Bollettino della Società Paleontologica Italiana, 51 (1), 2012, 49-62. Modena, 30 giugno 2012

Pleistocene Foraminiferida and Ostracoda from the Island of Procida (Bay of Naples, Italy)

Giuseppe Aiello, Diana Barra, Tommaso De Pippo & Carlo Donadio

G. Aiello, D. Barra, T. De Pippo, C. Donadio, Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II, Largo San Marcellino 10, I - 80138 Napoli (Italy); aie64llo@hotmail.com; dibarra@unina.it; depippo@unina.it; donadio@unina.it

Equal contributors; names listed alphabetically

KEY WORDS: Foraminiferida, Ostracoda, volcano tectonics, palaeoenvironment, Pleistocene, Phlegrean Fields.

ABSTRACT - Upper Pleistocene fossiliferous sands located in the north-western area of the Island of Procida at 2.5 m above sea level yield assemblages of benthic foraminifers and ostracods. The deposit occurs between the trachytic lava breccias of the Breccia Museo Formation, as a member of the Campanian Ignimbrite (~39.000 ka b.p.), and the pyroclastic deposits of Solchiaro (~ 22.000 ka b.p.). Detailed study of the assemblages has contributed in the reconstruction of the main morpho-evolutionary and palaeoenvironmental phases of this area in the Late Quaternary. The most abundant taxa are the foraminifers Ammonia beccarii *and* Elphidium crispum*, and the ostracods* Pontocythere turbida*,* Cytheridea neapolitana *and* Semicytherura incongruens*. In spite of the ecological preferences of these species, commonly recorded in infralittoral waters, analysis of the entire assemblage indicates an infralittoral/circalittoral palaeoenvironment of 60-30 m below sea level (probably at about 40 m b.s.l.), a silty-sandy substrate and coastal detritic bottom biocoenoses. Preservation of calcareous microfossils is generally poor, probably due to dissolution caused by slightly acidic waters. A low pH palaeoenvironment may also explain the absence of miliolids as well as thin-shelled ostracods. These features are typical of waters affected by volcanic activity, such as carbon dioxide submarine vents.*

RIASSUNTO - [Foraminiferida e Ostracoda pleistocenici dall'Isola di Procida (Golfo di Napoli, Italia)] - *Sul versante costiero nord-occidentale dell'Isola di Procida è presente un livello di sabbie fossilifere compreso tra la Formazione Breccia Museo, membro dell'Ignimbrite Campana (~39.000 ka b.p.) e i depositi piroclastici di Solchiaro (~ 22.000 ka b.p.), che testimonia una fase di deposizione marina del Pleistocene Superiore di particolare interesse vista l'estrema rarità di analoghe segnalazioni in questo settore del complesso dei Campi Flegrei. Le associazioni a foraminiferi e ostracodi provenienti da nove campioni sono state oggetto di uno studio di dettaglio al fine di definire le caratteristiche paleoecologiche della sequenza affiorante. Le specie di foraminiferi che dominano l'associazione sono* Ammonia beccarii *ed* Elphidium crispum*, gli ostracodi più abbondanti sono* Pontocythere turbida*,* Cytheridea neapolitana *e* Semicytherura incongruens*. Nonostante le preferenze ecologiche delle specie citate, che caratterizzano le acque infralittorali mediterranee, le associazioni nel loro complesso sono indicative di un paleoambiente al limite tra il circalittorale e l'infralittorale con una paleobatimetria compresa tra -60 e -30 m. Lo stato di conservazione dei microfossili calcarei è generalmente mediocre ma si evidenzia una notevole differenza tra i diversi campioni, alcuni dei quali hanno restituito associazioni abbondanti e relativamente ben diversificate mentre altri si sono dimostrati estremamente poveri, anche se la distanza di campionamento è limitata a poche decine di centimetri. Viene ipotizzato un paleoambiente con acque moderatamente acidificate, come viene suggerito dall'assenza di miliolidi e di ostracodi con carapace sottile. In aree vulcaniche, acque a basso pH sono frequentemente connesse con emissioni idrotermali sottomarine ricche in anidride carbonica.*

INTRODUCTION

The Island of Procida, located in the north-western sector of the Bay of Naples, belongs to the western part of the Phlegrean Fields complex, a multi-crater volcanic area active from the Late Pleistocene to the Holocene. A number of studies attempted to assess the history and magnitude of the vertical (volcano-tectonic and bradyseismic) movements of the Phlegrean Fields (Aiello et al., 2007, and literature therein), especially considering that a large part of the area is intensely urbanized. The report of fossiliferous levels in an almost entirely volcanic framework can provide reliable data on palaeoecological data and particularly contribute to the palaeobathymetric reconstruction of the studied area. The purpose of the present study is to describe in detail the results of the micropalaeontological analysis of benthic foraminifer and ostracod assemblages. A small part of these data have been reported in a previous paper (Aiello et al., 2007) concerning primarily the geomorphological evolution of the Phlegrean islands of Procida and Vivara (Fig. 1).

The finding in 2007 for the first time in the Island of Procida of a significant, but limited, fossiliferous marine layer associated with an overlying aeolian deposit, suggested us to extend the previous sampling in order to better understand the paleoenvironmental framework.The studied layers are both located between the volcanic formations of the continental trachytic lava breccias (Breccia Museo Auctt., member of the Campanian Ignimbrite; ~39.000 years b.p., De Vivo et al., 2001) at the base, and the local basal pyroclastics of the last eruption sequence of Procida at the top (Solchiaro, ~22.000 years b.p.; Alessio et al., 1976; Rosi et al., 1988; De Astis et al., 2004; de Alteriis et al., 2010). These layers have been deposited during the almost 18.000 years of volcanic quiescent period (~39.000÷22.000 years b.p.). Successively, these marine sediments have been uplifted by recent volcano-tectonic movements for more than 30 m, up to the present-day position at 2.5 m a.s.l.; then they have been covered by dune deposits, currently at 3 m a.s.l., and finally buried by the Solchiaro pyroclastics (Aiello et al., 2007). This stratigraphic sequence outcrops, well exposed, along the

ISSN 0375-7633 doi:10.4435/BSPI.2012.06

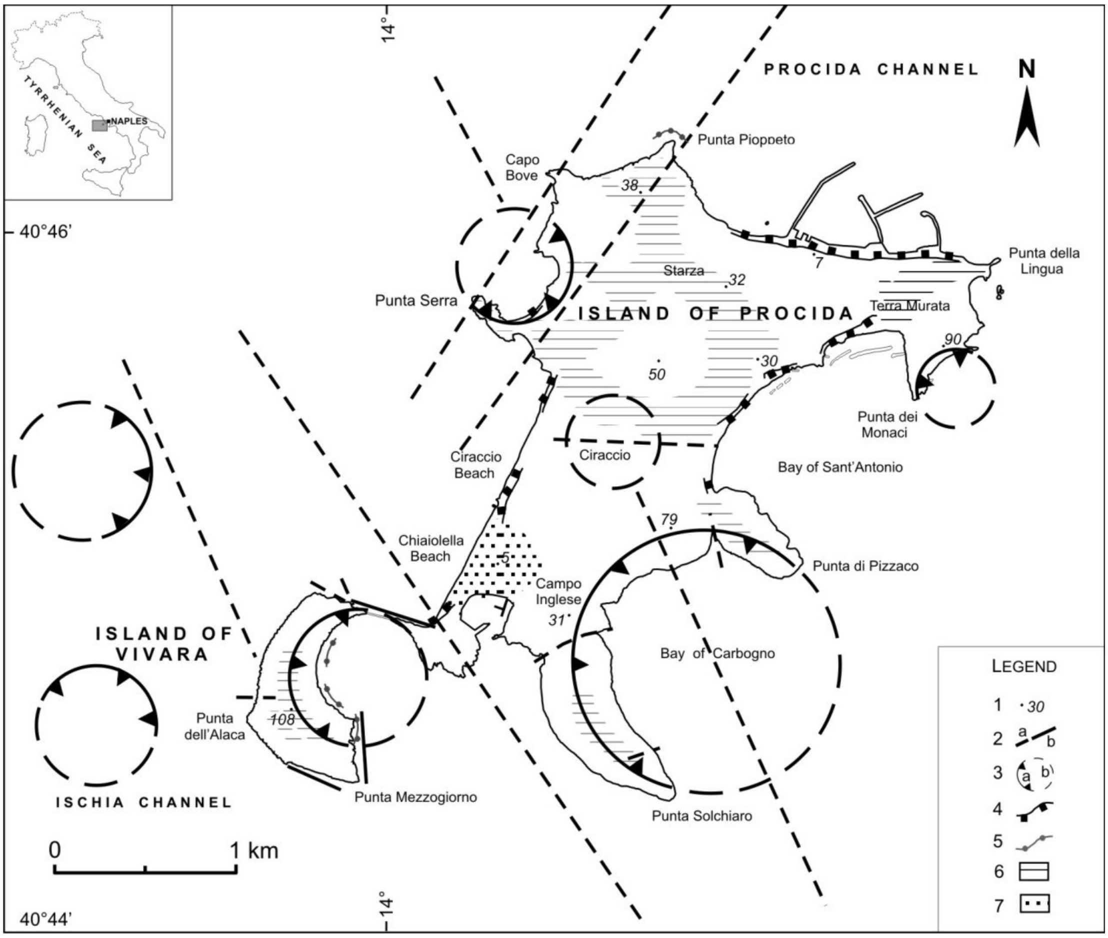


Fig. 1 - Geomorphologic scheme of the insular volcanic system of Procida -Vivara; 1) altitude (m a.s.l.); 2) fault: a) certain, b) buried or presumed; 3) crater rim: a) relic, b) reconstructed or buried; 4) palaeo-cliff; 5) submerged ancient coastline; 6) flattened surface of complex genesis; 7) sandy tombolo.

steep coastal cliff to the northwest of Procida (Cimitero beach; Fig. 2).

MATERIAL AND METHODS

Along the Cimitero beach, two sand levels with backshore and shoreface depositional features crop out at 2.5 and 3 m a.s.l. Ten samples were collected, one (P2) in the higher layer which resulted to be barren, while the nine samples belonging to the lower one (P1, P3-P10) are fossiliferous. Position samples location is reported in Fig. 2.

Samples (each of 200 grams dried weight) were disaggregated using hydrogen peroxide and washed with water through 230 and 120 mesh sieves (63 µm and 125 µm, respectively). Both residues have been observed and all the ostracod and foraminifer specimens were picked from the coarsest fraction (>125 µm) and analysed. Occurrence of remaining taxa has been reported in Tab. 1.

In Tab. 2 foraminifer abundance (number of specimens per 200 g of dried weight) has been reported.

For ostracod analysis (Tab. 3) the minimum number of individuals has been calculated by adding the greater number between right and left adult valves to the number of adult carapaces. The letter j in Tab. 3 indicates the presence of juvenile shells.

All studied specimens are housed in the Aiello Barra Micropalaeontological Collection (A.B.M.C.), at the Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II.

Ostracod and foraminifer species have been identified according to classic and recent literature dealing with Neogene-Recent Mediterranean foraminifers (i.e., Jorissen, 1988; Cimerman & Langer, 1991; Sgarrella & Moncharmont Zei, 1993) and ostracods (i.e., Müller, 1894; Barbeito-Gonzalez, 1971; Bonaduce et al., 1976; Breman, 1976; for extensive references see Aiello & Barra, 2010).

COMPOSITION OF FAUNAL ASSEMBLAGES

The fossiliferous samples yielded bryozoans and bivalve fragments, gastropods, echinoderm spines, siliceous sponge spicules, radiolarians, serpulid tubes, rare specimens of planktic foraminifers [*Globigerina bulloides* d'Orbigny, 1826, *Globigerinoides ruber* (d'Orbigny, 1839), *Globorotalia inflata* (d'Orbigny, 1839)], benthic foraminifers and ostracods (Tabs 1-3). Taxonomy and palaeoecological analysis were performed on the last two groups.

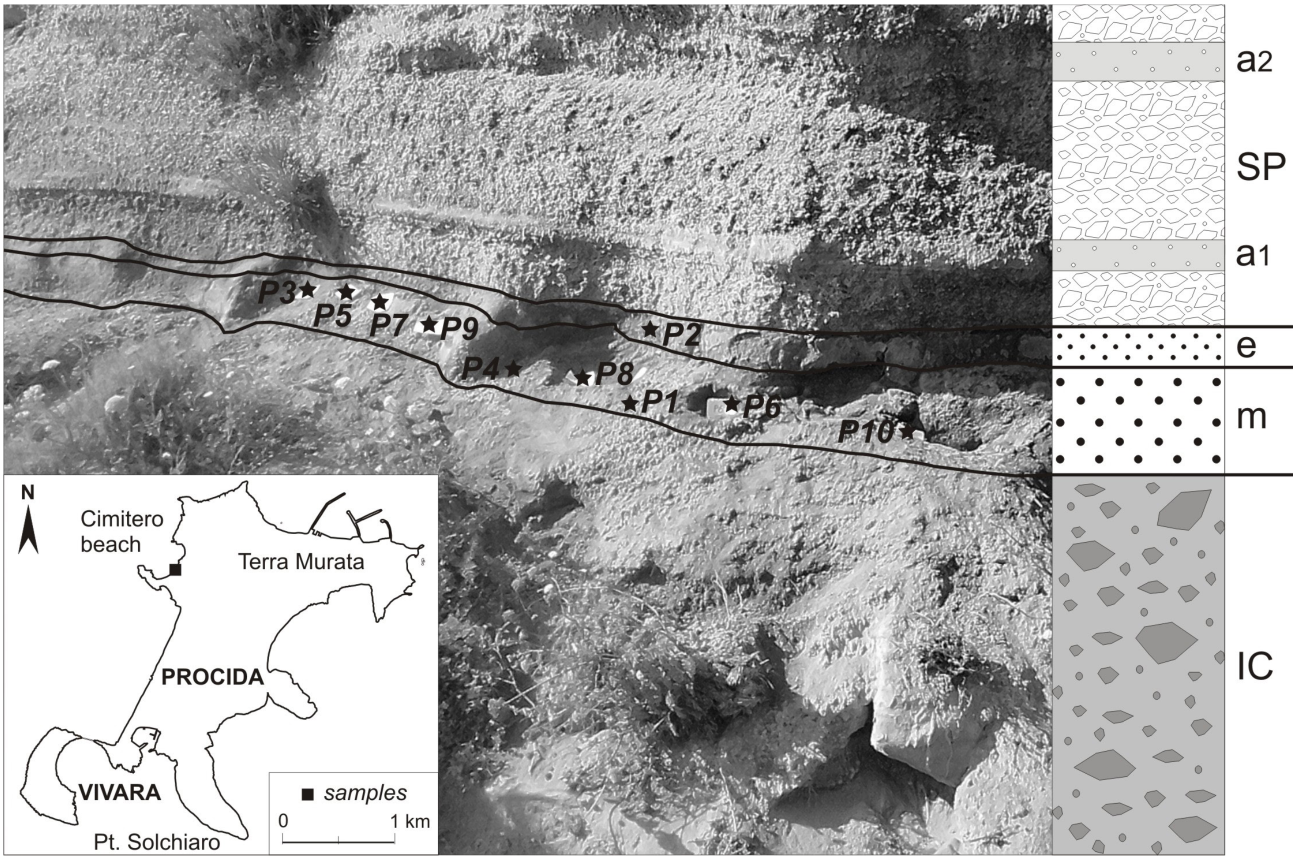


Fig. 2 - Marine and continental deposits sampled between +2.5 and +3 m a.s.l. along the cliff outcrop exposed at Cimitero beach, to the northwest of Procida Island. P1, P3-P10: fossiliferous infralittoral sediments; P2: aeolian reddish sediments; IC: trachytic lava breccias (Breccia Museo Auctt., member of the Campanian Ignimbrite, ~39.000 year b.p.); m: marine deposits, e: aeolian deposits (~39.000÷22.000 years b.p.); SP: Solchiaro tephra (~22.000 year b.p.), a1 and a2: interbedded ash levels with pumices. The samples P1 and P2 have been recovered in 2007, the other eight samples in the 2010 campaign.

In spite of the limited lateral and vertical extension of the outcrop, the assemblages of the nine fossiliferous samples show quite different abundance and diversity values.

Sample P1 yielded the most abundant and diversified assemblage (909 individuals and 33 species of foraminifers; 118 ostracod individuals included in 19 species). The remaining samples are generally poor both in foraminifer and ostracod species. Sample P8 is devoid of ostracod remains (Fig. 3).

Benthic foraminifer assemblages include 46 taxa belonging to 33 genera; species and their abundance are listed in Tab. 2. Specimens are mainly in a poor state of preservation (Pl. 1). Consequently, some taxa (*Bolivina* sp., *Elphidium* sp., *Rosalina* sp.) have been left in open nomenclature.

Assemblages are generally dominated by *Ammonia beccarii* (ranging from 37.5 to 70%) and *Elphidium crispum* (3.33-31.46 %) and secondarily by *Asterigerinata mamilla, Buccella granulata, Cibicidoides pachyderma, Lobatula lobatula*.

The ostracod assemblages consist of 23 taxa referred to 17 genera; the list of species and their abundance are reported in Tab. 3. Ostracod valves, as well as foraminifer tests, are poorly preserved (Pl. 2) and five taxa have been identified only at generic level, i.e., *Bosquetina* sp., *Carinocythereis* sp., *Loxoconcha* sp., *Paracytheridea* sp., and *Pterygocythereis* sp.

The most abundant species are *Pontocythere turbida*, *Cytheridea neapolitana* and *Semicytherura incongruens.*

Abundance and richness are constantly higher in foraminifers than in ostracods, as evidenced in Fig. 3.

DISCUSSION

The recorded microfossil assemblages testify the sedimentation in a marine palaeoenvironment during the first morphoevolutionary phase of the island system. Actually, foraminifer and ostracod species recorded in the fossiliferous samples are marine and presently living in the Mediterranean Sea, except for the euryhaline genus *Cyprideis* recorded in sample P1. The ecological distributions of species and assemblages are well defined in the literature, both for benthic foraminifers (i.e., Blanc-Vernet, 1969; Pujos, 1976; Haake, 1977; Blanc-Vernet et al., 1979; Vénec-Peyré, 1984; Sgarrella & Barra, 1985; Sgarrella et al., 1985; Jorissen, 1987; Sgarrella & Moncharmont Zei, 1993; Donnici & Serandei Barbero, 2002; Aiello et al., 2006; Frezza & Carboni, 2009; Milker et al., 2009) and ostracods (Rome, 1964; Uffenorde, 1972; see Aiello & Barra, 2010 for extensive references).

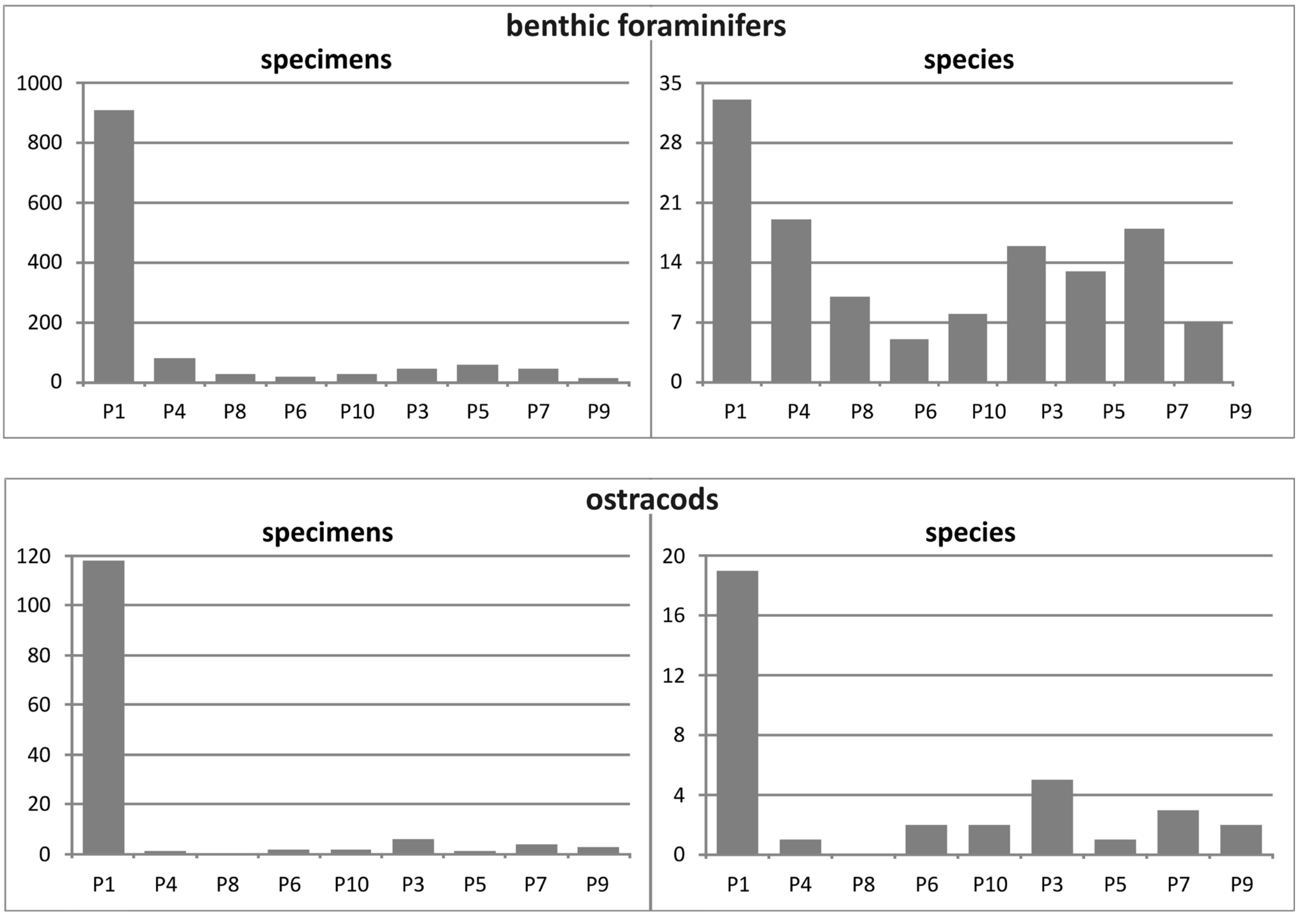


Fig. 3 - Benthic foraminifer and ostracod abundance (specimens/200 g) and simple diversity (number of species).

Depth distribution data allowed us to define three foraminifer and three ostracod groups (Tabs 2-3).

Benthic foraminifers have been separated in: typical "infralittoral" species (i.e., mainly occurring between 0-30 m of depth: group a); "upper circalittoral" species (i.e., present or more abundant below 30 m of depth: group b); non-significant taxa (eurybathic and undetermined species: group c).

EXPLANATION OF PLATE 1

Benthic foraminifers; sample P1, Cimitero beach outcrop, Late Pleistocene. Scale bar corresponds to 100 µm.

Fig. 1 - *Bulimina elongata* d'Orbigny, 1846, side view.

Fig. 2 - *Elphidium maioricense* Colom, 1942, side view.

Fig. 3 - *Elphidium crispum* (Linnaeus, 1758), side view.

Fig. 4 - *Lobatula lobatula* (Walker & Jacob, 1798), umbilical side.

Fig. 5 - *Asterigerinata mamilla* (Williamson, 1858), spiral side.

Fig. 6 - *Bulimina marginata* d'Orbigny, 1826, side view.

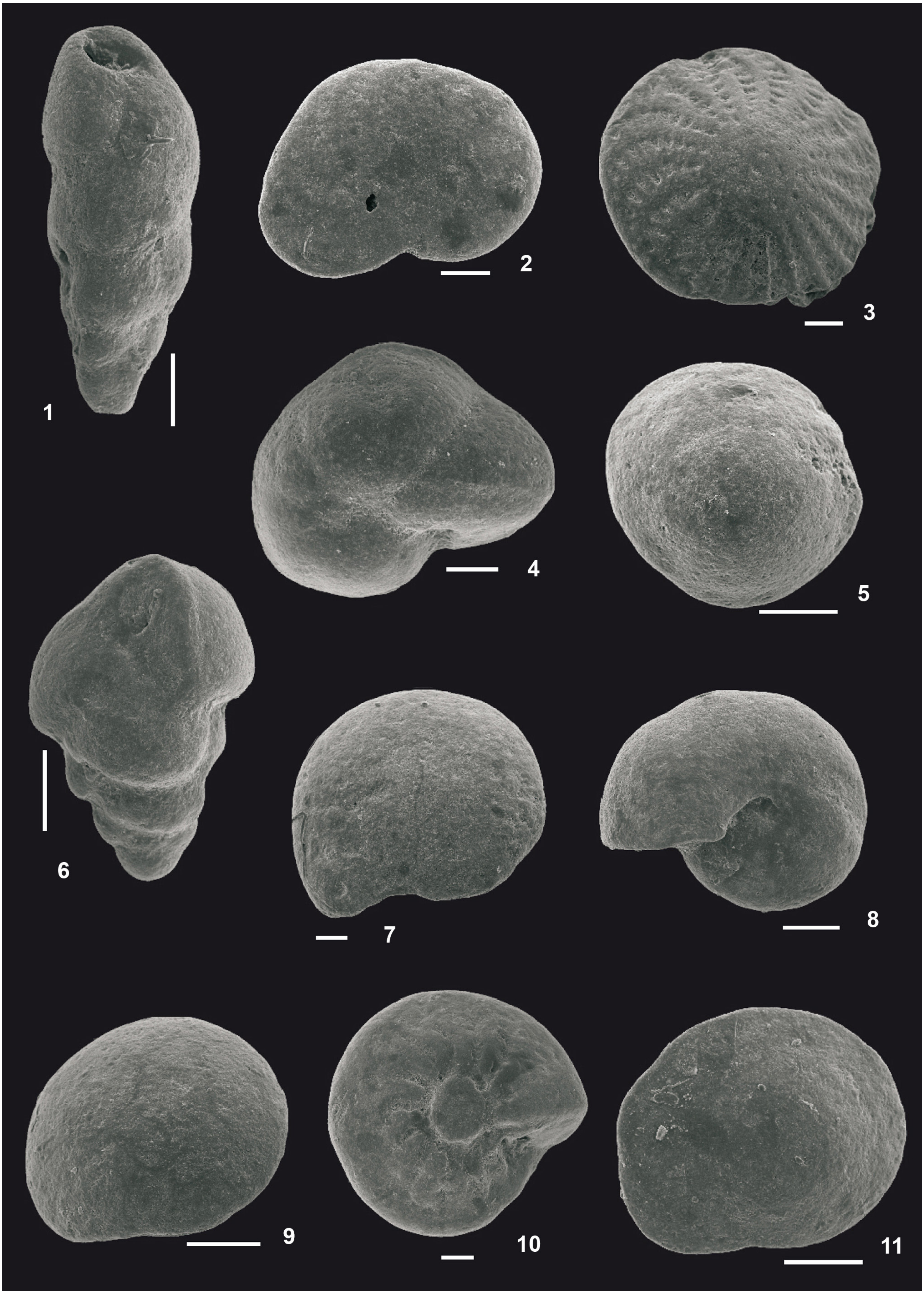
Fig. 7 - *Buccella granulata* (Di Napoli Alliata, 1952), spiral side.

Fig. 8 - *Melonis barleanum* (Williamson, 1858), side view.

Fig. 9 - *Ammonia beccarii* (Linnaeus, 1758), spiral side.

Fig. 10 - *Ammonia beccarii* (Linnaeus, 1758), umbilical side.

Fig. 11 - *Cibicidoides pachyderma* (Rzehak, 1886), spiral view.


1
2
3
4
5
6
7
8
9
10
11

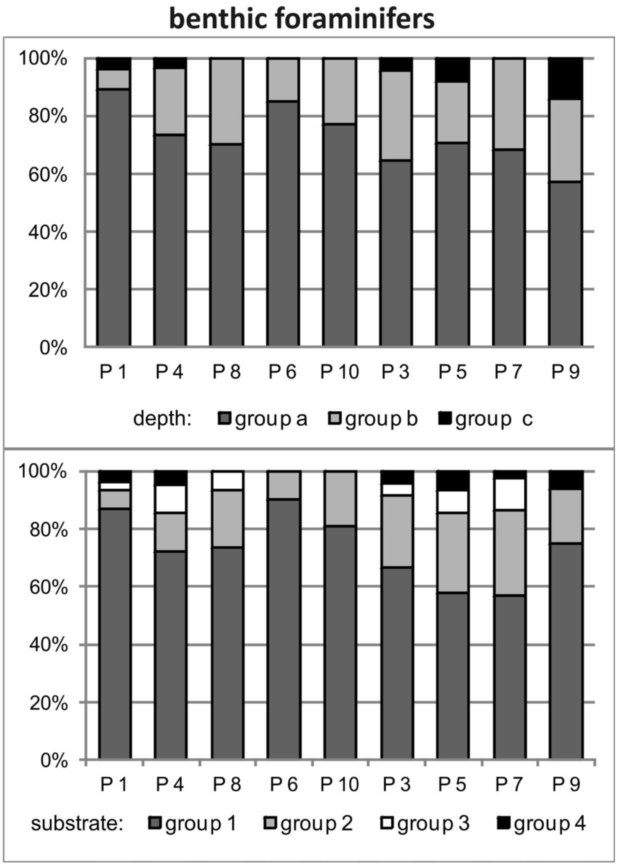


Fig. 4 - Percentages of benthic foraminifer ecological groups defined by means of depth and type of bottom distribution. Group a: typical infralittoral species. Group b: upper circalittoral species. Group c: non-significant taxa. Group 1: species linked to sand and fine sand substrates. Group 2: species linked to mud and sandy mud substrates. Group 3: phytophil species. Group 4: non-significant taxa (see text for details).

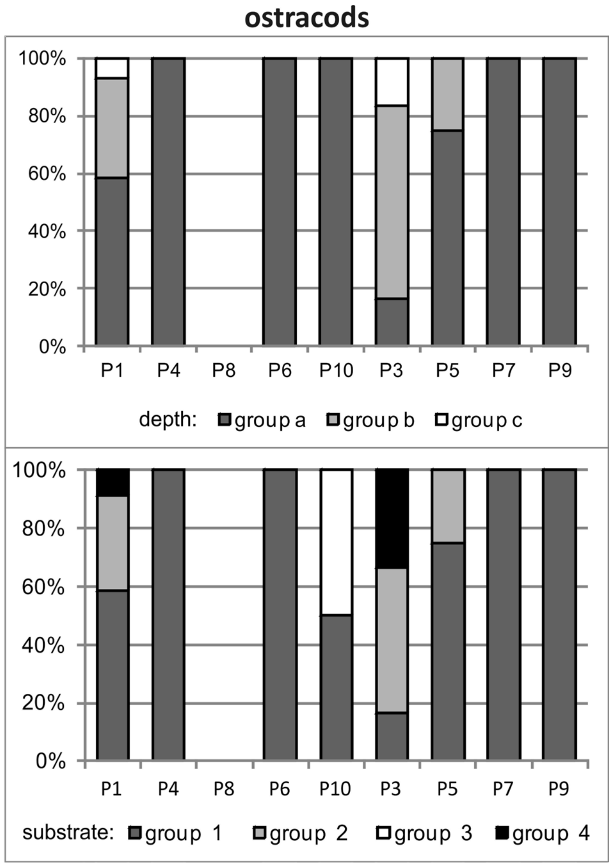


Fig. 5 - Percentages of ostracod ecological groups defined by means of depth and substrate distribution. Group a: upper infralittoral species. Group b: lower infralittoral - upper circalittoral species. Group c: non-significant taxa. Group 1: species linked to sand and fine sand substrates. Group 2: species linked to mud and sandy mud substrates. Group 3: phytophil species. Group 4: non-significant taxa (see text for details).

EXPLANATION OF PLATE 2

Ostracods; sample P1, Cimitero beach outcrop, Late Pleistocene. Scale bar corresponds to 100 µm.

Fig. 1 - *Cytheridea neapolitana* Kollmann, 1960, lateral exterior view of left valve.

Fig. 2 - *Cytheridea neapolitana* Kollmann, 1960, lateral exterior view of right valve.

Fig. 3 - *Semicytherura sulcata* (G.W. Müller, 1894), lateral exterior view of left valve.

Fig. 4 - *Semicytherura incongruens* (G.W. Müller, 1894), lateral exterior view of right valve.

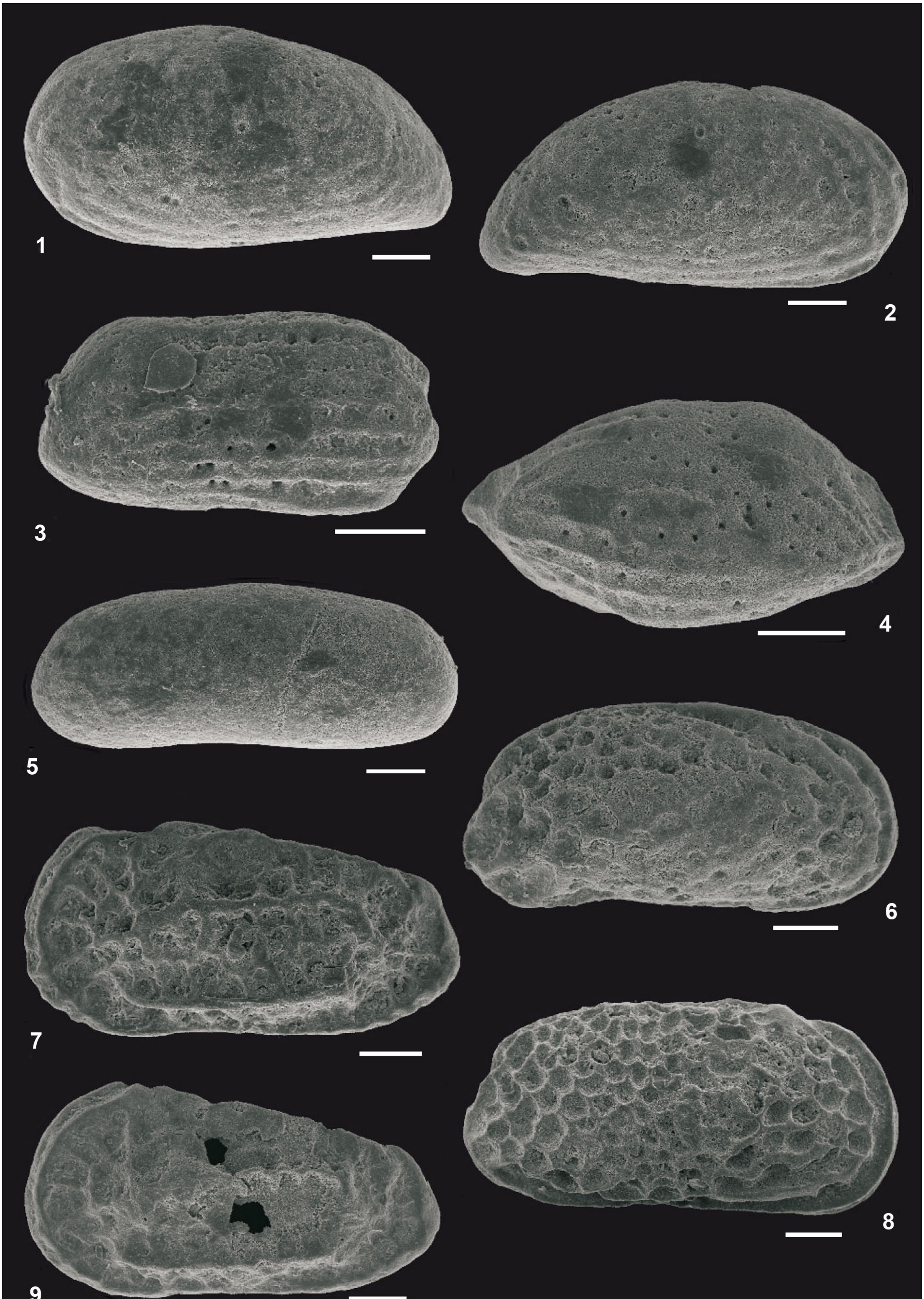
Fig. 5 - *Pontocythere turbida* (G.W. Müller, 1894), lateral exterior view of left valve.

Fig. 6 - *Urocythereis schulzi* (Hartmann, 1958), lateral exterior view of right valve.

Fig. 7 - *Costa edwardsi* (Roemer, 1838), lateral exterior view of left valve.

Fig. 8 - *Urocythereis margaritifera alba* Uliczny, 1969, lateral exterior view of right valve.

Fig. 9 - *Costa edwardsi* (Roemer, 1838), lateral exterior view of left valve.


1
2
3
4
5
6
7
8
9

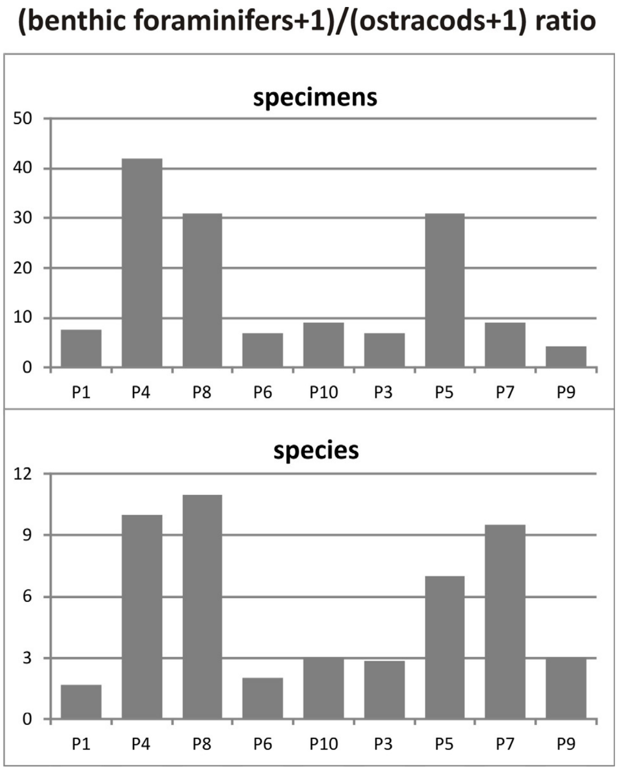


Fig. 6 - Foraminifers/ostracods ratio. The specimens ratio equals the number of benthic foraminifer specimens + 1 divided by the minimum number of ostracod individuals + 1. The species ratio equals the number of benthic foraminifer species +1 divided by the number of ostracod species +1.

The ostracod groups are the following: "upper infralittoral" species (mainly living in the range of depth 0-20 m: group a); "lower infralittoral - upper circalittoral" species (present or more abundant below 20 m in depth: group b); non-significant taxa (non-marine and undetermined species: group c).

Four groups of foraminifer and ostracod species were defined, taking into account their substrate distribution data. They are: species linked to sand and fine sand substrates (group 1); species linked to mud and sandy mud substrates (group 2); species linked to substrates with vegetation covers (group 3); non-significant taxa (ubiquitarian, non marine, undetermined species; group 4).

Number of species and frequency of the above defined groups are summarized in Figs 4-5.

As previously stated, assemblage abundance and diversity show remarkable differences in different samples. Due to the small sampling distances and to the faunal composition, we consider that the wide diversity and abundance range, as well as the wide range in foraminifers/ostracods ratio (Fig. 6), is due to taphonomic processes rather than the consequence of different palaeoenvironmental conditions.

The structure of the foraminiferal assemblages, dominated by *Ammonia beccarii* and *Elphidium crispum,* species typical of the Mediterranean infralittoral sandy bottoms, but characterized also by taxa such as Anomalinidae, Bolivinidae, Buliminidae, *Cassidulina carinata*, fits well with the description of the biocoenoses recorded by Blanc-Vernet (1969) on coastal detritic bottoms ("Détritique Côtier" in Pérès & Picard, 1964).

Pontocythere turbida, *Cytheridea neapolitana* and *Semicytherura incongruens* dominate the ostracod assemblages; this dominance, together with the presence of taxa such as *Bosquetina dentata*, *Costa edwardsi*, *Cytherella vulgatella*, *Buntonia sublatissima* and *Microcytherura* (*Tetracytherura*) *angulosa,* suggests a shallow neritic palaeoenvironment (intermediate infralittoral environment sensu Breman, 1976).

On comparing the available depth data for the Mediterranean Sea (Puri et al., 1964; Ascoli, 1965; Bonaduce et al., 1976; Breman, 1976; Lachenal, 1989), the composition of the ostracod assemblages allows a palaeodepth estimation of -60/-30 m (most probably about -40 m) on a muddy-sand substrate.

It cannot be excluded that some foraminifer as well as ostracod specimens were displaced from shallower waters, hence the not-dominant "deeper" taxa (i.e., group b, Figs 4-5) are highly significant for a palaeobathymetric reconstruction.

To clarify palaeobathymetric interpretation, the depth data of the foraminifer and ostracod species occurring in the Cimitero beach outcrop, reported in the above mentioned literature, have been summarized in Figs 7-8. Thick lines indicate the optimum depth range of the species. Thin lines show the depth of rare occurrence of the species.

The apparent discrepancy between the ostracod and foraminifer palaeobathymetric interpretation is merely terminological. The "Intermediate infralittoral assemblages" consist of biofacies defined by Breman (1976) on Adriatic Recent ostracods ranging from 20 to 60 m b.s.l. On the other hand, the coastal detritic bottoms recognized by Blanc-Vernet (1969) in the North-western Mediterranean from 55 to 69 m b.s.l. and in the Aegean Sea - Eastern Mediterranean from 35 to 75 m, have been included in the upper part of the circalittoral zone. Pérès (1982) considered the infralittoral/circalittoral limit in Mediterranean waters at about "35 m in the Western Mediterranean and a little deeper still in the Eastern Basin", consequently the "intermediate infralittoral" of Breman (1976) comprises both infralittoral and circalittoral assemblages. Pérès' (1982) zonation does not represent a standard in marine ecology and its general concepts and terminology have been criticized by Golikov (1985). For the continental shelf Golikov (1985) considers more appropriate, following the principle of priority, an integration of the terms introduced by Forbes & Hanley (1853) with those used by Golikov (1980). In the Golikov's (1985) scheme the bathymetrical range from 25-27 to 55-70 m b.s.l. is comprised in the median (or coralline) zone, under the influence of the "lower layer of surface water masses". Nonetheless, the terminology of the French authors remains widely accepted, consequently we prefer to assign the studied assemblages to the transitional zone between infralittoral and circalittoral sensu Pérès (1982).

Preservation and palaeoenvironment

As stated above, both ostracods and foraminifers are in poor state of preservation. Several chambers are missing and scattered holes are present. Both ostracods and foraminifers appear abraded or corroded. In the studied

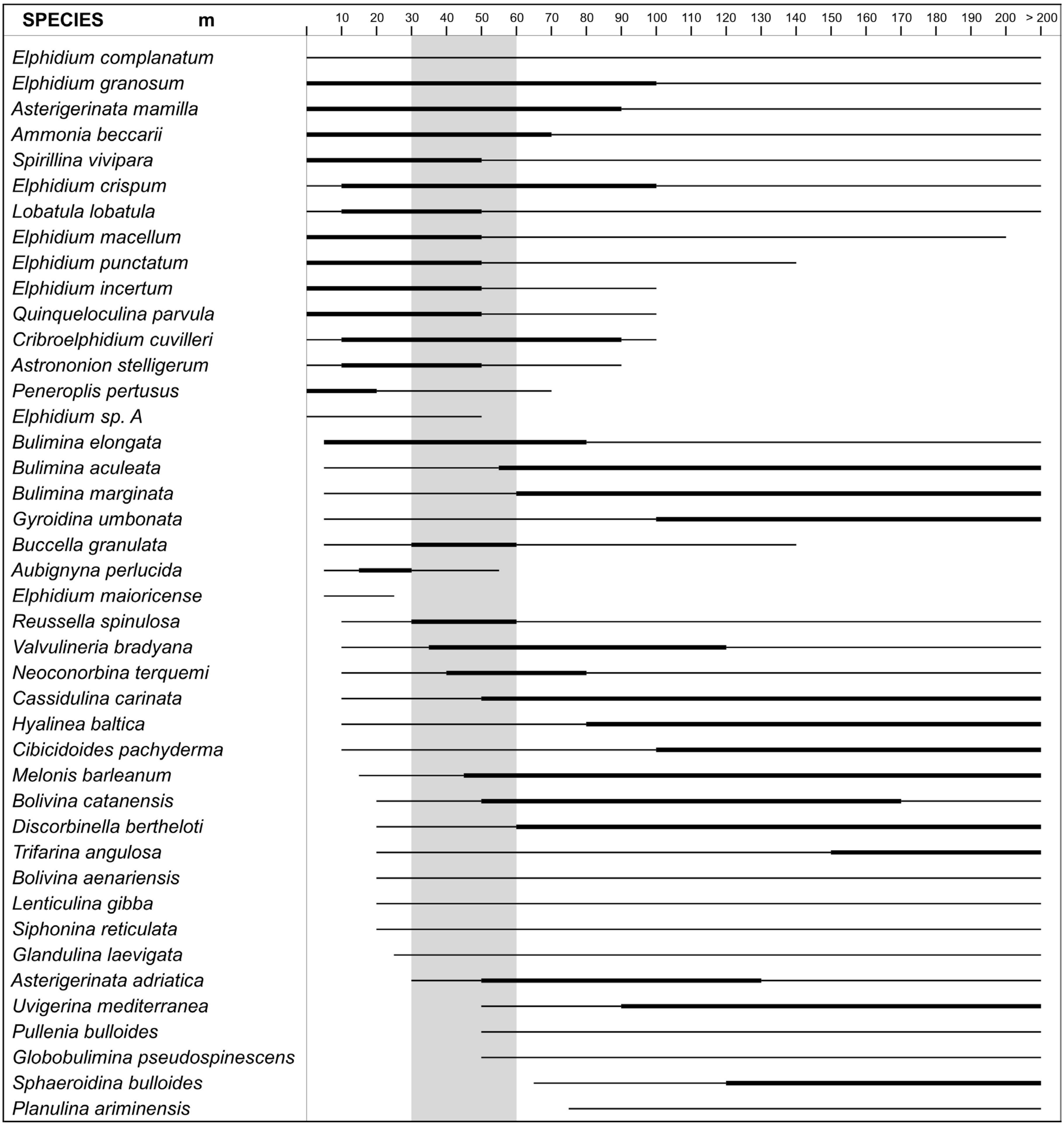


Fig. 7 - Foraminifer depth distribution data based on literature. In grey, estimated palaeobathymetry of the Cimitero beach outcrop sediments. Thick lines indicate the optimum depth range of the species. Thin lines show the rare occurrence depth of the species.

assemblages corrasion (sensu Zuschin et al., 2003, and literature therein) depends on physical fragmentation and transport-induced abrasion due to waves and currents, and chemical dissolution. Commonly ostracod shells are, in comparison with foraminifer tests, delicate and very sensitive to transport and destructive biostratinomic processes. Shell strength and toughness (Zuschin et al., 2003) are generally higher in foraminifers, and the dead assemblages recorded in high energy environments show very low ostracod/foraminifer abundance ratio (Aiello et al., 2006; Aiello & Barra, unpublished data). Some foraminifer species as *Ammonia beccarii* and *Elphidium crispum*, being partly displaced from the upper infralittoral zone, are possibly overrepresented, while ostracod assemblages seem to lack transported valves. Thin-shelled genera, commonly recorded in the intermediate infralittoral zone, are not present. The observation of valves and test indicates that carbonate dissolution has been one of the most important post-mortem process, which affected the calcareous microfossils. In some specimens the fossae are holed (Fig. 9), testifying that chemical action of acidic waters concentrated on lowered elements of the shell ornament. Conversely, transport-induced abrasion would act on ostracod valves smoothening the elements in relief

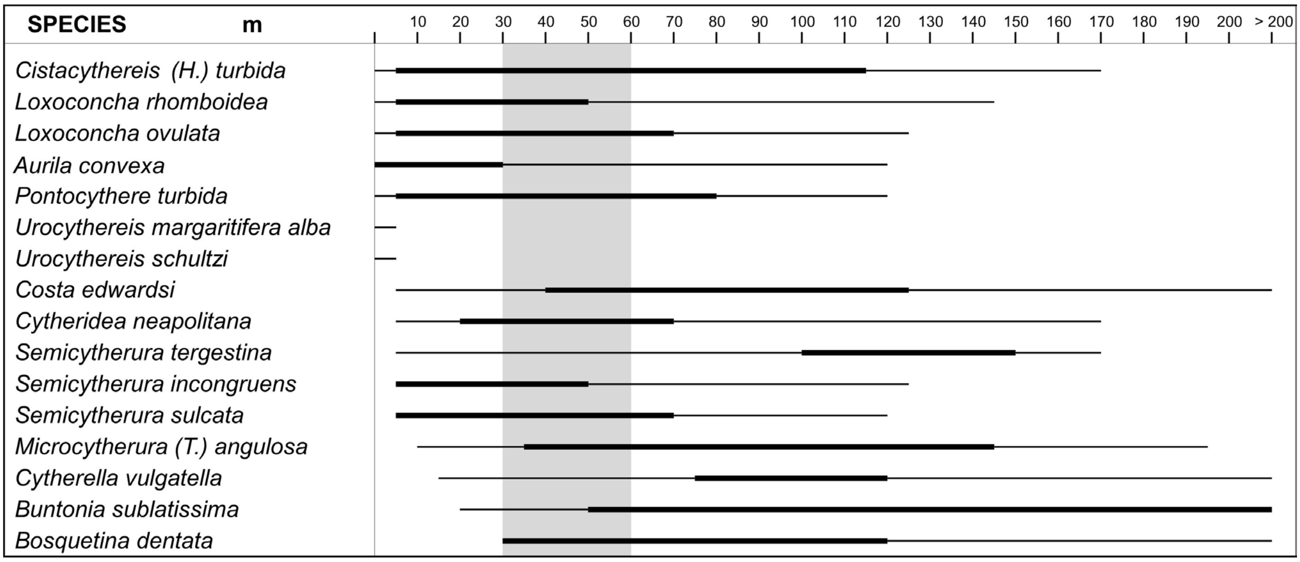


Fig. 8 - Ostracod depth distribution data based on literature. In grey, estimated palaeobathymetry of the Cimitero beach outcrop sediments. Thick lines indicate the optimum depth range of the species. Thin lines show the rare occurrence depth of the species.

(carinae, muri). This is supported also by the presence of well-preserved siliceous sponge spicules: they are neither abraded by transport, nor corroded, due to their siliceous nature.

Furthermore, miliolids are absent except one specimen of *Quinqueloculina parvula* recovered in sample P9. This group of benthic foraminifers seems to prefer waters strongly supersaturated in calcium carbonate (Jorissen, 1988) and are susceptible to dissolution processes (Douglas, 1973; Douglas & Woodruff, 1981).

Partial or complete dissolution of calcareous microfossils frequently occurs in sediments linked to volcanic activities. Ash falls, erosion of volcanic soils and especially volcanic carbon dioxide vents in shallow waters (Di Girolamo & Rolandi, 1975; Di Girolamo et al., 1984; Rosi & Sbrana, 1987; Rosi et al., 1988; Melluso et al., 1995; Kerrison et al., 2011) may lower pH and the calcite saturation index with remarkable effects on both living and dead specimens of marine taxa (Oki & Hayasaka, 1978; Finger & Lipps, 1981; Bodergat et al., 2002a, b; Hall-Spencer et al., 2008; Martin et al., 2008; Cigliano et al., 2010; Dias et al., 2010; Kroeker et al., 2011; Lombardi et al., 2011).

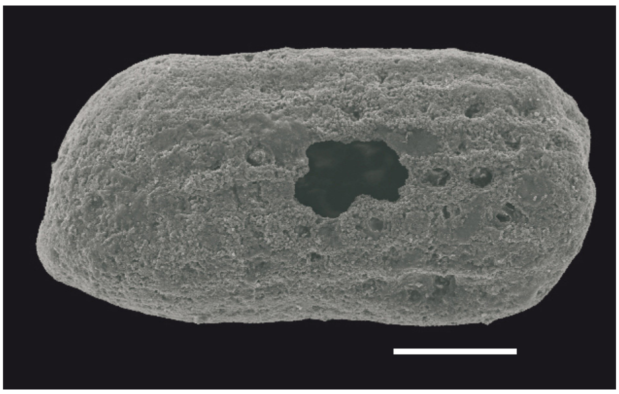


Fig. 9 - *Semicytherura sulcata* (G.W. Müller, 1894), left valve showing chemical dissolution; x 148, sample P1. Scale bar corresponds to 100 µm.

CONCLUSION

The finding of a marine Upper Pleistocene fossiliferous sandy level represented a noticeable contribution to the reconstruction of the evolution of the island volcanic system of Procida-Vivara. Analysis of calcareous microfossil assemblages demonstrates that sedimentation occurred in the uppermost part of the circalittoral zone. Species diversity and abundance vary significantly in samples collected at distances of few decimetres. Differences indicate an unusual high variability in taphonomic conditions linked to synsedimentary or postsedimentary bottom/pore water chemical composition, influenced by volcanic submarine activities.

ACKNOWLEDGMENTS

The authors thank Dr Roberto de' Gennaro (Cisag, Università degli Studi di Napoli Federico II) who carried out SEM micrographs and Dr Roberta Parisi who kindly provided technical support. Prof. Elsa Gliozzi (Università degli Studi Roma Tre) and Dr Maria Rose Petrizzo (Università degli Studi di Milano) are kindly acknowledged for their appropriate remarks that greatly ameliorated the original version of the manuscript.

REFERENCES

Aiello G. & Barra D. (2010). Crustacea, Ostracoda. *Biologia Marina Mediterranea*, 17 (suppl. 1): 401-419.

Aiello G., Barra D., Coppa M.G., Valente A. & Zeni F. (2006). Recent infralittoral Foraminiferida and Ostracoda from the Porto Cesareo Lagoon (Ionian Sea, Mediterranean). *Bollettino della Società Paleontologica Italiana*, 45 (1): 1-14.

Aiello G., Barra D., De Pippo T., Donadio C. & Petrosino C. (2007). Geomorphological evolution of Phlegrean volcanic islands near Naples, southern Italy. *Zeitschrift für Geomorphologie N. F.*, 51 (2): 165-190.

Alessio M., Bella F., Improta S., Belluomini G., Calderoni G., Cortes C. & Turi B. (1976). University of Rome Carbon-14 dates XIV. *Radiocarbon*, 18: 321-349.

Ascoli P. (1965). Crociera talassografica adriatica 1955, 6: ricerche ecologiche sugli ostracodi contenuti in 16 carote prelevate sul fondo del Mare Adriatico. *Archivio di Oceanografia e Limnologia*, 14 (1): 69-138.

Barbeito-Gonzalez P.J. (1971). Die Ostracoden des Küstenbereiches von Naxos (Griechenland) und ihre Lebensbereiche. *Mitteilungen aus dem hamburgischen zoologischen Museum und Institut*, 67: 255-326.

Blanc-Vernet L. (1969). Contribution à l'étude des foraminifères de Méditerranéee. Relations entre la microfaune et les sédiments; biocoenoses actuelles, thanatocoenoses Pliocènes et Quaternaires. *Recueil des travaux de la Station Marine d'Endoume*, 64: 1-281.

Blanc-Vernet L., Clairefond P. & Orsolini P. (1979). Les foraminifères. *In* Burollet P.F., Clairefond P. & Winnock E. (eds), La mer Pélagienne. *Géologie Méditerranée*, 6 (1): 171-209.

Bodergat A.-M., Ishizaki K., Oki K. & Rio M. (2002a). Currents, civilization, or volcanism? Ostracodes as sentinels in a patchy environment: Kagoshima Bay, Japan. *Micropaleontology*, 48 (3): 285-299.

Bodergat A.-M., Oki K., Ishizaki K. & Rio M. (2002b). Impact of volcanism, human activities, and water mass circulation on the distribution of ostracod populations in Kagoshima Bay (Kyushu Island, southern Japan). *Comptes Rendus Geoscience*, 334 (14): 1053-1059.

Bonaduce G., Ciampo G. & Masoli M. (1976). Distribution of Ostracoda in the Adriatic Sea. *Pubblicazioni della Stazione Zoologica di Napoli*, 40, suppl.1: 1-304.

Breman E. (1976). The distribution of ostracodes in the bottom sediments of the Adriatic Sea. *Academisch Proefschrift*. 165 pp. Vrije Universiteit te Amsterdam, Amsterdam.

Cigliano M., Gambi M.C., Rodolfo-Metalpa R., Patti F.P. & Hall-Spencer J.M. (2010). Effects of ocean acidification on invertebrate settlement at volcanic CO_2 vents. *Marine Biology*, 157: 2489-2502.

Cimerman F. & Langer M.R. (1991). Mediterranean Foraminifera. *Academia Scientiarum et Artium Slovenica*, 30: 1-118.

Colom G. (1942). Una contribución del conocimiento de los Foraminíferos de la bahia de Palma de Mallorca. *Notas y Resúmenes del Instituto Español de Oceanografia*, ser. II, 108: 1-53.

de Alteriis G., Insinga D.D., Morabito S., Morra V., Chiocci F.L., Terrasi F., Lubritto C., Di Benedetto C. & Pazzanese M. (2010). Age of submarine debris avalanches and tephrostratigraphy offshore Ischia Island, Tyrrhenian Sea, Italy. *Marine Geology*, 278: 1-18.

De Astis G., Pappalardo L. & Piochi M. (2004). Procida volcanic history: new insights into the evolution of the Phlegraean Volcanic District (Campania region, Italy). *Bulletin of Volcanology*, 66: 622-641.

De Vivo B., Rolandi G., Gans P.B., Calvert A., Bohrson W.A., Spera F.J. & Belkin H.E. (2001). New constraints on the pyroclastic eruptive history of the Campanian volcanic Plain (Italy). *Mineralogy and Petrology*, 73: 47-65.

Dias B.B., Hart M.B., Smart C.V. & Hall-Spencer J.M. (2010). Modern seawater acidification: the response of foraminifera to high-CO_2 conditions in the Mediterranean Sea. *Journal of the Geological Society*, 167: 843-846.

Di Girolamo P., Ghiara M.R., Lirer L., Munno R., Rolandi G. & Stanzione D. (1984). Vulcanologia e petrologia dei Campi Flegrei. *Bollettino della Società Geologica Italiana*, 103: 349-413.

Di Girolamo P. & Rolandi G. (1975). Vulcanismo sottomarino latitebasaltico-latitico (serie potassica) nel Canale d'Ischia (Campania). *Rendiconto dell'Accademia delle Scienze Fisiche e Matematiche, Napoli*, 42: 561-596.

Di Napoli Alliata E. (1952). Nuove specie di foraminiferi nel Pliocene e nel Pleistocene della zona di Castell'Arquato (Piacenza). *Rivista Italiana di Paleontologia e Stratigrafia*, 58 (3): 95-110.

Donnici S. & Serandei Barbero R. (2002). The benthic foraminiferal communities of the northern Adriatic continental shelf. *Marine Micropaleontology*, 44: 93-123.

d'Orbigny A. (1826). Tableau méthodique de la classe des Céphalopodes. *Annales des Sciences Naturelles*, 7: 96-314.

d'Orbigny A. (1839). Foraminifères. *In* Ramon de la Sagra (ed.), Histoire physique, politique et naturelle de l'Ile de Cuba. 224 pp. A. Bertrand, Paris.

d'Orbigny A. (1846). Foraminifères fossils du bassin Tertiaire de Vienne (Autriche). 303 pp. Gide et Comp., Paris.

Douglas R.G. (1973). Benthonic foraminiferal biostratigraphy in the Central North Pacific, Leg. 17, Deep Sea Drilling Project. *Deep Sea Drilling Project Initial Reports*, 17: 607-671.

Douglas R.G. & Woodruff F.C. (1981). Deep sea benthic foraminifera. *In* Emiliani C. (ed.), The Oceanic Lithosphere. *The Sea*, 7: 1233-1327.

Finger K.L. & Lipps J.H. (1981). Foraminiferal decimation and repopulation in an active volcanic caldera, Deception Island, Antarctica. *Micropaleontology*, 27 (2): 111-139.

Forbes E. & Hanley S. (1853). A history of the British Mollusca and their shells, 1-4. Van Voorst, London.

Frezza V. & Carboni M.G. (2009). Distribution of recent foraminiferal assemblages near the Ombrone River mouth (Northern Tyrrhenian Sea, Italy). *Revue de micropaleontologie*, 52: 43-66.

Golikov A.N. (1980). Molluscs Buccinidae of the World Ocean. *In* Fauna of USSR, Molluscs, 5 (2). New Series, 121. 508 pp. Nauka, Leningrad.

Golikov A.N. (1985). Zonation and organismic assemblages: comments on the comprehensive review by Peres (1982). *Marine Ecology,* Progress Series, 23: 203-206.

Haake F.W. (1977). Living benthic Foraminifera in the Adriatic sea: influence of water depth and sediment. *Journal of Foraminiferal Research,* 7 (1): 62-75.

Hall-Spencer J.M., Rodolfo-Metalpa R., Martin S., Ransome E., Fine M., Turner S.M., Rowley S.J., Tedesco D. & Buia M.C. (2008). Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. *Nature*, 454: 96-99.

Hartmann G. (1958). Ostracoden von der Französischen Mittelmeerküste. *Kieler Meeresforschungen*, 14 (2): 226-232.

Jorissen F.J. (1987). The Distribution of Benthic Foraminifera in the Adriatic Sea. *Marine Micropaleontology*, 12: 21-48.

Jorissen F.J. (1988). Benthic foraminifera from the Adriatic Sea; Principles of phenotypic variation. *Utrecht Micropaleontological Bulletins*, 37. 176 pp., Utrecht.

Kerrison P., Hall-Spencer J.M., Suggett D.J., Hepburn L.J. & Steinke M. (2011). Assessment of pH variability at a coastal CO_2 vent for ocean acidification studies. *Estuarine, Coastal and Shelf Science*, 94 (2): 129-137.

Kollmann K. (1960). Cytherideinae und Schulerideinae n. subfam. (Ostracoda) aus dem Neogen des Oestlichen Oesterreich. *Mitteilungen der Geologischen Gesellschaft in Wien*, 51 (4): 89-195.

Kroeker K.J., Micheli F., Gambi M.C. & Martz T.R. (2011). Divergent ecosystem responses within a benthic marine community to ocean acidification. *PNAS*, 108: 14515-14520.

Lachenal A.M. (1989). Écologie des ostracodes du domaine méditerranéen: application au Golfe de Gabès (Tunisie orientale). Les variations du niveau marin depuis 30000 ans. *Documents des Laboratoires de Géologie de Lyon*, 108. 239 pp. Lyon.

Linnaeus C. (1758). Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. 1, ed. 10. 824 pp. Salvius, Holmiae.

Lombardi C., Gambi M.C., Vasapollo C., Taylor P. & Cocito S. (2011). Skeletal alterations and polymorphism in a Mediterranean bryozoan at natural CO_2 vents. *Zoomorphology*, 130: 135-145.

Martin S., Rodolfo Metalpa R., Ransome E., Rowley S., Buia M.C., Gattuso J.P. & Hall Spencer J. (2008). Effects of naturally acidified seawater on seagrass calcareous epibionts. *Biology Letters*, 4: 689-692.

Melluso L., Morra V., Perrotta A., Scarpati C. & Adabbo M. (1995). The eruption of the Breccia Museo (Campi Flegrei, Italy):

fractional crystallization processes in a shallow, zoned magma chamber and implication for the eruptive dynamics. *Journal of Volcanology and Geothermal Research*, 68: 325-339.

Milker Y., Schmiedl G., Betzler C., Römer M., Jaramillo-Vogel D. & Siccha M. (2009). Distribution of recent benthic foraminifera in shelf carbonate environments of the Western Mediterranean Sea. *Marine Micropaleontology*, 73: 207-225.

Müller G.W. (1894). Die Ostracoden des Golfes von Neapel und der angrenzenden Meeres-Abschnitte. *Fauna und Flora des Golfes von Neapel und der angrenzenden Meeres-Abschnitte, Herausgegeben von der Zoologischen Station zu Neapel*, 21 (1-8): 1-404.

Oki K. & Hayasaka S. (1978). Geological Study of Kagoshima Bay, South Kyushu, Japan. Part IV - A note on the peculiar mode of occurrence of foraminifers in the bottom sediments of the bay-head area. *Reports of the Faculty of Science. Kagoshima University*, *Earth Science Biology*, 11: 1-11.

Pérès J.M. (1982). Major Benthic Assemblages, 8. *In* Kinne O. (ed.), Marine Ecology, A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters. John Wiley & Sons, Ltd., 5 (1): 373-522.

Pérès J.M. & Picard J. (1964). Nouveau manuel de bionomie benthique de la Mer Méditerranée. *Recueil des travaux de la Station Marine d'Endoume*, *Faculté des Sciences de Marseille*, 31 (47): 1-137.

Pujos M. (1976). Écologie des foraminiféres benthiques et des thecamoebiens de la Gironde et du plateau continental sud-Gascongne. Aplication la connaissance du Quaternaire terminal de la région ouest-Gironde. Thése de Doctorat d'Etat. *Memoires de l'Institut de Geologie du Bassin d'Aquitaine*, 8. 274 pp. Talence.

Puri H.S., Bonaduce G. & Malloy J. (1964). Ecology of the Gulf of Naples. *Pubblicazioni della Stazione Zoologica di Napoli*, 33, suppl.: 88-199.

Roemer F.A. (1838). Die Cytherinen des Molasse-Gebirges. *Neues Jahrbuch fuer Mineralogie, Geognosie, Geologie und Petrefaktenkunde*, 5: 514-519.

Rome D.R. (1964). Ostracodes des environs de Monaco, leur distribution en profondeur, nature des fonds marins explorés. *In* Ostracods as ecological and palaeoecological indicators. Simposio internazionale sotto gli auspici della Fondazione Antonio e Rinaldo Dohrn presso la Stazione Zoologica di Napoli, 10-19 Giugno 1963. *Pubblicazioni della Stazione Zoologica di Napoli*, 33, suppl.: 200-212.

Rosi M. & Sbrana A. (1987). Phlegrean Fields. *Quaderni de «La Ricerca Scientifica». Progetto Finalizzato Geodinamica, Monogr. Fin., CNR*, 144 (9). 168 pp. Roma.

Rosi M., Sbrana A. & Vezzoli L. (1988). Tephrostratigraphy of Ischia, Procida and Campi Flegrei volcanic products. *Memorie della Società Geologica Italiana*, 41: 1015-1027.

Rzehak A. (1886). Die Foraminiferenfauna der Neogenformation der Umgebung von Mähr.-Ostrau. *Verhandlungen des Naturforschenden Vereins in Brünn (Brno)*, 24: 77-126.

Sgarrella F. & Barra D. (1985). Distribuzione dei Foraminiferi bentonici nel Golfo di Salerno (Basso Tirreno, Italia). *Bollettino della Società dei Naturalisti in Napoli*, 93 (1984): 1-58.

Sgarrella F., Barra D. & Improta A. (1985). The benthic foraminifers of the Gulf of Policastro (Southern Tyrrhenian Sea, Italy). *Bollettino della Società dei Naturalisti in Napoli*, 92 (1983): 67-114.

Sgarrella F. & Moncharmont Zei M. (1993). Benthic Foraminifera of the Gulf of Naples (Italy): systematics and autoecology. *Bollettino della Società Paleontologica Italiana*, 32 (2): 145-264.

Uffenorde H. (1972). Oekologie und jahreszeitliche Verteilung rezenter bentonischer Ostracoden des Limski kanal bei Rovinj (nördliche Adria). *Göttinger Arbeiten zur Geologie und Paläontologie*, 13: 1-121.

Uliczny F. (1969). Hemicytheridae un Trachyleberididae (Ostracoda) aus dem Pliozän der insel Kephallinia (Westgriechenland). Dissertation. 152 pp. Universitaet Muenchen, Muenchen.

Vénec-Peyré M.T. (1984). Les Foraminifères et le milieu: Étude de trois écosistèmes. *In* Oertli H.J. (ed.), Benthos '83, ELF Aquitaine: 573-581.

Walker G. & Jacob E. (1798). *In* Kanmacher F. (ed.), Adam's Essays on the Microscope. 2nd ed., Dillon & Keating, London: 642.

Williamson W.C. (1858). On the Recent Foraminifera of Great Britain.107 pp. Ray Society, London.

Zuschin M., Stachowitsch M. & Stanton R.J. (2003). Patterns and processes of shell fragmentation in modern and ancient marine environment. *Earth-Science Reviews*, 63: 33-82.

Manuscript received 1 February 2012
Revised manuscript accepted 01 June 2012
Published online 27 June 2012

Appendix

Tables of the semiquantitative distributions of microfossils and lists of benthic foraminifer and ostracod species.

Samples	P1	P4	P8	P6	P10	P3	P5	P7	P9
planktonic foraminifers									
Globigerina bulloides d'Orbigny, 1826						1			
Globigerinoides ruber (d'Orbigny, 1839)	1	1							1
Globorotalia inflata (d'Orbigny, 1839)	1								
Radiolaria		R	VR	VR	VR	VR	R	VR	
Porifera	R	R	R	R	R	U	U		C
Briozoa					VR		U		
Serpulidae		VR			VR		R	U	
Bivalvia	R	R	R	R	R	U	VR	R	R
Gastropoda	R	R	R	R	R	U	VR	VR	VR
Echinodermata	R				VR				VR

Tab. 1 - Semiquantitative distribution of microfossils remain, except benthic foraminifers and ostracods (VR = very rare, R = rare, U = uncommon, C = common).

SPECIES / Samples	P1	P4	P8	P6	P10	P3	P5	P7	P9	d.g.	s.g.
Ammonia beccarii (Linnaeus, 1758)	420	35	17	14	12	18	25	18	10	a	1
Aubignyna perlucida (Heron-Allen & Earland, 1913)	4	2								a	1
Asterigerinata adriatica Haake, 1977							1			b	2
Asterigerinata mamilla (Williamson, 1858)	45		1			1	2	1	1	a	1
Astrononion stelligerum (d'Orbigny, 1839)						1				b	2
Bolivina aenariensis (Costa, 1856)	1									c	2
Bolivina catanensis Seguenza, 1862	1	1								b	2
Bolivina sp.		1								c	4
Buccella granulata (Di Napoli Alliata, 1952)	18	7	3	1	2	5	2	1		b	1
Bulimina aculeata d'Orbigny, 1826	6		2					1		b	2
Bulimina elongata d'Orbigny, 1846	11						3	1		a	2
Bulimina marginata d'Orbigny, 1826	5		2	1						b	2
Cassidulina carinata Silvestri, 1896	7		1		2	1	1	2		b	2
Cibicidoides pachyderma (Rzehak, 1886)	18	6	1			1	5	4		a	3
Cribroelphidium cuvillieri (Lévy, 1966)	4	2			1	3	5	1		b	2
Discorbinella bertheloti (d'Orbigny, 1839)								1		b	4
Elphidium complanatum (d'Orbigny, 1839)	3									c	1
Elphidium crispum (Linnaeus, 1758)	286	12	1	3	6	7	6	4	1	a	1
Elphidium incertum (Williamson, 1858)		1				1				a	1
Elphidium granosum (d'Orbigny, 1846)	3	1			1	1	5	1	1	a	2
Elphidium macellum (Fichtel & Moll, 1798)	2		1			2				a	2
Elphidium maioricense Colom, 1942	1							1		a	1
Elphidium punctatum (Terquem, 1878)	6									a	3
Elphidium sp. A Sgarrella & Moncharmont Zei, 1993	8									a	1
Elphidium sp.	2	3			1					a	1
Fissurina aff. *F. orbignyana* Seguenza, 1862	1									c	4
Glandulina laevigata (d'Orbigny, 1826)		1								b	2
Globobulimina pseudospinescens (Emiliani, 1949)		1								b	2
Gyroidina umbonata (Silvestri, 1898)								1		b	2
Hyalinea baltica (Schroeter, 1783)	2					1				c	4
Lenticulina gibba (d'Orbigny, 1839)	1									b	2
Lobatula lobatula (Walker & Jacob, 1798)	30	2				1	4		1	c	4
Melonis barleanum (Williamson, 1858)	6								1	b	2
Neoconorbina terquemi (Rzehak, 1888)	6	2	1			1		1		b	3
Planulina ariminensis d'Orbigny, 1826	2	1						1		b	2
Peneroplis pertusus (Forskål, 1775)		1								a	4
Pullenia bulloides (d'Orbigny, 1846)	1							1		b	2
Quinqueloculina parvula Schlumberger, 1894									1	b	2
Reussella spinulosa (Reuss, 1850)	1									b	2
Rosalina sp.	2									c	3
Siphonina reticulata (Czjzek, 1848)								1		b	2
Sphaeroidina bulloides d'Orbigny, 1826				1						b	2
Spirillina vivipara Ehrenberg, 1843	1									a	2
Trifarina angulosa (Williamson, 1858)							1			b	1
Uvigerina mediterranea Hofker, 1932	4	3			1	1				b	2
Valvulineria bradyana (Fornasini, 1900)	1	1				3	1	3		b	2

Tab. 2 - List of benthic foraminifer species, number of specimens, depth groups (d.g.) and substrate groups (s.g.). Group a: typical infralittoral species. Group b: upper circalittoral species. Group c: non-significant taxa. Group 1: species linked to sand and fine sand substrates. Group 2: species linked to mud and sandy mud substrates. Group 3: phytophil species. Group 4: non-significant taxa (see text for details).

SPECIES / Samples	P1	P4	P8	P6	P10	P3	P5	P7	P9	d.g.	s.g.
Aurila convexa (Baird, 1850)						1				a	1
Bosquetina dentata (G.W. Müller, 1894)						1				b	4
Bosquetina sp.	1									c	4
Buntonia sublatissima (Neviani, 1906)	1					1				b	2
Carinocythereis sp.	j									c	4
Cistacythereis (H.) turbida (G.W. Müller, 1894)	3							1		a	1
*Costa edwardsi (*Roemer, 1838)	2									b	2
Cyprideis torosa (Jones, 1850)	4 j									c	4
Cytherella vulgatella Aiello et al., 1996	j									b	4
Cytheridea neapolitana Kollmann, 1960	34 j					2	1			b	2
Leptocythere aff. *L. kellettae* Ruggieri, 1976						1				c	4
Loxoconcha ovulata (O.G. Costa, 1853)	2									a	2
Loxoconcha rhomboidea (Fischer, 1855)					1					a	3
Loxoconcha sp.	1									c	4
Microcytherura (*T.*) *angulosa* (Seguenza, 1880)	1									b	1
Paracytheridea sp.	1 j									c	4
Pontocythere turbida (G.W. Müller, 1894)	39 j	1		1	1		3 j	1	1	a	1
Pterygocythereis sp.	j									b	4
Semicytherura incongruens (G.W. Müller, 1894)	18			1				2	2	a	1
Semicytherura sulcata (G.W. Müller, 1894)	2									a	1
Semicytherura tergestina Masoli, 1968	1									b	1
Urocythereis margaritifera alba Uliczny, 1969	3									a	1
Urocythereis schulzi Hartmann, 1958	2									a	1

Tab. 3 - List of ostracod species, number of adult specimens, depth groups (d.g.) and substrate groups (s.g.). Group a: upper infralittoral species. Group b: lower infralittoral - upper circalittoral species. Group c: non-significant taxa. Group 1: species linked to sand and fine sand substrates. Group 2: species linked to mud and sandy mud substrates. Group 3: phytophil species. Group 4: non-significant taxa (see text for details); j: presence of juvenile specimens.