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Environmental changes by mean of foraminiferal assemblages in the Late Quaternary deposits of the Terracina basin (Central Tyrrhenian Sea, Italy)

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ABSTRACT - Micropaleontological analysis, from three cores collected on the Tyrrhenian continental shelf in the Terracina basin allowed to highlight a transgressive trend related to the Holocene sea-level rise. Four distinct environments identified by ten benthic foraminiferal assemblages were recognised. The oldest ones is related to lagoon-barrier system or brackish-water environment and is dominated by the eurihaline species *Ammonia tepida*. The progress of transgressive trend have resulted in the replacement of the paleo-lagoon (*Ammonia tepida* assemblage) with a sandy beach environment (*Ammonia* spp. and *Elphidium* spp. assemblage), locally interested by vegetated cover (marked by the dominance of epiphytic taxa). Finally, the presence of taxa typical of circalittoral zone (*Melonis pompilioides*, *Reussella spinulosa*, *Globocassidulina subglobosa*, *Gavelinopsis praegeri* and *Asterigerinata adriatica*) marked the sea-level stabilisation and the recent foraminiferal distribution.

Key words: benthic foraminifera, paleoenvironmental reconstruction, Late Quaternary, Terracina basin, Tyrrhenian Sea

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INTRODUCTION

This work is part of a multidisciplinary research project ("Tirreno Project"), based on micropaleontological, sedimentological, geophysical, geochemical and geomorphological studies. The project was signed between the Lazio Region and the University of Rome "La Sapienza" and it focused on the study of depositional environments with particular attention to the Holocene sedimentary processes. In this paper, benthic foraminiferal assemblages coming from three cores collected in the southern Latium continental shelf were analysed in order to reconstruct the paleoenvironmental evolution during the Holocene transgression along central Tyrrhenian coast. In the last decades many studies showed that the micropaleontological record is a very useful tool for the ecological and paleoecological characterisation of marine environments. A lot of literature data and the new recent knowledge about living foraminifera allow to apply the modern patterns of distribution to the fossil record. Such micropaleontological approach has been successfully applied to the Late Pleistocene-Holocene succession of the Mediterranean continental shelf to define its Late Quaternary evolution (Capotondi et al., 1999; Sbaffi et al., 2001; 2004; Buccheri et al., 2002; Amore et al., 2004; Carboni et al., 2005; Di Donato et al., 2009; Caruso et al., 2011; Milli et al., in press).

STUDY AREA

The Terracina basin is a peri-tyrrhenian basin located within the Eastern Tyrrhenian offshore of the Latium coast (Fig. 1). The basin represents the seaward extension of the Pontina Plain and covers, together with the Gaeta basin, an area of about 750 km². At NW, the basin is bordered by the Circeo Promontory, a structural high trending NW-SE, while at SE, it is separated from the Gaeta basin by the Terracina-Gaeta high, a wide high belt located immediately offshore the Gaeta coastline.

The shelf break is at a water depth of about -200 m and the continental slope is characterised by the occurrence of two important slope basins in the Pontine Archipelago (Palmarola and Ventotene basins; Zitellini et al., 1984).

The tectonics evolution of this area is strictly connected with the Neogene evolution of the Tyrrhenian sea and the Apennine Chain. Alternating compressional and extensional tectonic phases, during Plio-Quaternary times, produced in the Terracina basin a N-S half-graben structure downthrown seaward through normal faults, which becomes larger seaward and laterally merges into the Gaeta basin. The Plio-Quaternary fill of the basin is on the whole 2600 m thick and is constituted by alternating sands and shales, with intercalations of conglomeratic levels (Aiello et al., 2000). High resolution sismostratigraphic profiles highlighted clinostratigraphic units, locally incised by paleo-valleys going down to 10

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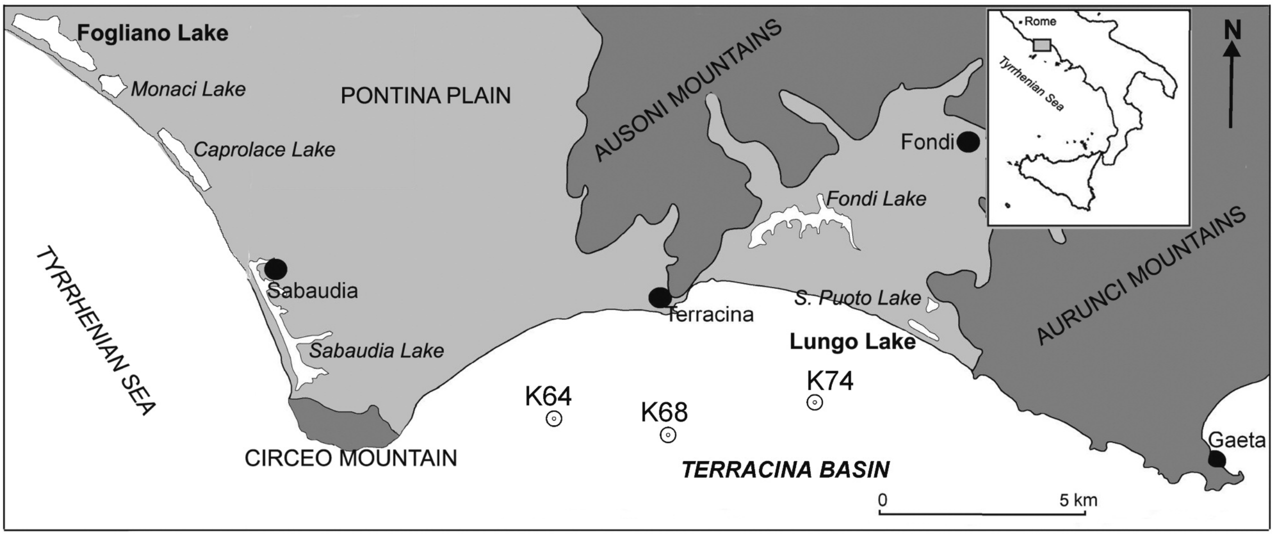

Fig. 1 - Location map of the studied cores.

meters near the coast. These structures are cut by an erosional surface related to the Würmian lowstand on which a depositional sequence 10 m thick lies (Chiocci and La Monica, personal communication).

MATERIALS AND METHODS

Three cores were collected by an Alpine gravity corer, during the cruise "Berenice" carried out by R/V Urania (June 1990). They were drilled on continental shelf (36-64 mwd), in the marine area in front of Terracina (Fig. 1) and are between 227 and 418 cm long (Tab. 1). The lithological description of the cores was carried out at the time of cores sampling. A total of 57 samples were collected: 32 samples from the core K64, 18 from the core K68, and 7 from the core K74.

In the laboratory, the sediment was wet-sieved through 125 μm, and then dried at 60 °C. Wherever possible (in 20 cases the quantity of the sediment or the foraminiferal assemblages were insufficient), washing residues were split with a microsplitter and 300 benthic foraminifera with well-preserved tests from each sample were hand-picked and counted using a binocular microscope.

Benthic foraminifera were classified according to Loeblich and Tappan (1987). Moreover, their identification was also based on Cimerman and Langer (1991), Sgarrella and Moncharmont Zei (1993) and Fiorini and Vaiani (2001).

Q-mode Hierarchical Cluster Analysis (HCA) were performed using SPSS (version 12) statistical software. The three cores were analysed separately, considering only the species that were more abundant than 5% in at least one sample. Infrequent occurring taxa (< 5% relative abundance) were omitted as they have insignificant effect on the formation of the major groups (Kovach, 1987; 1989). The 7 samples in which less than 100 specimens have been found were not included in the statistical analysis and, successively, were attributed to foraminiferal assemblages, considering the dominant species in each sample (as suggested by Pignatti et al., 2012). Distance of HCA is given in percentage by the Pearson correlation, while the similarities of the new fused clusters were calculated by adopting the Average Linkage method (within group) (Pielou, 1984; Parker and Arnold, 1999). The Q-mode 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).

Cores	Lat	Long	Depth (m)	Length (cm)
K64	41°14’.59	13°11’.66	36	418
K68	41°13’.84	13°15’.39	64	406
K74	41°14’.70	13°20’.35	56	227

Tab. 1 - Location data of the core.

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).

RESULTS

Lithology

The lithology of the core K64 is represented mainly by sands, silty and clayey sands (Fig. 2). From the bottom

(-418 cm) to -276 cm fine silty sands with a gravel level at -327 cm were found. From -276 to -212 cm clayey sands, with frequent scattered gravels in the basal part of this interval, follow. The transition to the upper part, where fine siliceous sands dominate, is marked by another gravel layers. From -40 cm to the top, silty and clayey sands rich in bioclasts and *Posidonia* rests are present.

In the core K68, two main intervals were highlighted (Fig. 2): the basal one is represented by silty clays; the second interval is constituted by sands evolving towards the top in muddy lithotypes. From the bottom to -212 cm a close dark silty clay interval is found. The transition to the upper part is marked by a gravel layer; 20 cm of silty sands follow. Till 50 cm from the top, fine sands with some fossiliferous gravel layers are present. From -50 to the top, muddy and silty sands rich in bioclasts and fossils are present.

The core K74 consists of sands at the base passing upward to silty sands and clayey sands. From the bottom to -60 cm well sorted fine sands are present with scarce macrofaunas and small size gravels. Successively, to -10 cm, silty sands are found becoming more clayey in the last 10 cm. In these last centimetres *Aporrhais* and *Murex* specimens are found.

Benthic foraminifera and statistical analysis

A total of 116 species (58 genera) were classified from 32 samples of core K64 (4 sample with <100 benthic foraminifera collected); 106 species belonging to 53 genera were identified in the 18 samples of core K68 (3 sample with < 100 specimens); finally, 97 species (and 47 genera) were recognised in the sediments of core K74.

In the core K64, the number of species in each sample ranges from 19 to 48. Twenty-six species showed a relative abundance higher than 5% in at least one sample of this core. *Ammonia beccarii* only shows very high frequencies (> 30%, in at least one sample), whereas *Ammonia parkinsoniana*, *Elphidium crispum*, *Elphidium macellum* and *Rosalina bradyi* show percentages > 15% in at least one sample. In the core K68 (5-51 species in each sample), 30 species are more abundant than 5%. *Ammonia tepida* shows very high percentages (> 50%), but in two samples only. *Ammonia beccarii*, *Ammonia parkinsoniana*, *Aubignyna perlucida*, *Elphidium crispum*, *Elphidium macellum*, *Lobatula lobatula*, *Melonis pompilioides* and *Triloculina adriatica* have frequencies higher than 15% in at least one sample. Finally, in the core K74 (29-53 species) no species shows frequencies higher than 30%. Only *Ammonia beccarii*, *Melonis pompilioides* and *Triloculina adriatica* reach percentages > 15%.

The Q-mode HCA grouped the analysed samples into clusters, characterised by distinct foraminiferal assemblages reflecting different ecological conditions. Each cluster is used to interpret the different paleoecological settings of the studied cores. As the 3 cores were analysed separately, the resulting dendrograms are described below.

Core K64

Because in 4 samples of core K64, <100 foraminifera were counted, the Q-mode HCA was performed utilising a dataset of 28 samples and 26 species (Tab. 2). The resulting dendrogram contains two main clusters (A and B), highlighted by a solid line placed at 15% distance in figure 3. Cluster A, can be subdivided into two subclusters of lower hierarchical rank (A1-A2), and is characterised by the dominance of *Ammonia* spp. and *Elphidium* spp. Subcluster A1 comprises 15 samples, in which *Ammonia beccarii* (5.5-23.0%, median 14.3%), *Ammonia parkinsoniana* (5.0-20.5%, median 10.7%), *Elphidium crispum* (0.3-18.3%, median 4.6%), *Elphidium macellum* (1.7-18.1%, median 6.7%), *Elphidium advenum* (0-14.6%, median 5.0%) and *Lobatula lobatula* (3.0-10.0%, median 5.7%) prevail. The diversity indices show relatively high values: the α-Fisher index ranges between 5.78 and 16.13 (median 11.94), whereas the Shannon index shows values from 2.59 to 3.32 (median 3.03). The percentage of dominance is relatively low (10.0-23.0%, median 16.0%). This assemblage includes also 3 samples with < 100 specimens. Along the core it is present between -355 and -132 cm.

Subcluster A2 includes 6 samples dominated by *Ammonia beccarii* (24.0-37.3%, median 30.2%). *Ammonia parkinsoniana* (1.7-11.7%, median 6.2%) and *Elphidium crispum* (2.0-11.0%, median 7.3%) are the other species having significant values (median ≥ 5%). The α-Fisher index ranges from 9.86 to 14.21 (median 11.09), whereas the Shannon index is comprised between 2.54 and 3.08 (median 3.27). The percentage of dominance shows the highest values (median 30.2%). This assemblage affects the lower part of the core, from the bottom to -380 cm and at -296 cm.

Cluster B (7 samples) is dominated by *Rosalina bradyi* (7.3-22.9%, median 11.8%), *Elphidium crispum* (3.7-18.8%, median 10.5%) and *Adelosina mediterranensis* (3.6-13.4%, median 10.3%). *Ammonia beccarii* (0-19.4%, median 1.3%) and *Lobatula lobatula* (4.6-11.0%, median 6.9%) are the only species showing significant values in some samples. The α-Fisher index shows values between 9.34 and 12.84 (median 10.81), whereas the Shannon index ranges from 2.74 to 3.14 (median 2.96). The percentage of dominance is generally low (10.9-22.9%, median 14.0%). This assemblage is present in the upper portion of the core, from -107 cm to the top (including also a sample with < 100 foraminifera counted).

Core K68

Fifteen samples, with more than 100 specimens classified, and 30 species were considered in the matrix of the Q-mode HCA for core K68 (Tab. 3). Three main clusters, C (including C1 and C2), D and E, were recognised in the dendrogram at a distance of 5% (Fig. 4).

Subcluster C1 (5 samples) is characterised by a dominance of *Triloculina adriatica* (6.6-25.2%, median 12.3%), *Ammonia beccarii* (0.5-17.4%, median 3.0%) and *Siphonaperta aspera* (7.3-11.0%, median 9.0%).

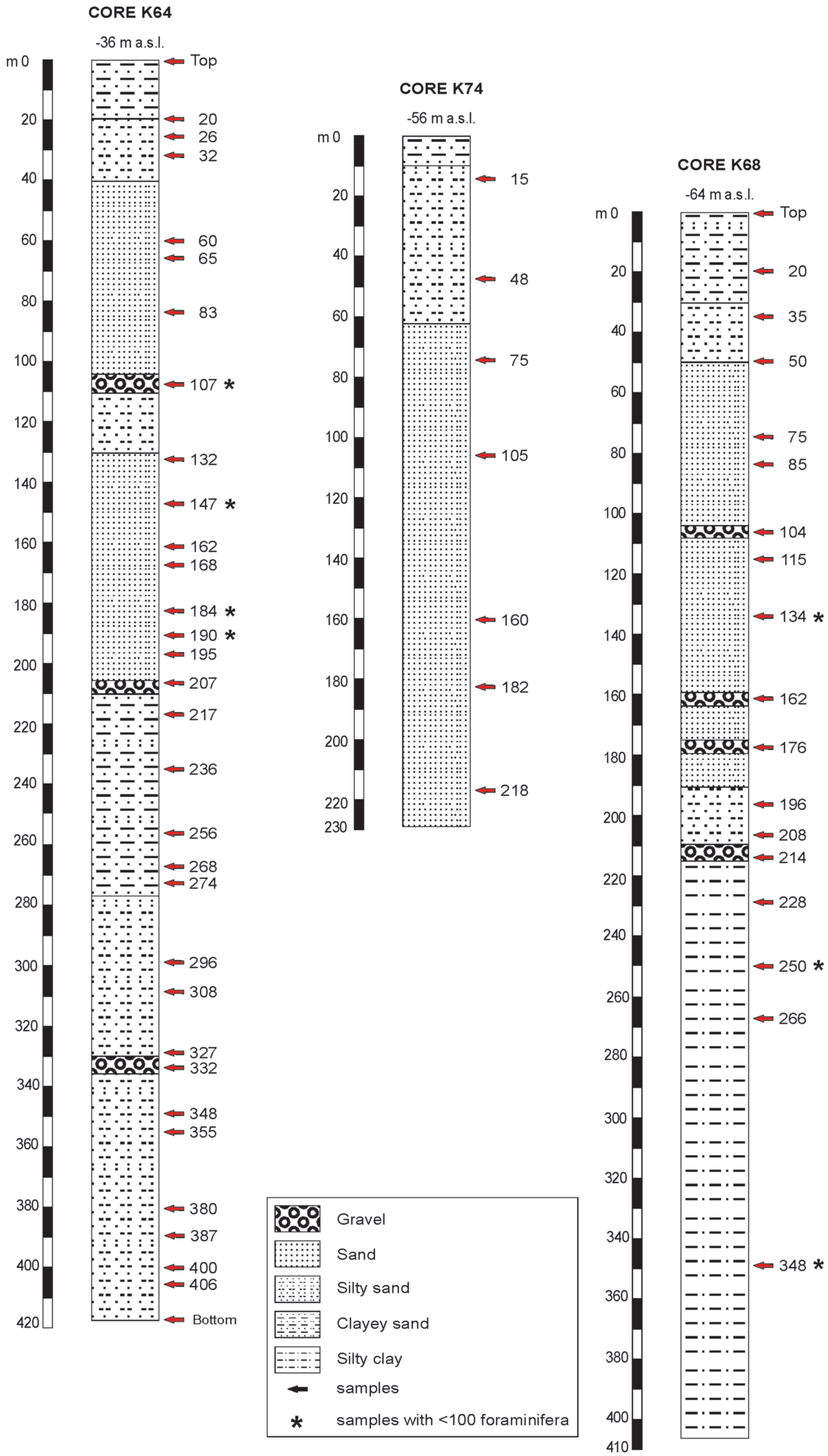

Fig. 2 - Lithological sketch of the studied cores.

Quinqueloculina seminulum (0.5-11.3%, median 6.0%) and *Ammonia parkinsoniana* (1.9-10.0%, median 7.7%) are the only subordinate species having significant frequencies. The α-Fisher index ranges between 11.07 and 18.76 (median 11.96), whereas Shannon index denotes values from 2.83 to 3.49 (median 3.02). The dominance is between 9.0 and 25.2% (median 16.7%). Along the core, this assemblage is present between -214 and -196 cm, and from -85 to -75 cm.

Four samples are included in the subcluster C2, in which *Ammonia parkinsoniana* (7.7-22.7%, median 12.6%), *Elphidium macellum* (6.9-18.0%, median 12.0%) and *Lobatula lobatula* (1.7-17.4%, median 6.3%) dominate the assemblages. *Elphidium crispum* (0-15.3%, median 5.1%), *Ammonia beccarii* (2.7-15.0%, median 8.2%) and *Elphidium aculeatum* (1.7-11.7%, median 6.1%) are significant accompanying taxa. The α-Fisher index ranges from 6.83 to 17.56 (median 13.04), and the Shannon index between 2.40 and 3.34 (median 2.94). The dominance is comprised between 9.6 and 22.7% (median 17.0%). This cluster, which one sample with very few foraminifera was attributed, was found from -176 to -162 cm, and from -115 to -104 cm.

Cluster D comprises four samples characterised by dominance of *Elphidium crispum* (0-20.0%, median 4.7%), *Melonis pompilioides* (3.3-17.7%, median 10.8%) and *Asterigerinata adriatica* (0-13.2%, median 3.7%). *Ammonia inflata* (0-12.0%, median 5.0%), *Reussella spinulosa* (3.7-8.7%, median 6.8%) and *Globocassidulina subglobosa* (4.9-7.3%, median 6.2%) are other species with relatively high frequencies. In comparison to previously described clusters, no significant changes in the diversity indices are recognised. This assemblage characterizes the upper part of the core, from -50 cm to the top.

The small cluster E includes only two samples (plus two sample with < 100 specimens founded), showing a very high dominance of *Ammonia tepida* (49.6-74.7%) and subordinate percentages of *Aubignyna perlucida* (4.0-22.8%), *Elphidium* sp. (12.0-13.4%), *Haynesina depressula* (1.0-10.6%) and *Ammonia parkinsoniana* (3.7-8.3%). As only 5 species are present in each sample, the diversity indices are very low, with the α-Fisher index lower than 1 and Shannon index ranging from 0.85 and 1.31. Consequently, the dominance reaches the highest values: 49.6-74.7%. Along the core, cluster E was found from the bottom to -228 cm.

Core K74

A small dendrogram was carried out from the seven samples of the core K74 and the relative 19 species more abundant than 5% (Tab. 4). Two main clusters (F and G) were recognised at the distance of 15% (Fig. 5). The cluster F was subdivided into two subclusters F1 and F2.

Subcluster F1 includes two samples in which *Ammonia parkinsoniana* is the more abundant species, but with a low dominance (11.7-12.9%), whereas *Triloculina adriatica* (7.1-11.1%), *Ammonia beccarii* (6.7-9.7%), *Buccella granulata* (3.2-7.8%), *Lobatula lobatula* (1.9-7.8%), *Siphonaperta aspera* (2.8-7.1%) and *Elphidium advenum* (3.3-5.2%) are accompanying taxa. The α-Fisher (> 19) and Shannon (> 3.3) indices are high. This assemblage is present along the core between -182 and -160 cm.

Subcluster F2 also groups two samples, dominated by *Triloculina adriatica* (23.5-27.0%). *Ammonia beccarii* (0-22.0%), *Elphidium aculeatum* (0.7-13.2%), *Lobatula lobatula* (0.7-13.2%), *Adelosina cliarensis* (1.7-11.0%), *Pseudotriloculina oblonga* (10.3-10.7%) and *Quinqueloculina seminulum* (1.2-7.0%) are other frequent species. Diversity indices decrease strongly, both α-Fisher index (7.92-10.31) and Shannon index (2.41-2.66). This cluster is found at -218 and -105 cm.

Three samples are included in the cluster G. This cluster is very heterogeneous, with the dominance of *Melonis pompilioides* (0.7-24.0%), *Gavelinopsis praegeri* (3.8-9.3%) and *Asterigerinata adriatica* (3.8-9.0%). *Spiroplectinella wrighti* (4.7-6.7%) and *Reussella spinulosa* (2.4-6.3%) are other significant taxa. Diversity indices (α-Fisher: 13.75-19.11; Shannon index: 3.02-3.56) and dominance (9.0-24.0%) are highly variables. This cluster characterizes the upper part of the core, from -75 to -15 cm.

DISCUSSION

Statistical analysis on benthic foraminifera

The Q-mode HCA on each of the three cores K64, K68 and K74 has allowed the recognition of 7 main clusters (Figs. 3-5). Cluster A, C and F were divided into two subclusters: A1-A2, C1-C2 and F1-F2, respectively. Consequently, 10 faunal assemblages were distinguished, each of them corresponding to different benthic environments, reflecting different ecological conditions.

*Cluster A: Subcluster A1 (*Ammonia *spp. and* Elphidium *spp. assemblage)*

This subcluster is characterised by a strong prevalence of taxa characteristic of infralittoral zone, such as *Ammonia beccarii*, *Ammonia parkinsoniana*, *Elphidium crispum*, *Elphidium macellum*, *Elphidium advenum* and *Lobatula lobatula*. *Ammonia beccarii* is a typical marine species, abundant in shallow-marine sandy bottoms, that tolerates moderate concentration of organic matter (Jorissen, 1988; Sgarrella and Moncharmont-Zei, 1993; Bellotti et al., 1994; Ruiz Muñoz et al., 1996; Mendes et al., 2004; Frezza and Carboni, 2009). In shallow marine deposits of the Mediterranean sea, *Ammonia parkinsoniana* has a similar behaviour (Sgarrella and Moncharmont-Zei, 1993), but can tolerate freshwater influence (Jorissen, 1988). *Elphidium* spp. are generally abundant from infralittoral sand, coarse sand, or vegetated bottom (Langer, 1988; Sgarrella and Moncharmont-Zei, 1993), nevertheless *Elphidium advenum* can tolerate also environmental stress as an organic matter enrichment or a salinity decrease

samples	**K64_BOTTOM**	**K64_406**	**K64_400**	**K64_387**	**K64_380**	**K64_355**	**K64_348**	**K64_332**	**K64_327**	**K64_308**	**K64_296**	**K64_274**	**K64_268**	**K64_256**
species														
Adelosina mediterranensis	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00
Ammonia beccarii	33.67	24.92	37.33	24.00	26.67	11.59	21.85	17.28	23.00	17.61	36.88	13.76	14.00	14.33
Ammonia inflata	0.00	0.00	6.33	2.33	3.33	0.00	4.64	2.33	2.67	0.00	5.98	0.00	2.33	1.67
Ammonia parkinsoniana	1.67	6.64	5.67	3.67	11.67	13.91	20.53	13.62	15.67	13.95	10.30	16.78	12.00	10.67
Ammonia tepida	11.33	3.99	3.33	9.33	4.33	4.30	5.96	6.31	6.67	7.31	1.33	1.68	0.67	0.33
Asterigerinata mamilla	0.00	1.00	1.00	0.33	0.00	0.66	0.33	0.33	0.00	0.66	0.66	1.01	1.00	0.67
Asterigerinata planorbis	1.67	1.99	0.67	1.67	4.67	6.95	1.99	1.99	2.33	1.66	2.33	2.01	3.33	3.67
Cassidulina neocarinata	1.33	2.66	0.33	3.67	2.00	2.65	0.00	2.66	1.00	2.66	0.33	6.38	2.67	0.67
Cibicidoides pachyderma	1.33	1.66	1.33	3.67	3.00	4.64	0.33	1.33	0.33	0.66	0.66	3.02	4.33	2.67
Cycloforina contorta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
Elphidium advenum	4.00	1.00	0.67	5.67	7.67	13.58	6.62	5.65	3.00	4.98	2.99	6.38	5.67	1.67
Elphidium craticulatum	0.00	8.31	2.67	1.00	0.67	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Elphidium crispum	11.00	1.99	8.00	6.00	6.67	1.32	6.29	2.33	5.00	2.33	7.97	0.34	2.00	16.00
Elphidium decipiens	5.00	0.66	3.67	0.33	0.00	0.66	1.66	0.33	0.67	0.00	0.00	0.00	0.00	0.00
Elphidium granosum	0.33	2.99	1.00	5.33	1.00	6.29	0.33	4.65	0.33	3.65	1.99	3.02	1.00	2.33
Elphidium macellum	2.33	2.99	3.00	2.33	3.00	1.66	5.63	3.65	9.33	3.99	4.32	3.36	6.33	8.67
Elphidium traslucens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.99	4.67	6.98	1.66	8.39	6.33	4.00
Lobatula lobatula	4.33	3.99	4.33	2.00	5.33	6.29	4.30	4.32	5.00	5.65	4.32	6.04	5.67	5.00
Planorbulina mediterranensis	0.33	0.66	0.67	0.33	0.33	0.00	0.33	0.00	0.67	0.33	0.66	0.34	0.33	0.00
Quinqueloculina berthelotiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina bidentata	3.67	8.97	1.33	1.67	1.33	0.33	0.66	0.66	1.33	1.00	1.00	2.35	3.67	2.00
Quinqueloculina limbata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00
Quinqueloculina seminulum	3.00	4.65	1.67	2.67	1.33	1.32	1.32	1.66	2.67	2.66	0.66	1.34	2.00	2.00
Rosalina bradyi	3.67	2.99	2.33	3.67	4.00	1.99	1.99	2.66	3.67	1.33	3.99	2.35	0.00	2.67
Triloculina adriatica	1.33	0.33	1.00	0.33	1.00	1.66	2.32	1.66	2.00	0.00	1.99	1.68	2.33	2.00
Triloculina marioni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Individuals	300	301	300	300	300	302	302	301	300	301	301	298	300	300
Taxa	34	38	40	44	35	36	34	37	34	39	36	38	48	42
α-Fisher index	9.86	11.51	12.40	14.21	10.27	10.65	9.84	11.09	9.86	11.94	10.67	11.56	16.13	13.29
Shannon index	2.55	2.92	2.65	3.08	2.76	3.00	2.67	3.05	2.75	3.05	2.54	3.03	3.26	3.03
% Dominance	33.7	24.9	37.3	24.0	26.7	13.9	21.9	17.3	23.0	17.6	36.9	16.8	14.0	16.0

Tab. 2 - Matrix with the relative abundances of the 26 foraminiferal species >5% from the core K64, utilised for statistical analysis.

samples	K64_236	K64_217	K64_207	K64_195	K64_168	K64_162	K64_132	K64_83	K64_65	K64_60	K64_32	K64_26	K64_20	K64_TOP
species														
Adelosina mediterranensis	0.00	0.66	0.00	0.00	0.00	0.00	4.74	3.64	5.96	8.43	10.26	10.93	12.00	13.44
Ammonia beccarii	12.33	15.18	5.67	14.77	19.00	12.88	9.49	19.39	10.55	7.63	0.00	1.32	0.33	0.33
Ammonia inflata	2.00	1.65	0.33	9.40	3.67	0.00	1.98	0.61	0.00	3.61	6.62	6.29	4.33	9.18
Ammonia parkinsoniana	5.00	6.93	9.00	7.38	9.00	6.82	5.93	3.64	1.83	2.01	1.99	4.30	1.00	2.30
Ammonia tepida	0.33	0.33	1.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
Asterigerinata mamilla	2.00	0.99	1.33	0.00	0.00	0.00	0.79	0.61	1.83	2.41	3.64	6.95	13.00	3.28
Asterigerinata planorbis	3.67	6.93	6.33	3.36	4.33	4.55	3.16	0.00	0.00	0.00	0.66	0.66	4.00	1.31
Cassidulina neocarinata	4.33	1.65	5.67	2.01	0.00	0.76	2.77	0.00	0.00	0.00	0.00	0.33	0.33	0.00
Cibicidoides pachyderma	6.33	4.29	4.33	0.00	0.33	4.55	3.16	0.61	0.00	0.80	0.00	0.33	0.00	0.00
Cycloforina contorta	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.38	1.20	0.99	2.98	1.00	5.90
Elphidium advenum	4.33	0.99	7.33	0.00	2.33	0.76	14.62	1.82	0.00	0.80	0.33	0.66	1.00	0.33
Elphidium craticulatum	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00
Elphidium crispum	9.00	11.22	2.00	12.75	18.33	4.55	1.58	18.79	9.17	14.86	10.93	6.95	3.67	10.49
Elphidium decipiens	0.33	0.00	0.67	0.00	0.00	0.76	0.79	0.00	0.46	0.00	0.00	0.00	0.00	0.00
Elphidium granosum	2.00	1.98	3.67	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.00
Elphidium macellum	5.67	13.20	9.00	18.12	9.33	6.82	6.72	6.67	2.75	3.21	3.97	2.65	1.33	1.64
Elphidium traslucens	3.33	4.62	5.67	0.00	0.67	2.27	1.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lobatula lobatula	5.33	7.59	10.00	7.38	3.00	9.85	7.91	7.27	7.80	6.02	4.97	4.64	11.00	6.89
Planorbulina mediterranensis	0.00	0.00	0.00	0.00	0.00	0.00	1.19	3.03	5.96	3.61	0.99	0.33	1.00	0.33
Quinqueloculina berthelotiana	0.00	0.00	0.00	0.00	0.00	3.03	0.00	1.21	1.38	0.00	6.29	8.94	4.33	4.92
Quinqueloculina bidentata	4.67	0.33	0.67	0.00	3.67	4.55	1.98	3.64	0.92	6.83	0.00	0.00	0.00	0.00
Quinqueloculina limbata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.83	1.61	5.30	4.30	2.33	1.31
Quinqueloculina seminulum	2.00	0.00	0.67	0.00	2.00	3.79	1.98	0.00	1.38	1.61	5.30	4.30	2.33	1.31
Rosalina bradyi	0.67	2.97	1.67	0.00	0.67	2.27	4.35	11.52	22.94	14.86	9.60	7.28	14.00	11.80
Triloculina adriatica	2.00	0.00	0.67	0.00	2.00	8.33	2.77	0.61	0.00	4.42	0.00	0.00	0.00	0.00
Triloculina marioni	0.00	0.00	0.00	3.36	0.00	0.00	0.00	0.00	4.59	0.00	3.64	2.32	3.00	5.90
Individuals	300	303	300	149	300	132	253	165	218	249	302	302	300	305
Taxa	45	37	41	19	7	6	41	34	22	43	17	33	33	31
α-Fisher index	14.68	11.06	12.84	5.78	5.57	10.91	12.84	14.83	17.01	14.87	9.23	12.40	10.81	9.34
Shannon index	3.32	2.96	3.20	2.59	1.73	1.73	2.87	3.12	2.80	3.23	2.50	2.74	2.84	2.92
% Dominance	12.3	15.2	10.0	18.1	19.0	12.9	14.6	19.4	22.9	14.9	10.9	10.9	14.0	13.4

Tab. 2 - ...Continued

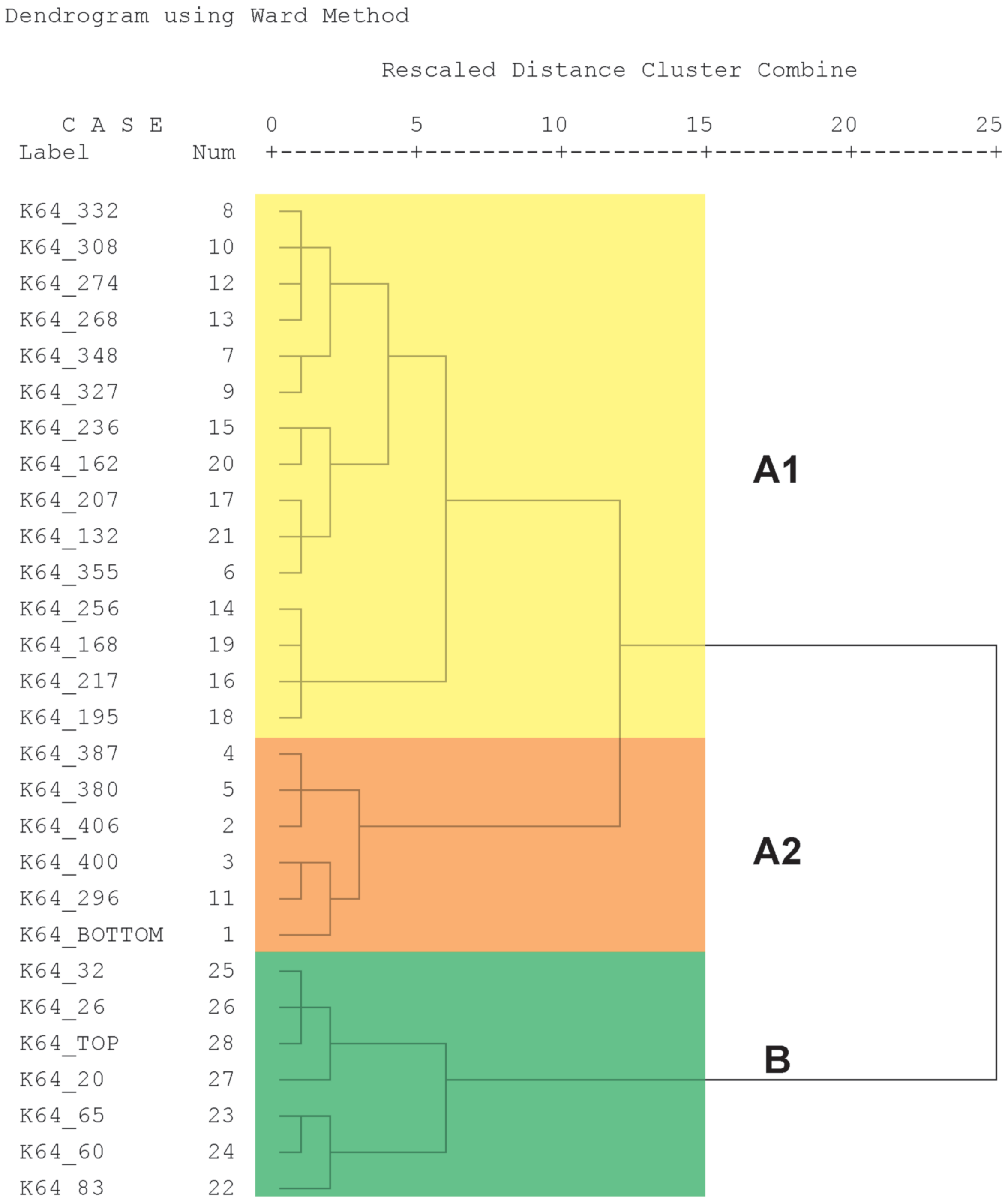

Fig. 3 - Dendrogram of Q-mode hierarchical cluster analysis of the core K64 samples, based on the relative abundance of species >5%.

(Jorissen, 1988; Barmawidjaja et al., 1992). *Lobatula lobatula* is abundant from infralittoral zone, especially on *Posidonia* prairies, but it is present also from circalittoral detritic bottoms (Jorissen, 1988; Langer, 1988; Sgarrella and Moncharmont Zei, 1993; Coppa et al., 1994; Frezza et al., 2005, 2010, 2011; Frezza and Carboni, 2009). The diversity indices show high values, whereas the percentage of dominance is relatively low. On the whole this assemblage is typical of infralittoral zone, characterised by sandy bottom, nevertheless the relative equilibrium between the frequencies of *Ammonia beccarii* and *Ammonia parkinsoniana* can indicate freshwater influences or organic matter inputs. On the other hand, the occurrence of epiphytic taxa as *Lobatula lobatula* can indicate a discontinuous seagrass present in nearby areas.

*Cluster A: Subcluster A2 (***Ammonia beccarii*** assemblage)*

Ammonia beccarii dominates strongly in all samples of this subcluster, characterised by diversity indices ranging from low to medium values, and the subordinate

samples	**K68_266**	**K68_228**	**K68_214**	**K68_208**	**K68_196**	**K68_176**	**K68_162**	**K68_115**	**K68_104**	**K68_85**	**K68_75**	**K68_50**	**K68_35**	**K68_20**	**K68_TOP**
species															
Adelosina cliariensis	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	1.90	10.93	0.33	0.00	0.00	0.00
Ammonia beccarii	0.00	0.00	17.39	5.33	3.00	7.26	2.68	15.00	9.09	0.47	0.66	0.00	0.00	0.33	0.00
Ammonia inflata	0.00	0.00	5.35	1.00	4.00	3.63	4.35	2.33	7.44	0.00	5.96	0.00	4.67	5.35	12.00
Ammonia parkinsoniana	3.66	8.33	9.03	10.00	7.67	8.58	7.69	22.67	16.53	1.90	2.32	3.62	0.00	0.00	0.00
Ammonia tepida	49.59	74.67	2.01	0.00	0.67	1.32	5.02	0.00	8.26	3.32	1.66	0.00	1.67	0.67	0.00
Asterigerinata adriatica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.84	0.00	13.16	6.67	0.00	0.67
Aubignyna perlucida	22.76	4.00	0.33	0.00	0.00	1.32	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Buccella granulata	0.00	0.00	2.68	2.00	0.67	0.66	2.01	2.33	1.65	0.47	0.00	1.97	3.67	5.35	2.00
Bulimina marginata	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.29	2.00	2.68	6.67
Cassidulina neocarinata	0.00	0.00	0.00	0.33	0.00	3.63	6.02	3.00	0.00	2.37	0.66	1.64	3.33	2.34	3.33
Cycloforina rugosa	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	6.29	0.00	0.00	0.00	0.00
Elphidium aculeatum	0.00	0.00	0.33	1.00	3.00	8.91	11.71	1.67	3.31	1.42	1.66	0.00	0.00	0.00	0.00
Elphidium crispum	0.00	0.00	4.68	4.33	2.00	3.63	0.00	15.33	6.61	0.95	0.66	0.00	1.00	8.36	20.00
Elphidium decipiens	0.00	0.00	0.33	0.67	0.00	0.00	0.67	0.33	0.83	0.00	0.00	2.63	6.33	0.00	7.33
Elphidium granosum	0.00	0.00	1.67	3.00	4.00	0.99	0.33	0.67	0.00	0.00	0.00	1.97	1.33	6.02	1.33
Elphidium macellum	0.00	0.00	2.01	4.67	6.00	6.93	12.37	18.00	11.57	1.90	2.98	0.99	1.33	1.67	1.00
Elphidium pulvereum	0.00	0.00	1.67	1.00	0.33	0.33	2.34	0.00	0.83	9.00	0.00	1.64	0.00	0.00	0.00
Elphidium sp.	13.41	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gavelinopsis praegeri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	11.18	5.67	0.67	0.00
Globocassidulina subglobosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.47	0.33	4.93	7.33	6.02	6.33
Haynesina depressula	10.57	1.00	0.00	0.00	0.00	0.66	0.00	1.33	0.00	0.47	0.99	1.64	0.33	1.34	0.00
Lobatula lobatula	0.00	0.00	1.00	1.67	4.33	9.57	17.39	3.00	1.65	1.42	2.32	0.00	1.00	0.00	0.00
Melonis pompilioides	0.00	0.00	0.33	0.00	0.00	0.66	1.67	1.33	0.00	0.47	0.33	3.29	8.00	17.73	13.67
Quinqueloculina bidentata	0.00	0.00	1.00	1.33	2.33	0.00	0.00	0.00	0.00	0.00	6.62	1.32	1.67	0.67	0.00
Quinqueloculina seminulum	0.00	0.00	6.02	11.33	10.00	1.98	0.00	0.00	0.83	0.47	0.99	0.66	0.00	0.67	0.00
Reussella spinulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.33	6.25	8.67	7.36	3.67
Siphonaperta aspera	0.00	0.00	10.37	11.00	7.33	0.66	0.00	0.00	1.65	9.00	8.28	0.99	0.00	0.00	0.00
Textularia bocki	0.00	0.00	0.00	0.33	0.00	1.98	0.33	0.00	0.83	0.00	1.32	2.96	6.00	6.02	3.00
Triloculina adriatica	0.00	0.00	10.70	16.67	12.33	1.65	0.33	0.00	0.00	6.64	25.17	0.00	0.00	0.00	0.00
Triloculina marioni	0.00	0.00	0.00	0.00	6.33	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.33
Individuals	246	300	299	300	300	303	299	300	121	211	302	304	300	299	300
Taxa	5	5	43	38	39	51	37	26	33	47	37	38	45	39	35
α-Fisher index	0.89	0.85	13.77	11.53	11.96	17.56	11.12	6.83	14.95	18.76	11.07	11.46	14.68	11.97	10.27
Shannon index	1.31	0.85	3.02	2.98	3.17	3.34	2.90	2.40	2.98	3.49	2.83	3.25	3.36	3.07	2.80
% Dominance	49.6	74.7	17.4	16.7	12.3	9.6	17.4	22.7	16.5	9.0	25.2	13.2	8.7	17.7	20.0

Tab. 3 - Matrix with the relative abundances of the 30 foraminiferal species >5% from the core K68, utilised for statistical analysis.

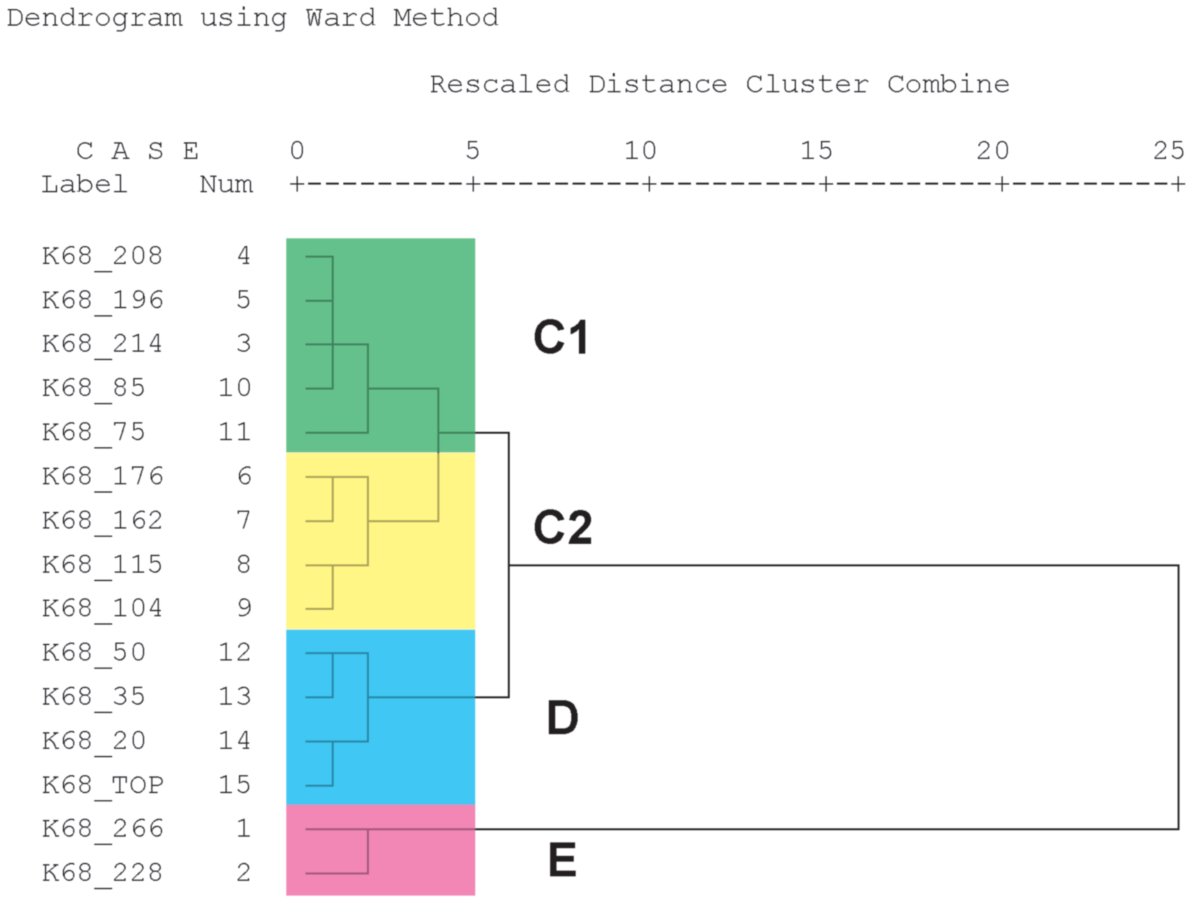

Fig. 4 - Dendrogram of Q-mode hierarchical cluster analysis of the core K68 samples, based on the relative abundance of species > 5%.

samples	K74_218	K74_182	K74_160	K74_105	K74_75	K74_48	K74_15
species							
Adelosina cliariensis	1.65	0.00	1.67	11.00	3.14	0.33	0.00
Ammonia beccarii	0.00	9.68	6.67	22.00	2.79	0.33	0.00
Ammonia parkinsoniana	2.88	12.90	11.67	0.67	2.44	3.00	3.67
Asterigerinata adriatica	0.00	0.00	0.00	0.00	3.83	9.00	7.67
Buccella granulata	0.00	3.23	7.78	0.67	8.36	3.33	1.33
Elphidium aculeatum	13.17	0.00	1.67	0.67	0.35	0.00	0.00
Elphidium advenum	0.00	5.16	3.33	0.33	5.23	2.33	0.00
Elphidium granosum	0.41	1.29	1.67	0.00	3.14	3.67	6.00
Gavelinopsis praegeri	0.00	0.00	1.11	0.00	3.83	8.33	9.33
Lobatula lobatula	13.17	1.94	7.78	0.67	0.35	2.67	0.33
Melonis pompilioides	0.00	1.94	0.56	0.00	0.70	7.00	24.00
Pseudotriloculina oblonga	10.70	2.58	3.89	10.33	2.44	0.00	0.00
Quinqueloculina seminulum	7.00	3.87	1.67	1.67	1.05	0.00	0.67
Reussella spinulosa	0.00	0.00	0.56	0.00	2.44	6.33	6.00
Rosalina bradyi	2.06	1.94	1.67	0.00	1.74	5.67	0.33
Siphonaperta aspera	4.53	7.10	2.78	4.33	1.74	0.67	1.00
Siphonaperta irregularis	0.82	0.00	1.11	2.33	9.41	2.33	0.00
Spiroplectinella wrighti	0.00	1.29	0.56	1.00	5.57	6.67	4.67
Triloculina adriatica	23.46	7.10	11.11	27.00	4.88	2.00	0.00
Individuals	243	155	180	300	287	300	300
Taxa	33	43	45	29	53	49	43
α-Fisher index	10.31	19.7	19.26	7.923	19.11	16.63	13.75
Shannon index	2.662	3.341	3.333	2.406	3.562	3.456	3.023
% Dominance	23.5	12.9	11.7	27.0	9.4	9.0	24.0

Tab. 4 - Matrix with the relative abundances of the 19 foraminiferal species >5% from the core K74, utilised for statistical analysis.

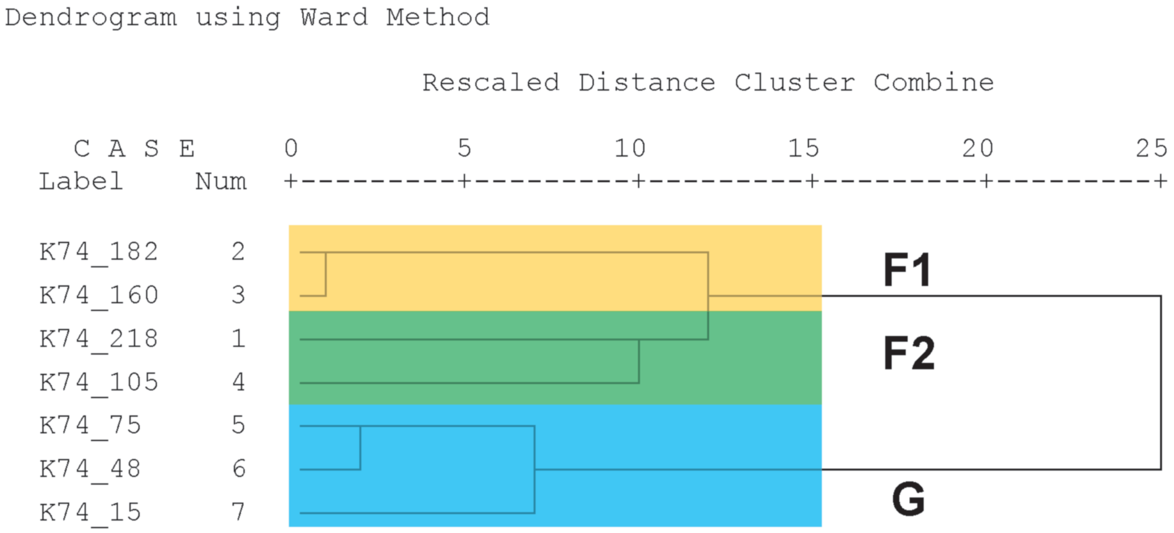

Fig. 5 - Dendrogram of Q-mode hierarchical cluster analysis of the core K74 samples, based on the relative abundance of species > 5%.

presence of *Ammonia parkinsoniana* and *Elphidium crispum*. This assemblage is really typical of the infralittoral zone and it is comparable to the *Ammonia beccarii* association of Murray (1991).

*Cluster B (*Rosalina bradyi, Elphidium crispum *and* Adelosina mediterranensis *assemblage)*

Rosalina bradyi, *Elphidium crispum* and *Adelosina mediterranensis* are the species characteristic of this assemblage. The occurrence of *Ammonia beccarii* and *Lobatula lobatula* is significant only in some samples. Except *Ammonia beccarii*, all these species are reported from infralittoral bottoms with vegetation cover (mostly *Posidonia oceanica*) and from detritic circalittoral bottoms (Langer, 1988, 1993; Sgarrella and Moncharmont Zei, 1993; Coppa et al., 1994; Frezza et al., 2005, 2010, 2011; Frezza and Carboni, 2009; Mateu-Vicens et al., 2010). This association, characterising modern sediments (sample K64_TOP), is typical of infralittoral zones and vegetated bottoms, generally linked to oligotrophic waters and as well as extensive photic zone. Nevertheless, in the sample between -83 and -60 cm of core K64, the simultaneous presence of *A. beccarii*, certainly not typical of seagrass, can suggest a not negligible organic matter content as this species is linked to a moderate nutrient input (Jorissen, 1988). The diversity indices denote intermediate values, but the percentage of dominance is medially low.

Cluster C: Subcluster C1 (miliolids assemblage)

It is characterised by a mixing between miliolids (as *Triloculina adriatica*, *Siphonaperta aspera* and *Quinqueloculina seminulum*) and *Ammonia* spp. (mainly *Ammonia beccarii* and *Ammonia parkinsoniana*). In the Mediterranean, *Triloculina adriatica* is reported from 5 to 70 m water depth (Cimerman and Langer, 1991; Yanko et al., 1994). *Siphonaperta aspera* is generally reported in the infralittoral zone from the sands (Jorissen, 1987, 1988; Sgarrella and Moncharmont Zei, 1993) and, rather rare, on the seagrass meadows (Langer, 1988; Mateu-Vicens et al., 2010). *Quinqueloculina seminulum* is widely distributed in the infralittoral zone but can occur also in the circalittoral zone (Albani and Serandrei Barbero, 1990; Sgarrella and Moncharmont Zei, 1993), generally on muddy or sandy-bottoms (Jorissen, 1988; Bellotti et al., 1994). On the whole, this assemblage can be attributed to infralittoral zone, characterised by a sandy or vegetated bottom, though the significant frequencies of *Ammonia beccarii* and *Ammonia parkinsoniana* testify a not negligible organic contribution. As in the cluster B, the diversity indices show intermediate values, whereas the dominance is relatively low.

*Cluster C: Subcluster C2 (*Ammonia *spp. and* Elphidium *spp. assemblage)*

This assemblage is similar to that of subcluster A1, both from the point of view of quality (taxa recognised) and quantity (species frequencies, diversity indices, percentage of dominance), as well as its environmental significance (typical infralittoral assemblage on sandy bottoms).

*Cluster D (*Melonis pompilioides, Reussella spinulosa *and* Globocassidulina subglobosa *assemblage)*

This cluster is characterised by the constant presence in each sample of *Melonis pompilioides*, *Reussella spinulosa* and *Globocassidulina subglobosa* that, although not being always the most abundant species, are those that maintain high enough frequencies in all samples. Instead *Ammonia inflata*, *Asterigerinata adriatica* and *Elphidium crispum* have a more discontinuous distribution. *Melonis pompilioides* and *Asterigerinata adriatica* have their maximum abundance in circalittoral assemblages

(Sgarrella and Moncharmont Zei, 1993; Bergamin et al., 1997; Frezza et al., 2005); *Reussella spinulosa* is very widespread in the Mediterranean, from infralittoral and circalittoral muds and fine sands (Sgarrella and Moncharmont Zei, 1993); *Globocassidulina subglobosa* is abundant in circalittoral and bathyal muds (Sgarrella and Moncharmont Zei, 1993). *Ammonia inflata* and *Elphidium crispum* are typical of infralittoral zone, but were found also in the upper circalittoral zone (Jorissen, 1988; Cimerman and Langer, 1991; Sgarrella and Moncharmont Zei, 1993). Therefore, this assemblage indicates a habitat deepening, corresponding to the upper circalittoral zone as confirmed by the fact that it also occurs at the top of the core K68 (at 64 mwd).

*Cluster E (*Ammonia tepida *assemblage)*

This small cluster includes only two samples, in which *Ammonia tepida* dominates with very high percentages, whereas *Aubignyna perlucida*, *Elphidium* sp., *Haynesina depressula* and *Ammonia parkinsoniana* have a subordinate importance. *Ammonia tepida* is an euryhaline species commonly found in shallow marine environments, lagoons and deltaic zones (Jorissen, 1988; Almogi-Labin et al., 1992; Favry et al., 1998; Abu-Zied et al., 2007; Carboni et al., 2009). *Ammonia parkinsoniana* is abundant in lagoonal settings (Almogi-Labin et al., 1992; Carboni et al., 2009) and is commonly found in shallow marine deposits of the Mediterranean, mostly on sandy bottoms (Sgarrella and Moncharmont-Zei, 1993), and locally in environments influenced by freshwater (Jorissen, 1988). *Ammonia parkinsoniana* and above all *Ammonia tepida* are typical species of paralic environments such as estuarine areas or lagoons, as they are tolerant of a wide range of salinity, temperature and oxygen content (Jorissen, 1988; Almogi-Labin et al., 1992; Carboni and Di Bella, 1996; Ruiz Muñoz et al., 1996; Reinhardt et al., 1998; Debenay et al., 2000; 2005; Mendes et al., 2004; Carboni et al., 2009; Frezza and Carboni, 2009; Di Bella et al., 2011). *Aubignyna perlucida* and *Haynesina depressula* also commonly occur in Mediterranean lagoons and coastal lakes (Murray, 1991; Donnici et al., 1997; Serandrei Barbero et al., 1999; Carboni et al., 2009); moreover, *Haynesina depressula* can survive in a wide range of oxygenation, salinity and temperature (Vaniček et al., 2000). The lowest values of diversity indices are recorded in this assemblage (α-Fisher index < 1), whereas the percentage of dominance shows the highest values, confirming unfavorable (stressed) conditions (Murray, 1991). This oligotypic assemblage could be referred to a high degree of confinement corresponding to a lagoon environment.

*Cluster F: Subcluster F1 (*Ammonia parkinsoniana *assemblage)*

This subcluster, characterised by low dominance and high diversity, shows the prevalence of species typical of infralittoral zone and, generally, related to sandy bottoms, as *Ammonia parkinsoniana*, *Triloculina adriatica*, *Ammonia beccarii*, *Buccella granulata*, *Lobatula lobatula*, *Siphonaperta aspera* and *Elphidium advenum* (Jorissen, 1988; Sgarrella and Moncharmont-Zei, 1993; Bellotti et al., 1994; Ruiz Muñoz et al., 1996; Mendes et al., 2004; Frezza and Carboni, 2009). Consequently, also this assemblage can be attributed to infralittoral zone.

*Cluster F: Subcluster F2 (*Triloculina adriatica *assemblage)*

This subcluster is dominated by *Triloculina adriatica*, with the significant presence of other miliolids (*Adelosina cliarensis*, *Pseudotriloculina oblonga* and *Quinqueloculina seminulum*), *Ammonia beccarii*, *Elphidium aculeatum* and *Lobatula lobatula*. All these taxa are typical of sandy infralittoral zones (Jorissen, 1988; Albani and Serandrei Barbero, 1990; Cimerman and Langer, 1991; Sgarrella and Moncharmont-Zei, 1993; Bellotti et al., 1994; Yanko et al., 1994; Ruiz Muñoz et al., 1996; Fiorini and Vaiani, 2001; Mendes et al., 2004; Frezza and Carboni, 2009) or, in some cases, vegetated bottoms, as *Adelosina cliarensis*, *Pseudotriloculina oblonga* and *Lobatula lobatula* (Langer, 1988; 1993; Sgarrella and Moncharmont Zei, 1993; Coppa et al., 1994; Fiorini and Vaiani, 2001; Frezza and others, 2005; 2010; 2011; Frezza and Carboni, 2009; Mateu-Vicens et al., 2010). The diversity indices are relatively low, while the dominance is high (> 20%). This assemblage can be compared to "miliolids assemblage" (subcluster C1) found in the core K68 and, consequently, attributed to an infralittoral environment. Because of the abundance of epiphytic species, the sea bottom is probably vegetated, even if the *Posidonia* meadows should not be too dense.

*Cluster G (*Melonis pompilioides*,* Gavelinopsis praegeri *and* Asterigerinata adriatica *assemblage)*

It is a heterogeneous cluster, in which *Melonis pompilioides*, *Gavelinopsis praegeri* and *Asterigerinata adriatica* are the more frequent species. *Spiroplectinella wrighti* and *Reussella spinulosa* are the main accompanying taxa. All these species live preferably in the circalittoral zone (Jorissen, 1987; Sgarrella and Moncharmont Zei, 1993; Bergamin et al., 1997; Frezza et al., 2005), especially in the upper circalittoral zone. As the "*Melonis pompilioides*, *Reussella spinulosa* and *Globocassidulina subglobosa* assemblage" (cluster D) found in the core K68, this association also indicates an increasing depth.

Foraminiferal assemblages and paleoenvironmental reconstruction

On the whole, the Q-mode cluster analyses on the foraminiferal content of the three studied cores have recognised 10 clusters (and subclusters) and relative foraminiferal assemblages, identifying 4 distinct environments (Tab. 5; Fig. 6). The cluster E (*Ammonia tepida* assemblage) is related to a lagoon or a brackish-water environment. Four clusters (A1, A2, C2 and F1) are characterised by *Ammonia* spp. and *Elphidium* spp.

assemblage, typical of infralittoral zones with sandy bottoms. Three clusters (B, C1 and F2) show the dominance of epiphytic taxa as *Rosalina bradyi* and miliolids and identify an infralittoral zone with vegetated bottoms. Finally, 2 clusters (D and G) are characterised by the dominance of taxa typical of circalittoral zone (*Melonis pompilioides*, *Reussella spinulosa*, *Globocassidulina subglobosa*, *Gavelinopsis praegeri* and *Asterigerinata adriatica*) and can be related to a deeper environment (upper circalittoral zone).

All these four recognised environments are present only in the core K68 (Fig. 6), which is the deepest core (-64 mwd). In the core K74, the infralittoral (sandy and vegetated bottoms) and upper circalittoral zones were found, whereas the lagoon environment (present at the bottom of K68) is lacking. Nevertheless, the core K74 (227 cm) is much shorter than the core K68 (406 cm). Consequently, the lagoon sediments might not have been recovered. In the core K64, only the sandy and vegetated infralittoral environments were identified, but this core was collected at lower depth (-36 mwd).

A good correlation among the different assemblages and their succession along each cores can be highlighted, although the basin deposition seems to be controlled by the geomorphological variability of the Pleistocene substrate. As the results in close core sites, different rates of sedimentation and fragmented environmental conditions are recorded.

The three cores intercepted sediments overlying the erosional surface formed during the last glacial lowstand. The core K68 (Fig. 6) is the only core that shows in its basal part a transitional environment characterised by brackish lagoon environment (E - *Ammonia tepida* assemblage). These deposits are the oldest ones and testify the beginning of the Holocene transgression in this area. The close core K74 (Fig. 6) for the minor thickness, does not intercepted these old lagoon sediments showing at the bottom an evident marine environment (F2 - epiphytic foraminifera assemblage). Likely in the shallowest core K64, any significant bathymetrical variations was recorded, only infralittoral environments were identified (Fig. 6). Nevertheless in the basal part of this core the significant presence of fine sediments and eutrophyc taxa suggest slight river influence (A2 - *Ammonia beccarii* assemblage).

Considering the lagoon deposits at the bottom of the core K68 as a sea-level marker (Carboni et al., 2010), we can suggest that the ancient shoreline shifted about 6 km off the recent coast. The littoral area was interested by one or more rivers that during the transgression, determined the formation of small brackish lagoon delimited towards the sea by a barrier island. In this area, an analogous barrier-lagoon system related to Holocene transgression were recognised also by Antonioli and Ferranti (1996). The development of a hydrographic system more consistent than recent one is presumable because of the increase in precipitation at the Pleistocene-Holocene transition and in the early Holocene (Orombelli and Ravazzi, 1996; Roberts et al., 2011).

Considering that the bathymetric excursion is about 60 meters and comparing this datum with the sea-level rise curve related to “Italia site 7” (Fondi area) of Lambeck et al. (2011), it is possible to date this event between 12000 and 11000 years BP (Fig. 7). As the beginning of the Holocene is dated at 11000 years BP, the basal portion of K68 could be attribute to the oldest Holocene sediments. Analogous transgressive lagoon-barrier system was identified by Barra et al. (1996) in the Volturno River plain (dated indirectly at about 10000 years ago), few kilometres south of Terracina area and in the Tiber River plain (Milli et al., in press), north of the studied area.

A transgressive surface separates the lagoonal deposits from the overlying beach deposits (lower shoreface) (Fig. 6). This infralittoral environment was colonised by *Posidonia oceanica* meadows during two distinct times, both highlighted in K68 and K74 (C1, F2 - epiphytic foraminiferal assemblage). In core K68, these events are separated by deposits related to an environment completely without vegetation cover (C2 - *Ammonia* spp., and *Elphidium* spp. assemblage), while in core K74 only a partial decrease is recorded (F1 - *Ammonia parkinsoniana* assemblage). A vegetated infralittoral environment is also present in the upper part of the core K64 and persists still now in that site (B - epiphytic foraminiferal assemblage). A further deepening, testified by the presence of upper circalittoral assemblages and the increase of fine-size fraction, is recorded in the upper part of K68 and K74 (D, G - *Melonis pompilioides*

Foraminiferal assemblage	**Cluster**	**Core**	**Environment**
A. tepida assemblage	E	K68	brackish water
R. bradyi, *E. crispum* and *A. mediterranensis* assemblage	B	K64	infralittoral vegetated bottom
miliolids assemblage	C1	K68	
T. adriatica assemblage	F2	K74	
Ammonia spp. and *Elphidium* spp. assemblage	A1, C2	K64, K68	infralittoral sandy bottom
A. beccarii assemblage	A2	K64	
A. parkinsoniana assemblage	F1	K74	
M. pompilioides, *R. spinulosa* and *G. subglobosa* assemblage	D	K68	upper circalittoral zone
M. pompilioides, *G. praegeri* and *A. adriatica* assemblage	G	K74	

Tab. 5 - Foraminiferal assemblages, clusters and relative environments recognised in the three cores from the Terracina basin.

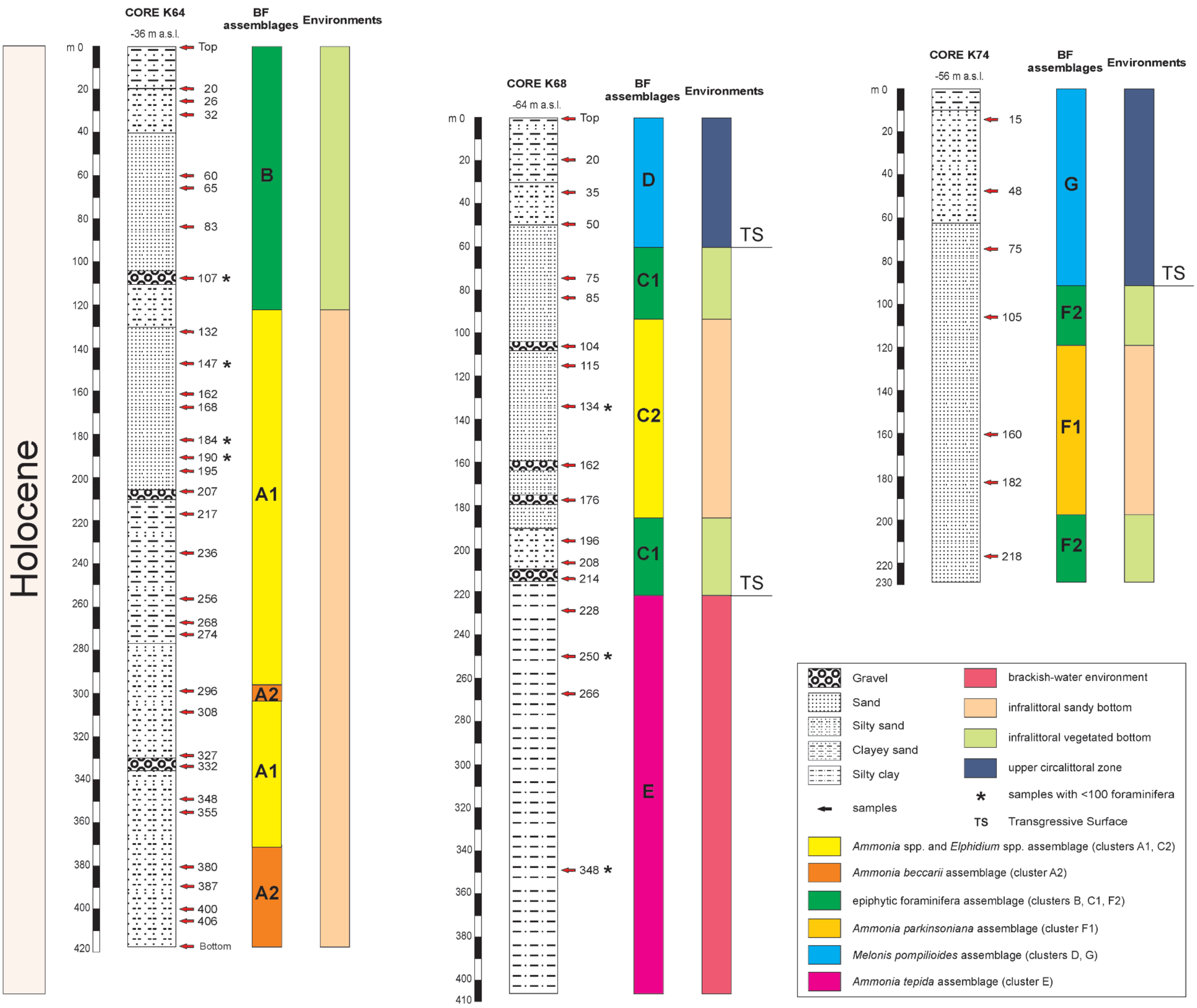

Fig. 6 - Distribution of foraminiferal assemblages along the studied cores and paleoenvironmental reconstruction.

assemblage). The develop of recent circalittoral assemblages (about -60 cm in K68 and K74) corresponds to the sea-level stabilisation dated at 6000 years BP (Milli et al., in press). Based on this consideration it is suggested that the transitional passage from infralittoral sandy bottom to upper circalittoral zone should be interpreted as the expression of the maximum landward position of the shoreline (i.e. the maximum flooding surface of sequence stratigraphy (Posamentier et al., 1988). Such shoreline migration, considering the tectonic stability of this area (Antonioli and Frezzotti, 1989; Carboni et al., 2010) it is suggested to be related to the relative sea-level rise (Holocene transgression) linked to the climate change and recognizable in the whole Tyrrhenian basin. Analogous results were carried out by Bellotti et al. (2007) and Milli et al. (in press) in the Tiber delta area.

CONCLUSIONS

The micropaleontological analysis of the three cores collected in the Tyrrhenian continental shelf in the Terracina basin allowed to highlight the Holocene transgression in this area. In the K68 core, collected at -64 m water depth, the whole transgressive process is represented. On the base of sea level curve performed in the proximity of Terracina site, the oldest sediments intercepted by this core are dated at the beginning of the Holocene. Benthic foraminiferal assemblages well testify the transition from brackish lagoon to recent upper circalittoral environment. Particularly two significant quick deepening episodes are recognised: the first one determined the drowning of the sandy barrier that delimited the brackish lagoon; the second episode caused the sinking of *Posidonia* meadows. The development of circalittoral assemblage marks the sea level stabilization and the establishment of modern water circulation pattern.

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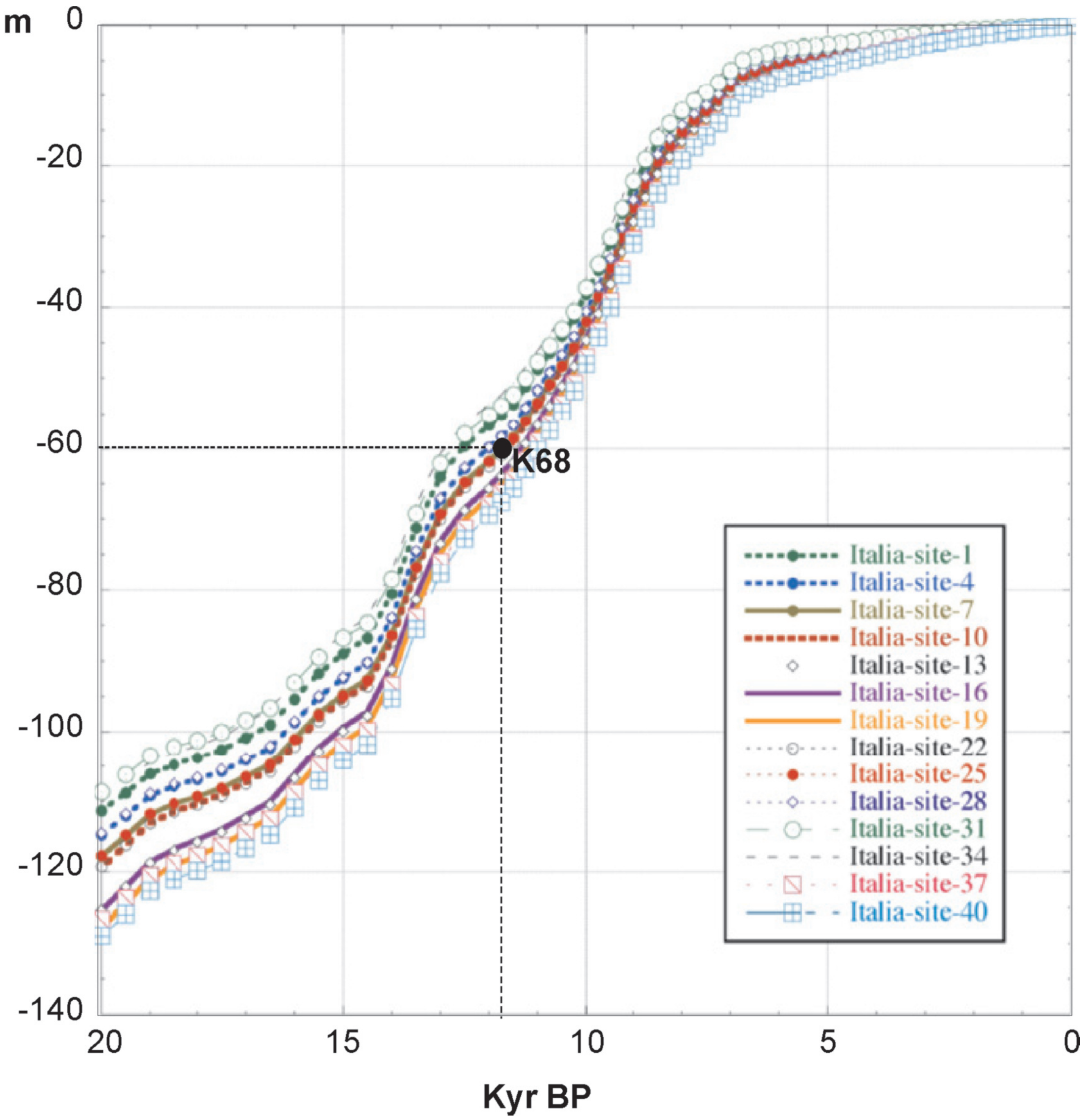

Fig. 7 - Eustatic and glacio-hydro-isostatic predictions for selected Italian sites for the past 20000 years (modified from Lambeck et al., 2011). Core K68 is plotted on the "Italia site 7" curve.

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