor 1 might indicate the interplay between water depth and oxygenation.

The second factor has no clear significance since it is loaded negatively with taxa of assemblages A2 (circalittoral-epibathyal taxa) and B (epiphytic-infralittoral taxa), which are indicators of extremely different environmental conditions. It is also related positively with taxa of assemblage A1 (circalittoral taxa).

Plotting factor 2 scores along transect II an irregular trend is evidenced (Fig. 8c). It shows negative values between 20 and 100 m water depth, and becomes positive between 100 and 200 m water depth. Negative values are present between 200 and 380 m water depth also, then factor 2 increases at 145 m water depth and becomes negative again at 135 m (samples near the Botte Rock).

CONCLUSIONS

The continental shelf and slope of Ponza show a very diversified benthic foraminiferal fauna, with 199 species recognised and high values of α -Fisher index. Thirty-four species show a relative abundance greater than 5% in at least one sample. Living specimens of benthic foraminifera are very few; high values of living foraminifera are present only in samples collected from vegetated bottom (*Posidonia oceanica* meadows).

A hierarchical classification of foraminiferal assemblages using R- and Q-mode analyses allowed recognising three foraminiferal assemblages, corresponding to three very different biofacies (Fig. 9).

Rosalina bradyi and *Asterigerinata mamilla* assemblage

This assemblage is found in shallower samples, between 20 and 87 m water depth (continental shelf) and is characterised by epiphytic species, living in *Posidonia oceanica* meadows, in well-oxygenated waters. *Lobatula lobatula*, *Spirillina vivipara*, *Tretomphalus concinnus* and miliolids are the other common taxa. It presents relatively high values of α -Fisher index, low percentage of Dominance and very low P/(P+B) ratio. This biofacies corresponds to the infralittoral-upper circalittoral zones, is located near Ponza island, and is dominated by benthic foraminiferal tests with, sometimes, rhodoliths. The high values of broken benthic foraminifera tests may be related to the wave action.

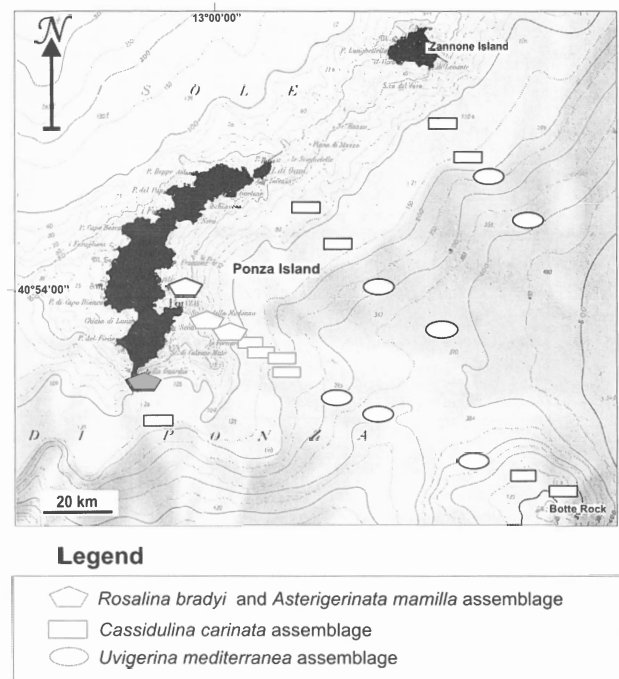


Fig. 9 - Distribution of the three assemblages, recognised by Q-mode cluster analysis, East to Ponza Island.

Cassidulina carinata assemblage

Bolivina difformis and *Textularia bocki* are also distinctive for this assemblage, corresponding to circalittoral environment. It occurs between 79 and 202 m water depth and is distributed in outer continental shelf and upper slope. The α -Fisher index presents high values; this assemblage also shows mainly significant P/(P+B) ratio. Among planktonic species, *Globigerina bulloides*, *Globigerinoides ruber*, *Globorotalia inflata* and *G. truncatulinoides* are the more common species. This biofacies corresponds to the circalittoral zone and is located parallel to coastline. High percentages of old glauconitic tests of shallow water taxa (*Elphidium*, *Lobatula* and *Asterigerinata*) were found at these depths. They are probably related to sea level stillstand conditions during the Late Pleistocene and at beginning of the Holocene, and document low sedimentations rates in this area.

Uvigerina mediterranea assemblage

This assemblage is characterised by other common species like *Bulimina marginata*, *Cassidulina crassa*, *Hyalinea balthica*, and *Melonis pompilioides*. The presence of some taxa (*Lenticulina* spp., *Uvigerina mediterranea*, *Hyalinea balthica*, and *Bulimina* spp.) probably tolerant to oxygen deficiency indicates that this environment may be characterised by periodical oxygen-content lowering. The assemblage is found between 250 and 380 m water depth (continental slope) and shows the lowest values of α -Fisher index, but very high percentages of dominance. The P/(P+B) ratio ranges between 32.8 and 50.3%, with the highest value at 380 m water depth. The planktonic assemblage is very similar to the circalittoral one, with a relatively decrease of *Globigerina bulloides* and an increase of *G. falconensis*. This biofacies corresponds to the upper epibathyal zone, and is characterised by bioclastic sediment with abundant benthic and planktonic foraminifera, pteropods and spicules of sponges.

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SYSTEMATIC APPENDIX

List of the benthic species recognised.

Adelosina cliarensis (Heron-Allen & Earland, 1930)

- 1930 *Quinqueloculina cliarensis* HERON-ALLEN & EARLAND, p. 58, Pl. 3, figs. 26-31.
- 1991 *Adelosina cliarensis* (Heron-Allen & Earland) - CIMERMAN & LANGER, p. 26, Pl. 18, figs. 1-4.

Adelosina duthiersi Schlumberger, 1886

- 1886 *Adelosina duthiersi* SCHLUMBERGER, p. 100, pl. 16, figs. 16-18.
- 1993 *Adelosina duthiersi* Schlumberger - SGARRELLA & MONCHARMONT ZEI, p. 178, Pl. 7, fig. 12 (*cum syn.*).

Adelosina intricata (Terquem, 1878)

- 1878 *Quinqueloculina intricata* TERQUEM, p. 73, Pl. 8, figs. 16-21.
- 1923 *Adelosina intricata* (Terquem) - WIESNER, p. 84, Pl. 16, figs. 236-238.

Adelosina italica (Terquem, 1878)

- 1878 *Quinqueloculina italica* TERQUEM, p. 69, Pl. 7, figs. 17-20.
- 1993 *Adelosina italica* (Terquem) - SGARRELLA & MONCHARMONT ZEI, p. 178, Pl. 7, figs. 13-14.

Adelosina mediterraneensis (Le Calvez & Le Calvez, 1958)

- 1958 *Quinqueloculina mediterraneensis* LE CALVEZ & LE CALVEZ, p. 177, Pl. 4, figs. 29-31.
- 1991 *Adelosina mediterraneensis* (Le Calvez & Le Calvez) - CIMERMAN & LANGER, p. 28, Pl. 19, figs. 1-16.

Adelosina partschi (d'Orbigny, 1846)

- 1846 *Quinqueloculina partschi* D'ORBIGNY, p. 293, Pl. 19, figs. 4-6.
- 1991 *Adelosina partschi* (d'Orbigny) - CIMERMAN & LANGER, p. 28, Pl. 20, figs. 7-8.

Ammolagena clavata (Jones & Parker, 1860)
Pl. 2, fig. 10

- 1860 *Trochammina irregularis* var. *clavata* JONES & PARKER, p. 304.
- 1918 *Ammolagena clavata* (Jones & Parker) - CUSHMAN, p. 89-90, Pl. 34, figs. 2-5; Pl. 35, figs. 1-3.

Amphicoryna scalaris (Batsch, 1791)
Pl. 2, fig. 9

- 1791 *Nautilus (Ortoceras) scalaris* BATSCHE, p. 91, Pl. 2, figs. 4 a-b.
- 1991 *Amphicoryna scalaris* (Batsch) - CIMERMAN & LANGER, p. 52, Pl. 54, figs. 1-9.

Asterigerinata mamilla (Williamson, 1858)
Pl. 1, fig. 4

- 1858 *Rotalina mamilla* WILLIAMSON, p. 54, Pl. 4, figs. 109-111.
- 1970 *Asterigerinata mamilla* (Williamson) - VON DANIELS, p. 86, Pl. 6, fig. 11.

Bigenerina nodosaria d'Orbigny, 1826
Pl. 2, fig. 5

- 1826 *Bigenerina nodosaria* D'ORBIGNY, p. 261, Pl. 11, figs. 9-12.
- 1993 *Bigenerina nodosaria* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 164, Pl. 4, fig. 12 (*cum syn.*).

Bolivina difformis (Williamson, 1858)

- 1858 *Textularia variabilis* var. *difformis* WILLIAMSON, p. 77, Pl. 6, figs. 166-167.
- 1937 *Bolivina difformis* (Williamson) - CUSHMAN, p. 164-165, Pl. 15, figs. 13-17.

Bulimina costata d'Orbigny, 1852

- 1852 *Bulimina costata* D'ORBIGNY, p. 154.
- 1993 *Bulimina costata* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 211, Pl. 15, fig. 3 (*cum syn.*).

Bulimina elongata d'Orbigny, 1846

- 1846 *Bulimina elongata* D'ORBIGNY, p. 187, Pl. 11, figs. 19-20.
 1993 *Bulimina elongata* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 211, Pl. 15, figs. 10-11 (*cum syn.*).

Bulimina etnea Seguenza, 1862

- 1862 *Bulimina etnea* SEGUENZA, p. 108-125, Pl. 1, fig. 9.
 1999 *Bulimina etnea* Seguenza - DI BELLA, p. 26, Pl. 1, figs. 1-5.

Bulimina inflata Seguenza, 1862

- 1862 *Bulimina inflata* SEGUENZA, p. 109, pl. 1, fig. 10.
 1993 *Bulimina inflata* Seguenza - SGARRELLA & MONCHARMONT ZEI, Pl. 15, fig. 2 (*cum syn.*).

Bulimina marginata d'Orbigny, 1826
Pl. 2, fig. 3

- 1826 *Bulimina marginata* D'ORBIGNY, p. 269, Pl. 12, figs. 10-12.
 1993 *Bulimina marginata* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 212, Pl. 15, figs. 5-7 (*cum syn.*).

Cassidulina carinata Silvestri, 1896
Pl. 2, fig. 2

- 1896 *Cassidulina laevigata* var. *carinata* SILVESTRI, p. 104, Pl. 2, fig. 10 a-c.
 1993 *Cassidulina carinata* Silvestri - SGARRELLA & MONCHARMONT ZEI, p. 236, Pl. 23, figs. 8-9 (*cum syn.*).

Cassidulina crassa d'Orbigny, 1839

- 1839c *Cassidulina crassa* D'ORBIGNY, p. 56, Pl. 7, figs. 18-20.
 1993 *Cassidulina crassa* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 236, Pl. 23, figs. 10-11 (*cum syn.*).

Cibicides refulgens Montfort, 1808

- 1808 *Cibicides refulgens* MONTFORT, p. 123, fig. p. 122.
 1991 *Cibicides refulgens* Montfort - CIMERMAN & LANGER, p. 70, Pl. 75, figs. 5-9 (*cum syn.*).

Clavulina crustata (Cushman, 1936)

- 1936 *Pseudoclavulina crustata* CUSHMAN, p. 19, Pl. 3, fig. 12.
 1993 *Clavulina crustata* (Cushman) - SGARRELLA & MONCHARMONT ZEI, p. 167, Pl. 4, fig. 10.

Connemmarella rudis (Wright, 1900)

- 1900 *Gaudryina rudis* WRIGHT, p. 53, Pl. 2, figs. 1 a-b.
 1989 *Connemmarella rudis* (Wright) - LOEBLICH & TAPPAN, p. 774, Pl. 1, figs. 1-7.

Elphidium aculeatum (d'Orbigny, 1846)

- 1846 *Polystomella aculeata* D'ORBIGNY, p. 131, Pl. 6, figs. 27-28.
 1991 *Elphidium aculeatum* (d'Orbigny) - CIMERMAN & LANGER, p. 77, Pl. 89, figs. 1-4.

Elphidium advenum (Cushman, 1922)

- 1922 *Polystomella advena* CUSHMAN, p. 56, Pl. 9, figs. 11-12.
 1988 *Elphidium advenum* (Cushman) - JORISSEN, p. 22, Pl. 2, figs. 9-10.

Elphidium complanatum (d'Orbigny, 1839)
Pl. 1, fig. 9

- 1839b *Polystomella complanata* D'ORBIGNY, p. 129, Pl. 2, figs. 35-36.
 1939 *Elphidium complanatum* (d'Orbigny) - CUSHMAN, p. 56, Pl. 15, figs. 18-19.

Elphidium crispum (Linnaeus, 1758)

- 1758 *Nautilus crispus* LINNAEUS, p. 709, Pl. 1, figs. 2 d-f.
 1939 *Elphidium crispum* (Linnaeus) - CUSHMAN, p. 50-51, Pl. 13, figs. 17-21.

Elphidium decipiens (Costa, 1856)

- 1856 *Polystomella decipiens* COSTA, p. 220, Pl. 19, fig. 13.
 1987 *Elphidium poeyanum* forma *decipiens* (Costa) - JORISSEN, p. 47, Pl. 2, fig. 6.

Elphidium excavatum (Terquem, 1876)

- 1876 *Polystomella excavata* TERQUEM, p. 429, Pl. 2, fig. 2.
 1982 *Elphidium excavatum* (Terquem) - MILLER ET AL., p. 124, Pl. 1, figs. 9-12.

Elphidium granosum (d'Orbigny, 1846)

- 1846 *Nonionina granosa* D'ORBIGNY, p. 110, Pl. 5, figs. 19-20.
 1958 *Elphidium granosum* (d'Orbigny) - PARKER, p. 270, Pl. 4, figs. 10-11.

Elphidium incertum (Williamson, 1858)

- 1858 *Polystomella umbilicata* var. *incerta* WILLIAMSON, p. 44, Pl. 3, fig. 82 a.
 1993 *Elphidium incertum* (Williamson) - SGARRELLA & MONCHARMONT ZEI, p. 229, Pl. 21, fig. 5.

Elphidium jenseni Cushman, 1924

- 1924 *Elphidium jenseni* CUSHMAN, p. 49, Pl. 16, figs. 4-6.
 2001 *Elphidium jenseni* Cushman - FIORINI & VAIANI, p. 390, Pl. 7, figs. 14-15 (*cum syn.*).

Elphidium macellum (Fichtel & Moll, 1798)

- 1798 *Nautilus macellum* FICHTEL & MOLL, p. 66, Pl. 10, figs. h-k.
 1939 *Elphidium macellum* (Fichtel & Moll) - CUSHMAN, p. 51-52, Pl. 14, figs. 1-3; Pl. 15, figs. 9-10.

Elphidium maioricensis Colom, 1942

- 1942 *Elphidium maioricensis* COLOM, p. 34, Pl. 10, figs. 189-193.
 1991 *Elphidium maioricensis* Colom - CIMERMAN & LANGER, p. 79, Pl. 91, fig. 7 (*cum syn.*).

Elphidium pulvereum Todd, 1958

- 1958 *Elphidium pulvereum* TODD, p. 201, Pl. 1, figs. 19-20.
 1993 *Elphidium pulvereum* Todd - SGARRELLA & MONCHARMONT ZEI, p. 230, Pl. 21, fig. 6 (*cum syn.*).

Elphidium translucens Natland, 1938

- 1938 *Elphidium translucens* NATLAND, p. 144, Pl. 5, figs. 3-4.
 1991 *Elphidium translucens* Natland - CIMERMAN & LANGER, p. 79, Pl. 92, figs. 7-11 (*cum syn.*).

Gavelinopsis praegeri (Heron-Allen & Earland, 1913)

- 1913 *Discorbina praegeri* HERON-ALLEN & EARLAND, p. 122, Pl. 10, figs. 8-10.
 1958 *Gavelinopsis praegeri* (Heron-Allen & Earland) - PARKER, p. 264, Pl. 3, figs. 24-25.

Globocassidulina subglobosa (Brady, 1881)

- 1881 *Cassidulina subglobosa* BRADY, p. 60.
 1991 *Globocassidulina subglobosa* (Brady) - CIMERMAN & LANGER, p. 61, Pl. 63, figs. 4-6.

Hyalinea balthica (Schröter, 1783)
Pl. 2, fig. 11

- 1783 *Nautilus balthicus* SCHRÖTER, p. 20, fig. 2.
 1958 *Hyalinea balthica* (Schröter) - PARKER, p. 275, Pl. 4, fig. 39.

Lenticulina calcar (Linnaeus, 1758)

- 1758 *Nautilus calcar* LINNAEUS, p. 709, Pl. 1, figs. 3 g-i, 41 n.
 1960 *Lenticulina calcar* (Linnaeus) - BARKER, Pl. 70, figs. 9-11.

Lenticulina orbicularis (d'Orbigny, 1826)

- 1826 *Robulina orbicularis* D'ORBIGNY, p. 288, Pl. 15, figs. 8-9 bis.
 1982 *Lenticulina orbicularis* (d'Orbigny) - AGIP, Pl. 10, figs. 5-5 a.

Lenticulina rotulata (Lamarck, 1804)

- 1804 *Lenticulites rotulata* LAMARCK, p. 188.
 1982 *Lenticulina rotulata* (Lamarck) - AGIP, Pl. 10, fig. 6.

Lenticulina stellata (Seguenza, 1880)

- 1880 *Robulina stellata* SEGUENZA, p. 144, Pl. 13, fig. 29.
 1982 *Lenticulina stellata* (Seguenza) - AGIP, Pl. 10, fig. 10.

Lobatula lobatula (Walker & Jacob, 1798)
Pl. 1, figs. 1-2

- 1798 *Nautilus lobatulus* WALKER & JACOB, p. 642, Pl. 14, fig. 36.
 1987 *Lobatula lobatula* (Walker & Jacob) - LOEBLICH & TAPPAN, p. 583, Pl. 637, figs. 10-13.

Melonis barleanum (Williamson, 1858)

- 1858 *Nonionina barleana* WILLIAMSON, p. 32, Pl. 3, figs. 68-69.
 1958 *Melonis barleanum* (Williamson) - PARKER, p. 258, Pl. 1, figs. 36-37.

Melonis pompilioides (Fichtel & Moll, 1798)
Pl. 2, figs. 7-8

- 1798 *Nautilus pompilioides* FICHEL & MOLL, p. 31, Pl. 2, figs. a-c.
 1976 *Melonis pompilioides* (Fichtel & Moll) - HANSEN & LYKKE-ANDERSEN, p. 24, Pl. 22, figs. 10-13.

Miliolinella subrotunda (Montagu, 1803)

- 1803 *Vermiculum subrotundum* MONTAGU, p. 521
 1991 *Miliolinella subrotunda* (Montagu) - CIMERMAN & LANGER, p. 42, Pl. 38, figs. 4-9.

Neoconorbina posidonicola (Colom, 1942)

- 1942 *Discorbis posidonicola* COLOM, p. 37, Pl. 7, figs. 149-150.
 1993 *Neoconorbina posidonicola* (Colom) - SGARRELLA & MONCHARMONT ZEI, p. 218, Pl. 16, fig. 13.

Neoconorbina terquemi (Rzehak, 1888)
Pl. 1, figs. 5-6

- 1888 *Discorbina terquemi* RZEHAK, p. 228.
 1991 *Neoconorbina terquemi* (Rzehak) - CIMERMAN & LANGER, p. 66, Pl. 70, figs. 5-7.

Nubecularia lucifuga Defrance, 1825

- 1825 *Nubecularia lucifuga* DEFANCE, p. 210, Pl. 44, figs. 3 a-d.
 1991 *Nubecularia lucifuga* Defrance - CIMERMAN & LANGER, p. 26, Pl. 17, figs. 5-7 (*cum syn.*).

Planorbulina mediterraneensis d'Orbigny, 1826
Pl. 1, figs. 10-11

- 1826 *Planorbulina mediterraneensis* D'ORBIGNY, p. 280, Pl. 14, figs. 4-6.
 1993 *Planorbulina mediterraneensis* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 235, Pl. 23, fig. 4 (*cum syn.*).

Planulina ariminensis d'Orbigny, 1826

- 1826 *Planulina ariminensis* D'ORBIGNY, p. 280, Pl. 14, figs. 1-3.
 1993 *Planulina ariminensis* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 234, Pl. 22, fig. 9 (*cum syn.*).

Quinqueloculina berthelotiana d'Orbigny, 1839

- 1839b *Quinqueloculina berthelotiana* D'ORBIGNY, p. 142, Pl. 3, figs. 25-27.
 1993 *Quinqueloculina berthelotiana* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 170, Pl. 6, figs. 1-2 (*cum syn.*).

Quinqueloculina bidentata d'Orbigny, 1839

- 1839a *Quinqueloculina bidentata* D'ORBIGNY, p. 197, Pl. 12, figs. 18-20.
 1991 *Quinqueloculina bidentata* d'Orbigny - CIMERMAN & LANGER, p. 36, Pl. 32, figs. 10-14 (*cum syn.*).

Quinqueloculina bosciana d'Orbigny, 1839

- 1839a *Quinqueloculina bosciana* D'ORBIGNY, p. 191, Pl. 11, figs. 22-24.
 2001 *Quinqueloculina bosciana* d'Orbigny - FIORINI & VAIANI, p. 376, Pl. 3, figs. 17-18 (*cum syn.*).

Quinqueloculina disparilis d'Orbigny, 1826

- 1826 *Quinqueloculina disparilis* D'ORBIGNY, p. 302, n. 21.
 1993 *Quinqueloculina disparilis* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 170, Pl. 8, fig. 2 (*cum syn.*).

Quinqueloculina jugosa Cushman, 1944

- 1944 *Quinqueloculina seminulum* var. *jugosa* CUSHMAN, p. 13, Pl. 2, fig. 15.
 1991 *Quinqueloculina jugosa* Cushman - CIMERMAN & LANGER, p. 37, Pl. 33, figs. 12-14.

Quinqueloculina laevigata d'Orbigny, 1839

- 1839 *Quinqueloculina laevigata* D'ORBIGNY, p. 143, Pl. 3, figs. 32-33.
 1991 *Quinqueloculina laevigata* d'Orbigny - CIMERMAN & LANGER, p. 37, Pl. 33, figs. 8-11 (*cum syn.*).

Quinqueloculina limbata d'Orbigny, 1826

- 1826 *Quinqueloculina limbata* d'ORBIGNY, p. 302, n. 20.
 1991 *Quinqueloculina limbata* d'Orbigny - CIMERMAN & LANGER, p. 37, Pl. 34, figs. 1-5 (*cum syn.*).

Quinqueloculina neapolitana Sgarrella & Moncharmont Zei, 1993

- 1993 *Quinqueloculina neapolitana* SGARRELLA & MONCHARMONT ZEI, p. 172, Pl. 5, figs. 10-12.

Quinqueloculina nodulosa Wiesner, 1923

- 1923 *Quinqueloculina nodulosa* WIESNER, p. 49, Pl. 7, fig. 72.
 1991 *Quinqueloculina nodulosa* Wiesner - CIMERMAN & LANGER, p. 36, Pl. 32, figs. 3-4 (*cum syn.*).

Quinqueloculina padana Perconig, 1954

- 1954 *Quinqueloculina padana* PERCONIG, p. 95-96, figs. 1-4.
 1993 *Quinqueloculina padana* Perconig - SGARRELLA & MONCHARMONT ZEI, p. 172, Pl. 7, fig. 1 (*cum syn.*).

Quinqueloculina seminulum (Linnaeus, 1758)

- 1758 *Serpula seminula* LINNAEUS, p. 786, Pl. 2, figs. 1 a-c.
 1893 *Quinqueloculina seminulum* (Linnaeus) - SCHLUMBERGER, p. 66, Pl. 4, figs. 80-81.

Quinqueloculina stalker Loeblich & Tappan, 1953

- 1953 *Quinqueloculina stalker* LOEBLICH & TAPPAN, p. 40, Pl. 5, figs. 5-9.
 1993 *Quinqueloculina stalker* Loeblich and Tappan - SGARRELLA & MONCHARMONT ZEI, p. 174, Pl. 5, figs. 13-14 (*cum syn.*).

Quinqueloculina stelligera Schlumberger, 1893

- 1893 *Quinqueloculina stelligera* SCHLUMBERGER, p. 210, Pl. 2, figs. 58-59.
 2001 *Quinqueloculina stelligera* Schlumberger - FIORINI & VAIANI, p. 377, Pl. 4, figs. 2-3 (*cum syn.*).

Quinqueloculina undulata d'Orbigny, 1852

- 1852 *Quinqueloculina undulata* d'ORBIGNY, p. 195.
 1993 *Quinqueloculina undulata* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 175, Pl. 7, fig. 6 (*cum syn.*).

Quinqueloculina viennensis Le Calvez & Le Calvez, 1958

- 1958 *Quinqueloculina viennensis* LE CALVEZ & LE CALVEZ, p. 187, Pl. 5, figs. 42, 44, 45.
 1993 *Quinqueloculina viennensis* Le Calvez & Le Calvez - SGARRELLA & MONCHARMONT ZEI, p. 176, Pl. 7, fig. 8 (*cum syn.*).

Rosalina bradyi (Cushman, 1915)
Pl. 1, fig. 3

- 1915 *Discorbis globularis* var. *bradyi* CUSHMAN, p. 12, Pl. 8, fig. 1.
 1960 *Rosalina bradyi* (Cushman) - BARKER, Pl. 86, figs. 8 a-c.

Reussella spinulosa (Reuss, 1850)

- 1850 *Verneuilina spinulosa* REUSS, p. 374, Pl. 47, fig. 12.
 1970 *Reussella spinulosa* (Reuss) - VON DANIELS, p. 83, Pl. 6, fig. 2.

Sigmoilinita costata (Schlumberger, 1893)
Pl. 1, fig. 7

- 1893 *Sigmoilina costata* SCHLUMBERGER, p. 61, Pl. 1, figs. 51-52.
 1991 *Sigmoilinita costata* (Schlumberger) - CIMERMAN & LANGER, p. 47, Pl. 45, figs. 1-6.

Spirillina vivipara Ehrenberg, 1843
Pl. 1, fig. 8

- 1843 *Spirillina vivipara* EHRENBURG, p. 323, 422, Pl. 3, fig. 41.
 1993 *Spirillina vivipara* Ehrenberg - SGARRELLA & MONCHARMONT ZEI, p. 226, Pl. 20, fig. 2 (*cum syn.*).

Spiroplectinella wrighti (Silvestri, 1903)

- 1903 *Spiroplecta wrighti* SILVESTRI, p. 59, figs. 1-6.
 1991 *Spiroplectinella wrighti* (Silvestri) - CIMERMAN & LANGER, p. 20, Pl. 6, figs. 1-4.

Textularia bocki Höglund, 1947
Pl. 2, fig. 6

- 1947 *Textularia bocki* HÖGLUND, p. 171, Pl. 12, figs. 5-6.
 2001 *Textularia bocki* Höglund - FIORINI & VAIANI, p. 368, Pl. 1, figs. 5-6 (*cum syn.*).

Textularia pseudorugosa Lacroix, 1931

- 1931 *Textularia pseudorugosa* LACROIX, p. 11, fig. 3.
 1993 *Textularia pseudorugosa* Lacroix - SGARRELLA & MONCHARMONT ZEI, p. 166, Pl. 3, figs. 6-7 (*cum syn.*).

Textularia sagittula Defrance, 1824

- 1824 *Textularia sagittula* DEFRANCE, p. 177, Pl. 13, figs. 5 a-b.
 2001 *Textularia sagittula* Defrance - FIORINI & VAIANI, p. 368, Pl. 1, fig. 10 (*cum syn.*).

Tretomphalus concinnus (Brady, 1884)

- 1884 *Discorbina concinna* BRADY, p. 646, Pl. 90, figs. 7-8.
 1968 *Tretomphalus concinnus* (Brady) - MONCHARMONT ZEI, Pl. 4, figs. 7 a-b.

Uvigerina auberiana d'Orbigny, 1839

- 1839a *Uvigerina auberiana* d'ORBIGNY, p. 106, Pl. 2, figs. 23-24.
 1993 *Uvigerina auberiana* d'Orbigny - SGARRELLA & MONCHARMONT ZEI, p. 214, Pl. 15, fig. 13 (*cum syn.*).

Uvigerina mediterranea Hofker, 1932
Pl. 2, figs. 1, 4

- 1932 *Uvigerina mediterranea* HOFKER, p. 118-119, figs. 32 a-g.
 1993 *Uvigerina mediterranea* Hofker - SGARRELLA & MONCHARMONT ZEI, p. 214, Pl. 16, figs. 1-2 (*cum syn.*).

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