Morphological variations of benthonic foraminiferal tests from Holocene sediments of the Punta Campanella Shelf (south Tyrrhenian Sea)

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ABSTRACT

We investigated the distribution and presence of theratological specimens in benthonic foraminiferal assemblages along the coast of the Sorrento Peninsula (southern part of the Tyrrhenian margin). Thirtyeight samples were analyzed from surficial shallow water sediments and a total of 97 benthonic foraminiferal species, belonging to 21 families, were identified along the shelf zone (between -6 and -102 m). Calcareous forms were dominant and equal to 82.6 % of the total population, whereas agglutinated forms characterised only 17.4 % of the total assemblage. A small number of specimens, related to eleven species, *Connemarella rudis*, *Quinqueloculina disparilis*, *Q. milletti*, *Q. seminulum*, Q. sp., *Adelosina pulchella*, *Peneroplis pertusus*, *Asterigerinata mamilla*, *Elphidium crispum*, *Cibicides lobatulus* and *Planorbulina mediterranensis*, from six calcareous families and one agglutinated family, exhibited ten distinct types of morphological deformities of their tests. These include: (1) aberrant chamber shape and lack of sculpture; (2) aberrant shape of last chamber; (3) abnormal growth of last chamber; (4) double aperture; (5) wrong coiling; (6) anomalous protuberance; (7) tendency to siamese twin; (8) high spire giving a spiroconvex test, (9) additional chambers and (10) poor development.
Morphological deformities are independent of latitude, taxonomic position, mode of life, and feeding strategy of foraminifera. They can occur within the range of natural variability of a given species in given environmental conditions. Benthonic foraminifera can reflect human-induced environmental perturbation and can be used as bioindicators for monitoring coastal pollution.

keywords. Morphological deformities, benthonic foraminifera, Holocene, Gulf of Naples, Tyrrhenian Sea.

INTRODUCTION

With increasing worldwide awareness to environmental problems, ways to detect and monitor pollution inputs over time are continuously sought. Through these studies a considerable effort has been made to develop new methodologies for biological monitoring of different contaminants. In addition, because of increased knowledge of foraminifera biology, these studies have shown that benthonic foraminifera have great potential as indicators of pollution, providing one of the most sensitive markers of environmental stress in both naturally and anthropogenically stressed acquatic environments.

Foraminifera are by far one of most useful group of paleoenvironmental indicators utilized by geoscientists because (a) their shells are important sediments constituents, (b) they are small and widely abundant, (c) different taxa have evolved to exploit most environments, substrates and nutritional modes in the marine system, (d) taxonomic references are widely available, and (e) their shells represent a morphological and geochemical record of environmental conditions.

Foraminifera are particularly useful in environmental studies, because some taxa have the remarkable ability to survive in heavily polluted environments, while recording evidence of that stress both in their shell morphologies (Samir & El-Din, 2001; Alve, 1995; Yanko, 1994, 1998) and in trace-element concentrations in their shells (Samir & El-Din, 2001). Unfortunately, in most areas with toxic-metal pollution, the biological effects are complicated and compounded by nutrient and organic pollution (Caralp, 1989).

It is the shallow near-shore environment which is generally subjected to frequent and abundant industrial and seawage outfalls. Shallow water benthonic foraminifera are a useful tool for biological monitoring of this ecological zone. Moreover, they are particularly sensitive pollution indicators in estuarine and costal areas (Alve, 1995; Cearreta *et*

al., 2002; Geslin *et al.*, 2002) because they vary spatially and temporally in relation to environmental variables and can respond to almost imperceptible pollutant induced physical change in the environment. In addition, the ability of foraminifera to respond to environmental degradation is enhanced because they reproduce quickly, as often as every three months to one year (Murray, 1991). Benthonic foraminifera are useful in environmental studies also because they are easily acquired, since they live mostly in the uppermost centimenters of sediment (Collison, 1980; Buzas, 1977) and are very abundant in marine and estuarine habitats (Buzas, 1977; Lankford, 1959); one study estimated that the maximum foraminiferal density sometime can reach, at a single site, than 4 million living individuals per square meter with sediment thickness of 1 cm (Sen Gupta, 1971). As primary consumers, foraminifera occupy a position near the bottom of the trophic structure of marine and estuarine communities, making them critical components of many, if not all, food chains (Lipps, 1983; Lipps & Valentine, 1970). They feed on items which cannot be utilized by most larger invertrebates, such as diatoms, bacteria, nannoplankton, detritus, small arthropods, small sea scaphopods, and other creatures (Murray, 1991; Lipps, 1983; Lipps & Valentine, 1970). They, in turn are eaten by copepods, plankton larvae, crabs, worms, scaphopods, shrimp, gastropods, fish, and other foraminifera.

Morphological deformities in live and dead benthonic foraminiferal tests have been widely reported during the last century (Caralp, 1989; Coccioni, 2000; Geslin *et al.*, 1998, 2002; Yanko *et al.*, 1994; Lidz, 1965; Seiglie, 1964; Watkins, 1961; Arnal 1955; Rhumbler, 1911; Heron-Allen & Earland, 1910; Carpenter, 1856). In recent years, reports of deformities have become increasingly more common and the documentation of deformities are recorded in different geological time interval (Foresi & Zampi, 2003; Coccioni & Venturati, 2003; Galeotti and Kaminski, 2003; Geslin *et al.*, 2000; Stouff *et al.*, 1999; Bogdanowich, 1971).

The presence of morphological deformities has been suggested to result from natural environmental stresses due to either changes in ecological parameters or from extreme environmental conditions (Almogi-Labin *et al.*, 1992; Boltovskoy *et al.*, 1991; Zaninetti, 1982). Some authors consider them the result of anthropogenic influences e.g., oil slicks (Vénec-Peyré, 1982) and heavy metal contamination (Coccioni, 2000; Yanko *et al.*, 1994; Alve, 1991; Sharifi *et al.*, 1991) or related to stressed natural areas (i.e. ipo and/or iperaline areas).

Deformities have been linked to changes in ecological parameters (Boltovskoy *et al.*, 1991): 1) temperature; 2) salinity; 3) dissolved oxygen content; 4) solubility of calcium carbonate; 5) nutrition; 6) substrate; 7) illumination; 8) trace elements; 9) depth and 10) water motion. These parameters can affect foraminifera producing tests with aberrant growth, thin-walled and lack of ornamentations.

In order to understand the causes of test deformation it is necessary to unravel the mineralization mechanisms that produce deformations. Most previous studies, however, sought only to establish the relationship between deformed test and environmental stresses, regardless of these mechanisms. The Tyrrhenian Sea, due to the position of several industrial cities close to the shoreline, represent a key-area to perform these studies. The aim of this work is to provide some documentation of presence of morphological deformities affecting benthonic foraminiferal tests along the south Campanian coast.

GEOLOGICAL SETTING

The Sorrento Peninsula, situated on the eastern Tyrrhenian Sea margin of southwestern Italy and trarsversally to the Appennine Chain, is mainly constituted by Mesozoic carbonatic units to the east and in the western sector by transgressive siliciclastics units, Miocene in age (Perrone, 1988) and extending NE-SW between two different physiographic settings, the Naples Gulf and the Salerno Gulf (Fig. 1).

The Gulf of Naples is a pronounced embayment bounded by the Islands of Procida and Ischia to the NW and the Sorrento Peninsula and Capri Island to the SE.

The main access to external waters is through the mouth of the Gulf which has a cross-sectional area of about 9.5 km^2. This configuration provides a source of surface and deep Tyrrhenian waters (Carrada *et al.*, 1980), that flow southward through the Bocca Piccola passage (which has a -74 m sill and a cross section of 0.4 km^2) into the deep portions of the Gulf of Salerno, and northward through the Procida and Ischia channels into the Gaeta Gulf (with shallow sills of -24 m and -12 m; Carrada *et al.*, 1980). The Holocene sediments of the Gulf of Naples are mainly composed of fine-grained sands to muds and are strictly related to the geology of the coastal areas. Where volcanic rocks occur, the detritic portion is mainly composed of volcanic debris (north and east part of the Gulf). In the southern part, where the outcrops along the coast (from Castellamare to Capri island) are composed by Mesozoic limestones, the detritic fraction is mainly calcareous. The Gulf of Salerno is a WSW-ENE elongated deep depression bounded by NW-SE normal faults with an offset of about 3000 m (Brancaccio *et al.*, 1986; Russo, 1990) of Mesozoic and Cenozoic Appenninic Units and filled by Plio-Quaternary sediments 1000 m thick (Agip, 1977; Ippolito *et al.*, 1978; Bartole, 1984).

The continental shelf is characterized by upper
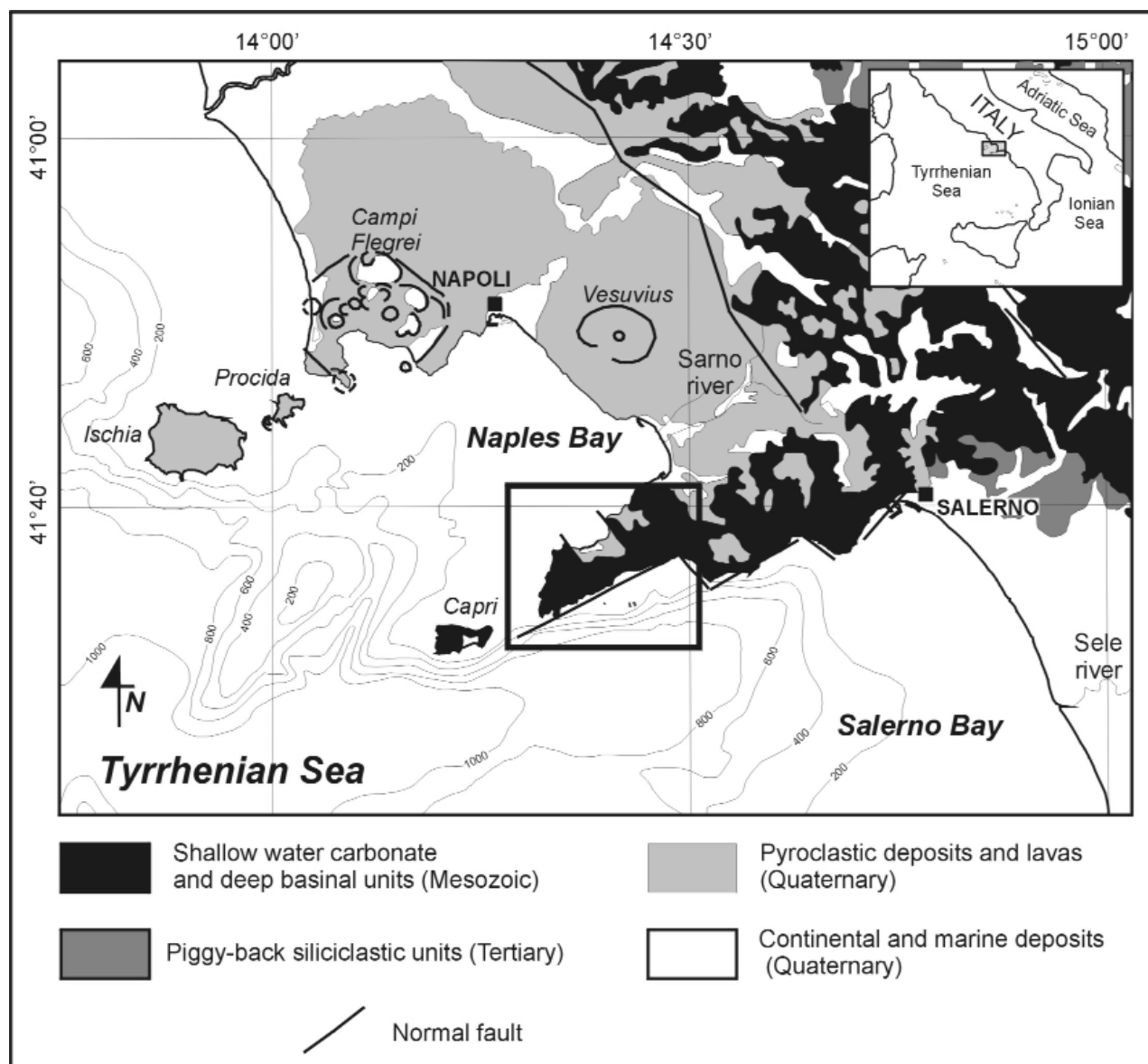
Figure 1. Location map of the studied area.

Pleistocene sediments cut by a Wurmian erosional surface which is draped by transgressive and (or) highstand deposits (Trincardi & Field, 1990).

The studied area includes two different submarine domains that are located along the north and south coasts of the Sorrento Peninsula. The northern continental shelf is primarily characterized by sands and secondarily by pelitic sands and sandy pelite with a southward decreasing grain-size. According to De Lauro *et al.* (2001), sediments in the northwestern sector are mainly composed by sands, in the depth range of -9/-50 m, whereas the outer part of the shelf is covered by pelitic sands and very sandy pelite. The south sector is characterized by very coarse-grained sands with *Posidonia oceanica* prairies and subordinately by pelitic sands and very sandy pelite. The Sorrento Peninsula promontory is not characterized by high industrial activity, although the natural marine and coastline environment is mainly influenced by the near by Sarno

River (Fig. 1).

The Sarno River is the most polluted river in Italy and the coastal areas around the river are considered among the most impacted by organic and inorganic pollution. The high pollution levels of the river are well known. In 1992 the Council of Ministers proclaimed the Sarno Basin an area at high risk of environmental crisis and proposed a reclamation project.

The Sarno River is affected by multiple pollution sources of industrial, domestic and agricultural origin; as a consequence its waters and sediments contain numerous pollutants (Melluso *et al.*, 1994; Paoletti *et al.*, 1995), and upon flowing into the sea its waters can induce biological damage on ecosystems and organism (Russo *et al.*, 2004).

The distribution of heavy metals (As, b, Cd, Cu, Pb, Fe and K) in superficial marine sediments from the Salerno and Napoli Gulfs (Dall'Aglio *et al.*, 2000) shows that anomalies recorded near the Sorrento

Peninsula are unexpected and probably indicate a pollution caused by human activity.

MATERIAL AND METHODS

The study was carried out on 38 bottom sediment collected by means of a box-corer during two oceanographic cruises, GMS98-01 and GMS_PM1, between - 6 m and - 102 m of water depth along northern and southern sector of the Sorrento Peninsula (Fig. 2; Tab. 1). The studied material was recovered from the top portion (1-3 cm) of undisturbed sediments of 27 box-corer samples and analysed for micropaleontological study. The other 11 samples were barren and four (PM12 - PM14 - PM16 - PM21) were mainly composed by *Posidonia oceanica* leaves and rhizomes (Tab.1).A constant weight (about 300 g) of wet sample was processed with peroxide and weighed, then gently washed through 63 and 90 micron sieves and dried at 50°C. At least three hundred specimens were separated from the fraction >90 micron by hand-picking and identified (under binocular microscope Leica MZ6) following the generic classification of Loeblich & Tappan (1987). All deformed tests, whenever present, were picked from each sample and morphologically examined. All the studied material was recovered from dead foraminiferal assemblages.

Examples of morphological deformities are illustrated by SEM microphotographs in Plate 1, Plate 2 and Plate 3.

RESULTS AND DISCUSSION
Characteristics of foraminiferal assemblages
The dead foraminiferal assemblage of the studied area is almost entirely composed by benthonic species. The range-chart of benthonic and planktonic species, recognised in each station, is listed in Table 2 and Table 3. Considering the low number of planktonic species, the percentage reported in Table 3, are only indicative.

Due to the shallow water of the shelf zone, between -6 and -102 m of water depth, planktonic species are very rare and represented by *Globorotalia truncatulinoides*, *G. inflata*, *Globigerinoides ruber*, *Hastigerina siphonifera*, *Globigerina bulloides* and *G. sacculifer* (Fig. 3). The relationship between planktonic foraminiferal abundance (where *G. trunatulinoides* reaches the highest values) and depth (- m) is clearly evident (Tab. 3 and Fig. 4).

A total number of 97 benthonic foraminiferal species, related to 21 families, were identified (Tab. 2).

Agglutinated foraminifera, belonging to 3 families, are represented by 10 species and characterize 17.4 % of the total assemblage with *Connemarella rudis* (6.3%) and *Textularia calva* (5.6%) being the most abundant and *Bigenerina nodosaria* restricted to samples PM27, PM25 and S31 from upper circalittoral sandy pelitic bottoms (Tab. 2).

Calcareous benthonic foraminifera are represented by 18 families and 87 species. The miliolids are the most dominant representing 19.3% of the total assemblage (Fig. 5) with a total number of 33 species the most prevailing of which are *Quinqueloculina jugosa* (2.4%), *Triloculina plicata* (2.2%) and *Q. contorta* (1.9%) whereas *Q. vulgaris* is restricted to samples PM6, PM7 and PM28 located in the west part of the investigated area (Tab. 2).

The order *Rotaliida* represents the second most important component of the recorded foraminiferal assemblages, comprising 56.4% of the total assemblage (Fig. 5).

Major families (in decreasing order) are: *Elphidiidae* (17.6%), *Discorbidae* (10.5%) and *Cibicidae* (9.1%) (Fig. 5). *Elphidium crispum* is highly dominant
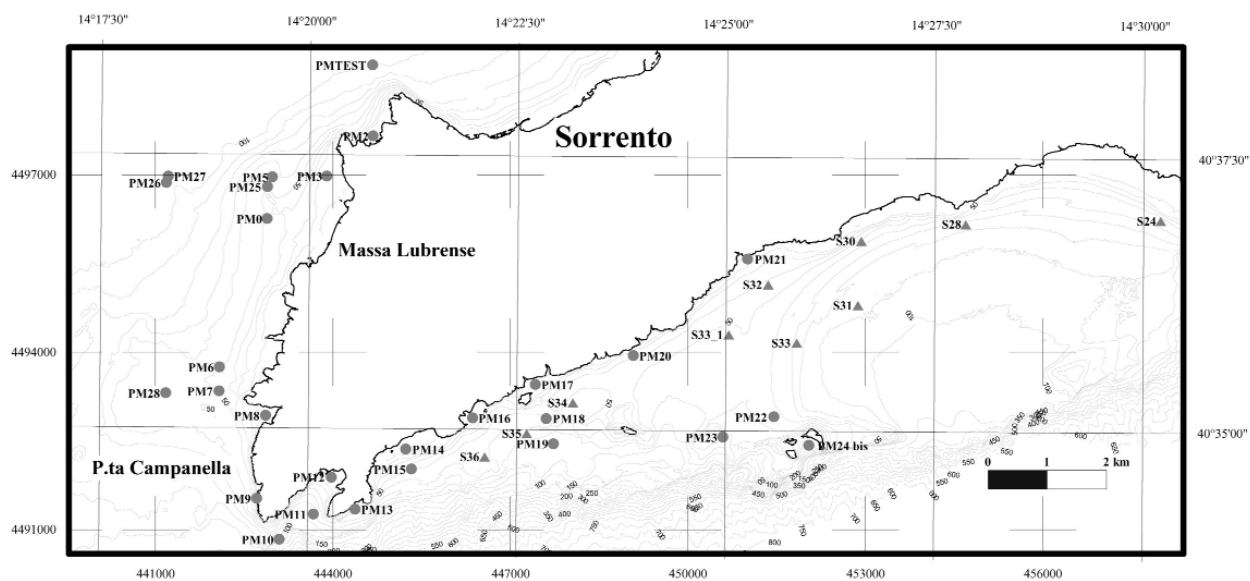
Figure2. Location map of sampling stations with bathymetric map of study area (modified after De Lauro *et al.*, 2001). The triangles represent samples from Cruise GMS98_01 and the circles represent samples from Cruise GMS_PM1.

Table1. Water depth, coordinates and grain-size of sampling stations.

Station	Depth (-m)	Latitude	Longitude	Grain-size
PM14	6	40°34'48"	14°21'10"	*Posidonia oceanica*
PM2	9	40°37'40"	14°20'44"	Sand
PM17	10	40°35'24"	14°22'43"	Sand
PM21	11	40°36'34"	14°25'15"	*Posidonia oceanica*
PM16	12	40°35'06"	14°21'58"	*Posidonia oceanica*
PM12	14	40°34'33"	14°20'16"	*Posidonia oceanica*
PM3	16	40°37'17"	14°20'12"	Sand
PM8	16	40°35'06"	14°19'29"	Sand
PM9	20	40°34'20"	14°19'23"	Sand
PM13	26	40°34'15"	14°20'34"	Pelitic sand
PM20	36	40°35'40"	14°23'53"	Sand
PM24bis	37	40°34'52"	14°26'00"	Sand
S32	43	40°36'20"	142.530	Pelitic sand
PM0	46	40°36'54"	14°19'29"	Pelitic sand
PM18	47	40°35'06"	14°22'51"	Pelitic sand
PM7	48	40°35'19"	14°18'55"	Sand
PM15	48	40°34'37"	14°21'14"	Pelitic sand
PM6	50	40°35'32"	14°18'55"	Sand
S33_1	52	40°35'52"	14°25'01"	Pelitic sand
PM22	52	40°35'07"	14°25'34"	Very sandy pelite
PM28	52	40°35'18"	14°18'17"	Sand
S30	53	40°36'44"	14°26'36"	Very sandy pelite
S34	53	40°35'14"	14°23'09"	Pelitic sand
PM25	55	40°37'12"	14°19'29"	Pelitic sand
PM5	56	40°37'17"	14°19'32"	Sand
S24	57	40°36'56"	14°30'12"	Sandy pelite
S36	59	40°34'44"	14°22'06"	Pelitic sand
S35	63	40°34'57"	14°22'36"	Pelitic sand
PM11	64	40°34'12"	14°20'04"	Very sandy pelite
PM23	70	40°34'56"	14°24'58"	Very sandy pelite
S33	70	40°35'48"	142.550	Pelitic sand
PM19	73	40°34'52"	14°22'56"	Very sandy pelite
S28	76	40°36'54"	14°27'51"	Sandy pelite
S31	89	40°36'09"	14°26'34"	Sandy pelite
PM10	92	40°33'58"	14°19'39"	Very sandy pelite
Pmtest	98	40°38'19"	14°20'44"	Pelitic sand
PM26	101	40°37'13"	14°18'16"	Pelitic sand
PM27	102	40°37'17"	14°18'17"	Very sandy pelite

with the exception of stations PM27, PM6, PM10, PM15 and S31, located in the circalittoral zone (Fig. 2). The *Discorbidae* Family is represented mainly by *Rosalina floridiana* (6.0 %) and subordinatily by *R. bradyi* (1.7 %). The *Cibicidae* Family is dominated by *Cibicides lobatulus* (7.0 %) with higher percentages recorded from infralittoral and upper circalittoral detritic bottoms.

Families recorded in low frequency are: *Rotalidae*, *Anomalinidae* and *Cassidulinidae* (Fig. 5). *Ammonia beccarii* is restricted to stations PM15, S34 and S32 from infralittoral sandy bottoms (Tab. 2) wheras *A. gaimardi* presents higher values in infralittoral and upper circalittoral pelitic sands and very sandy pelitic bottoms (Pmtest, PM6, PM11, PM19, S32; Tab. 2). *Melonis barleeanum* is the only representative of the family *Anomalinidae* exhibiting higher values at stations PM10, PM11, PM19 from very sandy pelitic bottoms and S31 from sandy pelitic bottoms (Tab. 2). The *Planorbulinidae* Family is represented by *Planorbulina mediterranensis* (5.7%) with higher values at stations PM0, PM11 and PM20; this may be due to the sandy nature of the infralittoral bottom sediments mainly composed by bioclastic fraction (Tab. 1). The *Eponididae* family is represented by *Eponides repandus*, which presents highest number

of specimens at stations PM10 and PM26; the distribution of this species appears restricted to areas characterised by bottom currents and to circalittoral detritic bottoms (Sgarrella & Moncharmont-Zei, 1993).

Other components of the recorded assemblages are represented by benthonic foraminifera belonging to the suborder *Uvigerinidae*, *Nubecularidae*, *Nodosaridae* and *Polimorphinidae* constituted the 2.2%, 1.7%, 0.6% and 0.1% of the total assemblages respectively (Fig. 5). *Guttulina communis* is restricted only to station PM28. The *Soritidae* Family is represented by *Peneroplis pertusus* and *P. planatus* which appear restricted to stations PM12 and PM24bis. Their high percentages (Tab. 2) are related to sandy bottoms with vegetation cover (mainly *Posidonia oceanica*).

Test deformities

The development of deformities in test morphology is not a common feature of benthonic foraminifera from the south sector of Tyrrhenian margin. In the investigated area test morphological deformities have been observed at stations: PM0, PM6, PM7, PM11, PM13, PM27, PM24bis, S30, S33, S33_1, S34 and S36.

Out of the 97 species found in the present study, only 11 species, including 6 calcareous and 1 agglutinated families, exhibited morphological deformations that vary from mild to severe and sometimes making taxonomic identifications difficult. The number of deformed species is very low, with an average percentage of ca. 1% for sample.

The deformities were restricted to the families: *Pseudogaudrynidae*, *Miliolidae*, *Soritidae*, *Discorbidae*, *Elphidiidae*, *Cibicidae* and *Planorbulinidae*; within these families the following forms exhibit morphological deformities: *C. rudis*, *Q. disparilis*, *Q. milletti*, *Q. seminulum*, *Q.* sp., *Adelosina pulchella*, *P. pertusus*, *Asterigerinata mamilla*, *E. crispum*, *C. lobatulus* and *P. mediterranensis*.

According to Alve (1991), Sharifi *et al.* (1991), Almogi-Labin *et al.* (1992) and Yanko *et al.* (1994, 1998), ten different modes of deformities have been recognized: (1) aberrant chamber shape and lack of sculpture; (2) aberrant shape of last chamber; (3) double aperture; (4) abnormal growth of last chamber; (5) wrong coiling; (6) anomalous protuberance; (7) tendency to siamese twin; (8) high spire giving spiroconvex test; (9) additional chamber and (10) poor development.

The species *Q. disparilis* (Pl. III, Fig. 10) presents wrong coiling (Pl. III, Figs. 11-12) and aberrant shape of the last chamber (Pl. III, Fig. 11). For *Q. milletti* (Pl. II, Fig. 5), the morphological deformation is manifest as a double aperture (Pl. II, fig. 6), poor development and wrong coiling of last chamber (Pl. II, Fig. 7), while *Q. seminulum* (Pl. II, Fig. 8), shows a

Table 2. Percentages of non-living benthonic foraminifera at each station.

Station	Puttest	PM27	PM25	PM26	PM0	PM6	PM7	PM28	PM10	PM11	PM12	PM13	PM15	N36	S35	PM18	PM19	N34	PM20	PM23	S33_1	PM22	PM24bis	N32	S33	N31
Number of specimens	85	797	729	504	467	82	355	351	764	301	132	60	92	702	799	313	338	319	213	306	369	791	705	356	408	82
Adelosina dubioserxi SCHLUMBERGER																										
Adelosina elegans (WILLIAMSON)							2,3	2,8						5,9	0,7	1,6	1,8	2,5	0,5	2,6	4,1	0,7	1,0	2,0	2,3	
Adelosina intricata (TERQUEM)							0,3	0,6		0,7			1,1		0,7	3,2		1,9		2,6	4,3	3,0	0,5	6,7		1,1
Adelosina mediterranensis (TERQUEM)		0,7		0,7			1,7					1,7			1,0	0,6										
Adelosina pulchella (TERQUEM)		0,3		0,7	1,1				0,4		0,8		1,1	1,0		0,6					1,9	0,4	0,5		1,0	1,1
Ammonia beccarii (LINNEO)	12,0				1,1	11,0	3,9		4,9	9,3		6,7	21,7	3,5	3,6		8,9	11,9			1,1	8,4	0,5	8,4		
Ammonia guiloneuti (d'ORBIGNY)			15,8	13,6			4,5	3,4							4,0	4,2			3,3		3,3		1,5	8,7	1,6	
Ammonia parkinsoniana (d'ORBIGNY)		2,7	2,2	1,0					0,4					2,5		3,2		0,6					6,3	0,3	2,3	1,1
Amphicoryma vsculare (BATSCH)		0,3																								
Aragoloegerina unspooleosa (WILLIAMSON)		1,4	1,7		3,0					1,0			1,1			0,6	0,6			0,4	0,3	1,0		0,3	1,0	1,1
Asterigerinata mamilla (WILLIAMSON)		9,6	1,0	1,0					1,1								0,4	0,3								9,9
Bigenerina cylindrica CUSHMAN																										
Bigenerina nodosaria d'ORBIGNY														2,5										1,7	1,0	
Bilonsiloselle infloto (WRIGHT)	6,0			0,3	0,5		0,6	1,4			1,5		1,1		2,0	4,5	0,9	0,3	1,9	0,3	0,8	3,3			1,3	2,2
Bodinina oloto SPGRUPNZA																										3,3
Buccella frigida granulata DI NAPOLI		0,3	1,8	4,3	1,4				0,4			3,3			0,7			0,3	1,4	0,4			0,5	0,6		1,1
Bulimina gibba FORNASINI	21,7	7,1			7,6	11,0	30,1	32,2	1,9	6,6	8,3	23,3	8,7	18,8	22,8	14,4	13,6	19,4	8,9	15,4	23,2	14,0	8,3	24,7	21,4	
Bulimina marginata d'ORBIGNY									0,8										1,4							
Cassidulina carinata SILVESTRI		3,8	2,6	4,0	13,4	12,2	3,1	1,1	6,1	12,0	12,9		7,6	7,4	9,6	7,3	9,8	6,9	17,8	3,9	3,7	7,7	8,3	3,7	8,4	1,1
Cibicidella variabilis (d'ORBIGNY)	8,4								0,4			3,3				0,6	0,3	0,3					0,5	0,6		
Cibicides lobatulus (WALKER & JACOB)		4,8	0,4	1,7					0,8	0,7				16,8	6,6	11,2	4,7	6,6	0,5	19,0	5,1	6,4	0,5	5,9	10,7	
Cibicidoides pachyderma (RZEHAK)		4,5	0,4	7,9		18,9		10,3		0,4		1,7						0,3					0,5			
Cornuspira radii (WRIGHT)			1,8		1,4				0,8										1,4							
Cyclocibordes vermiculatus (d'ORBIGNY)		0,3																								
Elphidium complanatum (d'ORBIGNY)	1,2	1,0	0,9	12,6	7,6			1,1	6,1	6,6	8,3	23,3		18,8	22,8	14,4	13,6	19,4	8,9	15,4	23,2	14,0	8,3	24,7	21,4	
Elphidium crispum (LINNEO)									0,8							0,3										
Elphidium cuvillieri HVY					0,5						0,8		4,4				0,5									
Elphidium grumosum (d'ORBIGNY)																										
Elphidium incertum (WILLIAMSON)								2,8																		
Elphidium macellum (FICHTEL & MOLL)	1,2	4,8	0,9		1,9	1,2	3,9	7,8		0,7		6,7		4,0	7,0	3,7	0,9	2,5	1,4	4,7	8,4	2,3	0,5	3,1	4,5	5,5
Elphidium paurciloculum (CUSHMAN)		0,7	3,5	2,6	1,6	1,2	1,4	2,8	17,4	3,3	9,1		2,2	1,0	0,3	1,9		0,6		4,9	0,5		2,9		0,6	1,1
Elphidium punctatum (TERQUEM)		3,4	3,1	0,3					0,4	0,3																
Eponides repandus (d'ORBIGNY)	0,7		0,4					2,8	9,8	0,7						0,6			5,6			1,0	6,3			
Gymnadine nonionidane TROYTZEN	7,4	7,4	1,8						1,9		18,7	1,7			0,4		0,3									7,2
Guttulina communis (d'ORBIGNY)			0,4	0,7		1,2		0,3	9,5	3,0	12,1		1,1	3,0	0,7	0,3	8,3	0,3	0,5	2,0	2,7	4,0	0,5	1,1	0,4	1,1
Haynesina rhodoensis (CUSHMAN)	3,6	2,1	3,5	2,6	1,4	7,4		0,6	1,5	3,3		3,3	4,3		0,3	2,6	2,1	0,9	1,1		1,6	3,0			1,6	
Heterolepa pseudoungeriana (CUSHMAN)																								0,3		
Hauglundina elegans (d'ORBIGNY)																				0,3				0,3	1,0	
Hyalinea baltica (SCHROETER)	1,2	0,7	0,4	0,3	6,0					0,7	0,8					0,6			1,4			1,0	6,3	0,3		
Lenticulina cultrata (d'ORBIGNY)																				0,4						
Lenticulina peregrina (SCHWAGER)															0,4		0,3									
Lenticulina rotulata (LAMARCK)						7,4						1,7											14,1			7,2
Melonis barleeanum (WILLIAMSON)	7,4	4,1	5,3	5,3	21,8	3,7			6,8	21,3	0,8	1,7	5,4	1,0	8,6	3,8	5,9	5,3	10,8	2,6	1,9	3,7	7,8	0,3	2,3	15,4
Miliolidae		2,1																								
Miliolinella webbiana (d'ORBIGNY)	1,2														3,0	2,6							0,5			1,1
Neocorovbina iesquem (RZEHAK)																				0,3			0,5	0,3		
Nodosaria raphanus (LINNEO)																0,6										
Pononopho portaius (FORSKAL)	7,4	0,3	0,4						0,3			1,7			0,4	0,3	0,3			0,4				0,3	1,0	7,2
Porosrotalia plunutes (FORSKAL)	4,8	2,4	3,1	2,3			0,9							1,0						2,6			14,1			
Planorbulina mediterranensis d'ORBIGNY	4,8	2,4	3,1	2,3	21,8	3,7	0,9		6,8	21,3	0,8		5,4	1,0	8,6	3,8	5,9	5,3	10,8	2,6	1,9	3,7	4,9	5,1	2,3	2,2

Table 2. Continued.

Station	Pontest	PM27	PM25	PM26	PM0	PM6	PM17	PM28	PM10	PM11	PM12	PM13	PM15	S36	S35	PM18	PM19	S34	PM20	PM23	S33_1	PM22	PM24bis	S32	S33	S31
Number of specimens	383	797	299	404	367	82	555	451	764	301	132	60	92	702	299	313	338	319	213	306	369	291	705	856	808	82
Pyrgo anomala (SCHLUMBERGER)		2,4							1,5													0,3				8?
Pyrgo depressa (d'ORBIGNY)		1,0	1,8	0,7					1,1					0,3			0,6			0,3						1,1
Pyrgo elongata (d'ORBIGNY)		0,7	0,4						0,8																	
Pyrgo murrhina (d'ORBIGNY)				3,0				0,3												2,0			7,4			1,1
Quinqueloculina agglutinans d'ORBIGNY																										
Quinqueloculina berthelotiana d'ORBIGNY												3,3	4,3													
Quinqueloculina boueana d'ORBIGNY	4,8		0,4	0,3	4,6	1,2		2,3	1,1		4,5	5,0		2,5		5,8	2,1	0,6		0,3	1,4	4,3	2,0	0,6	2,9	
Quinqueloculina contorta d'ORBIGNY								2,0		0,3		6,7									0,3		2,4	3,9	0,6	
Quinqueloculina disparilis d'ORBIGNY	2,4			0,3		2,4		3,1		2,0	5,3	3,3	6,5	0,5	2,0		5,0	0,3	8,5	4,6	3,8	8,4	0,5	0,3		
Quinqueloculina lutgosa CUSHMAN	1,2		2,6			1,2	2,3	1,7				1,7	1,1	0,5		1,9	1,8	0,9		0,7	0,5	0,7	4,9		1,6	
Quinqueloculina milletti (WIESNER)														0,5					0,5							
Quinqueloculina oblonga MONTAGU		0,3	0,9	0,3													0,9		3,8				1,0	1,1		1,1
Quinqueloculina padana PERCONIG								0,3				1,7	2,2	0,3						0,3	0,8	0,3				
Quinqueloculina poeyana d'ORBIGNY	4,8		0,4					0,3						0,5	1,3			3,1		0,7				2,2		
Quinqueloculina pulchella d'ORBIGNY														5,0				0,6								
Quinqueloculina rugosa d'ORBIGNY	1,2		0,4		0,8	6,1	0,3	0,6		0,7	6,1	11,7	7,2	4,0	0,3		0,9	0,3		0,3		7,7	5,4	0,6		7,2
Quinqueloculina seminulum (LINNEO)											0,8															
Quinqueloculina sp.	4,8	0,3	0,4	1,0		1,2			3,0	1,0	12,9			1,0			0,9	0,6	22,5	0,7			2,1			1,1
Quinqueloculina stelligera SCHLUMBERGER										7,3				1,5						1,0						
Quinqueloculina undulata d'ORBIGNY	7,2	2,4		2,0	10,1	7,3		1,4	5,3							2,2	0,3									
Quinqueloculina viennensis LE CALVEZ & LE CALVEZ	3,6	1,4	0,4												0,3	0,6	3,6	0,9				0,7	4,9		1,3	
Quinqueloculina villafranca LE CALVEZ & LE CALVEZ		1,7	7,6	7,0		25,6	7,3	19,7																		
Quinqueloculina vulgaris d'ORBIGNY		0,3	0,4	1,0	0,8				0,4	1,3			1,1	0,5	1,0		2,1			1,3	1,4	0,3	0,5	1,1	1,0	1,1
Rectuvigerina phlegeri LE CALVEZ		1,0	1,8	0,7				0,3		0,7	0,8	1,7		1,0		0,6	1,8	1,6	0,5	0,3	13,3	0,3	0,5		0,3	1,1
Reussella spinulosa (REUSS)			0,9							1,7					0,3	0,3	0,6	0,3		0,3		0,3				
Rosalina bradyi (CUSHMAN)		0,7	0,4							1,0							0,9				0,5			1,4		1,1
Rosalina floridana (CUSHMAN)		7,4	1,3	17,6	5,7	1,7	7,5	7,0	1,9	2,7	2,4	3,4	7,7	7,5	4,4	4,7	5,9	7,5	7,4	6,9	4,9	6,0	1,0	9,4	6,7	7,7
Rosalina obtusa d'ORBIGNY		1,0		1,3	6,0		8,7			1,7					0,7			2,5		3,6		2,0			0,6	
Sigmoilopsis schlumbergeri (SILVESTRI)				5,3					3,8											2,6		0,3	1,0			
Siphonaperta aspera (d'ORBIGNY)	1,4			0,3	0,5	0,8		0,3	0,4	0,3				0,5	4,3	1,6	5,0	2,8	0,5	0,3	3,3	3,7			0,6	
Spiroloculina concava (KARRER)			0,4							0,3																
Spiroloculina depressa d'ORBIGNY		7,4	1,3	1,3	3,8	1,7	2,8	2,6	7,5	2,0	1,5		2,7	2,0	1,0	6,1	1,8	1,3	5,7	7,6	2,7	1,0	7,4	0,8	4,9	1,1
Spiroloculina excavata d'ORBIGNY		13,1	18,9	3,3					11,0																15,4	
Spiroloculina gratica TERQUEM		1,4	0,4	1,3					2,7	1,0	0,8	1,7	2,2				0,3	0,3				0,3	2,0	4,2	5,5	
Spiroloculina rostrata REUSS	1,2	1,0	0,4		6,1					1,3	0,8		2,2								0,3	1,3				9,9
Spirophthalmidium sergfeni (SILVESTRI)	4,8																									

Table 3. Percentages of non-living planktonic foraminifera at each station.

Station	PM27	PM25	PM26	PM0	PM10	PM11	PM15	PM18	PM19	PM22
Number of specimens	23	18	14	6	24	7	2	3	5	3
Globigerina bulloides d'ORBIGNY			5,1							
Globigerinoides ruber (d'ORBIGNY)	13,0	22,2	36,5		16,7					
Globigerinoides sacculifer (BRADY)					4,2					
Globorotalia inflata (d'ORBIGNY)		16,7	58,4		33,3	57,1	50,0	100,0	20,0	33,3
Globorotalia truncatulinoides (d'ORBIGNY)	56,5	50,0		100,0	41,7	42,9	50,0		80,0	66,7
Hastigerina siphonifera (d'ORBIGNY)	30,4	11,1			4,2					

specimen with poor development of the last chamber (Pl. II, Fig. 9). *Q.* sp. (Pl. III, Fig. 1) presents specimen with a double aperture (Pl. III, Figs. 2-3-4) and wrong coiling (Pl. III, Figs. 5-6-7).

Test deformities in *E. crispum* (Pl. I, Fig. 6) included the tendency to siamese twin (Pl. I, Fig. 7) and wrong coiling (Pl. I, Fig. 8).

For *C. lobatulus* (Pl. I, Figs. 1-2) the morphological deformation is manifest by abnormal growth of last chamber (Pl. I, Fig. 3) and wrong coiling (Pl. I, Figs. 4-5).

Deformities were also readily noticeable in other species including: *A. pulchella* (Pl. III, Fig. 8) with aberrant shape and size of the last chamber (Pl. III, Fig. 9); *C. rudis* (Pl. I, Fig. 9) with anomalous protuberance (Pl. I, Fig. 10); *P. pertusus* (Pl. II, Fig. 3) with growth of last formed chamber (Pl. II, Fig. 4); *A. mamilla* (Pl. I, Fig. 11) with high spire giving a spiroconvex test (Pl. I, Fig. 12) and *P. mediterranensis* (Pl. II, Fig. 1) with additional chamber (Pl. II, Fig. 2). in Plate II Fig. 10, is also reported an example of deformed specimen of miliolid with aberrant chamber and lack of sculpture.

CONCLUSIONS

It is not the aim of this work to explain the mechanisms which produce morphological deformities in benthonic foraminifera. Species exhibiting deformities are common features of foraminifera popula-

Figure 3. Distribution of planktonic foraminifera in the studied area.

tions inhabiting stress environments resulting from anthropogenic heavy-metal pollution and from natural effects (extreme conditions and/or rapid changes in physical-chemical parameters; see Boltovskoy *et al.*, 1991). Caution must be exercised in distinguishing between test abnormalities and infraspecific variation. Some of the relatively recent literature correlating morphological variation in benthonic foraminifera with environmental parameters such as: temperature, salinity, carbonate solubility, depth, nutrition, substrate, dissolved oxygen, illumination, pollution, trace elements and water motion. It appears that almost no variables act independently on test morphologies. Some deformities are spontaneous or naturally-occuring within the range of variability for each species in particular environmental conditions and many species may change their morphology in response to changing conditions.

The present study deals with the foraminiferal distribution and gives the first documentation of the presence of deformities in benthonic foraminifera in Recent bottom sediments of Sorrento Peninsula continental shelf.

Eleven species, six from calcareous families and one from an agglutinated family, exhibited ten distinct types of morphological deformities of their test. Test deformities are restricted mainly to the families *Pseudogaudrynidae*, *Miliolidae*, *Soritidae*, *Discorbidae*, *Elphidiidae*, *Cibicidae* and *Planorbulinidae* and characterised a low number of specimens. These include: (1) aberrant chamber shape and lack of sculpture; (2) aberrant shape of last chamber; (3) double aperture; (4) abnormal growth of last chamber; (5) wrong coiling; (6) anomalous protuberance; (7) tendency to siamese twin; (8) high spire giving spiroconvex test; (9) additional chamber and (10) poor development.

Punta Campanella Peninsula is one of the Marine Protected Areas along the Italian Coast. The 40 km of coasts of the Sorrentina Peninsula are a succession of green promontories and welcoming inlets; the territory of the Reserve is characterised by homogeneity in the landscape as well as in the globally important natural aspects. Although the nature of the area, the marine environment is characterised by notable pollution and receives domestic and
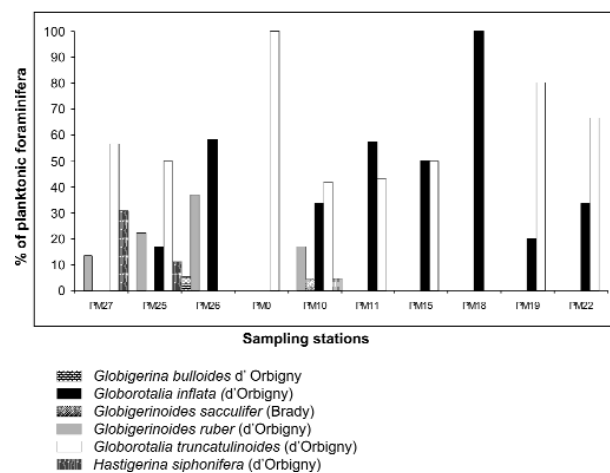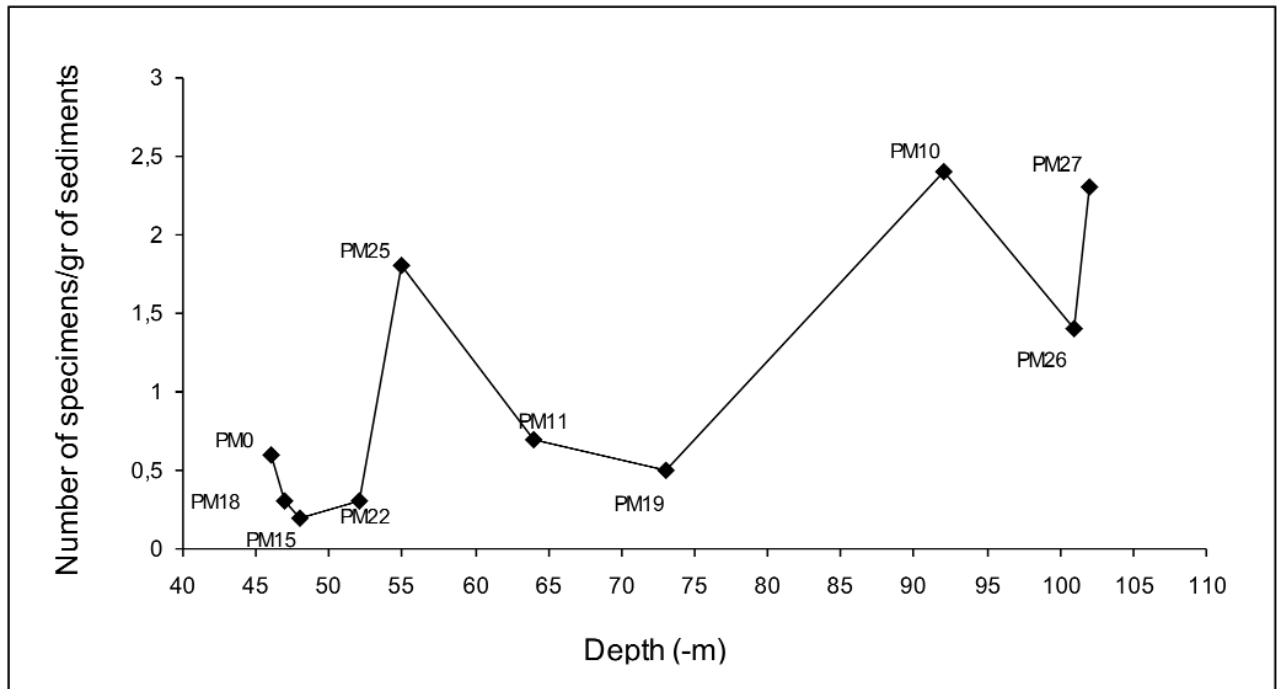
Figure 4. Relationship between depth and number of planktonic specimens/gr of sediments.

agricultural wastes from surrounding lands; in particular the Sarno River, affected by multiple pollution sources of industrial, domestic and agricultural origin, introduces substantial amounts of contaminants into to the sea that may produce damage to the benthonic foraminiferal ecosystem. In this environmental condition the distribution and the occur-

rence of deformities in benthonic assemblage may be related to a individual evolutionary trend and/or adaptation of each species to new environmental conditions. We think that future studies, including culture experiment under controlled conditions, can help to resolve and/or understand the mechanisms of development of test deformities.
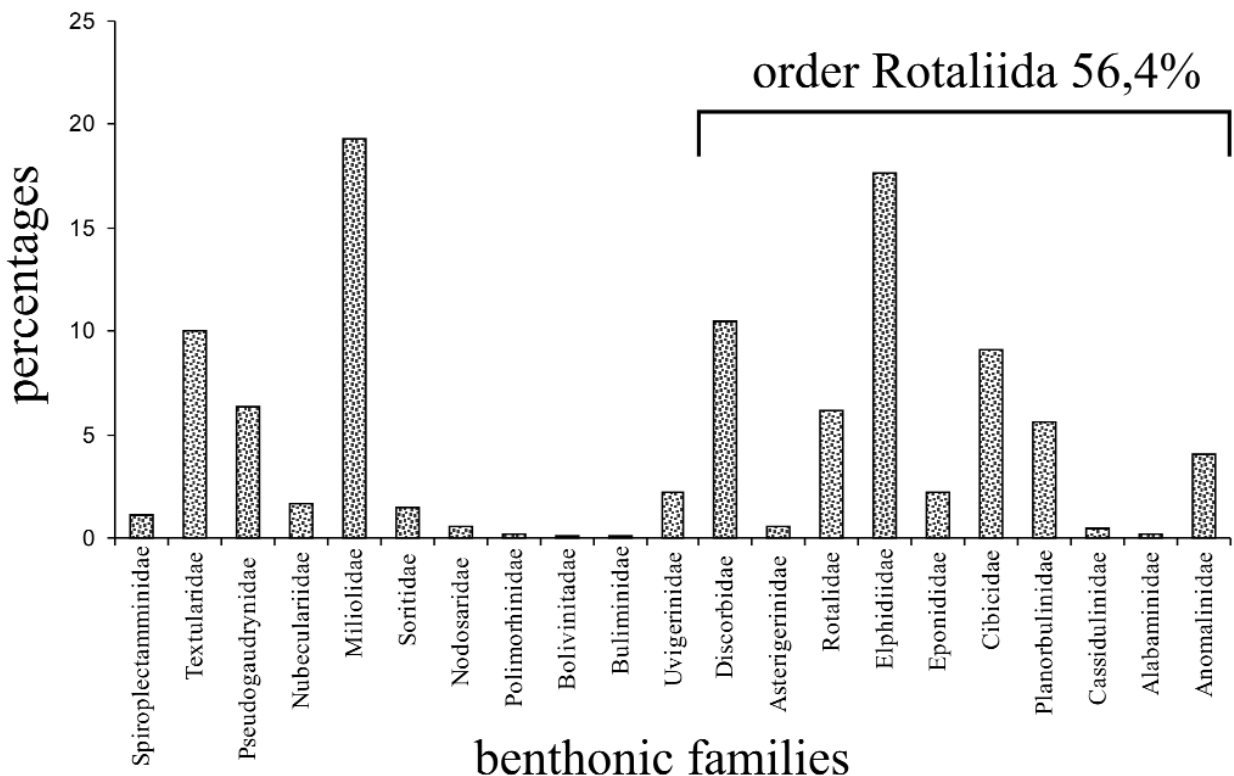
Figure 5. Distribution of benthonic foraminiferal families in the studied area.

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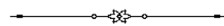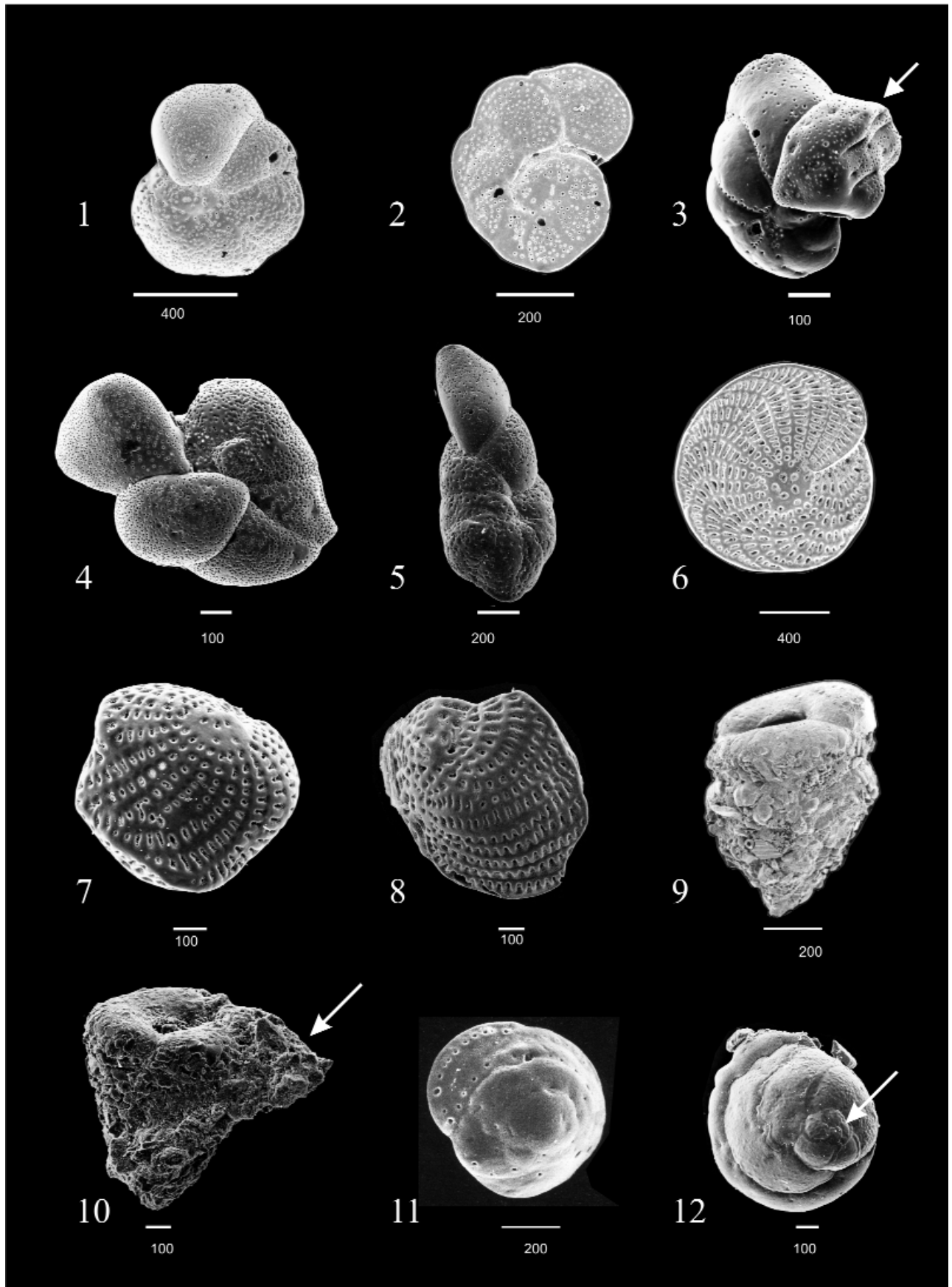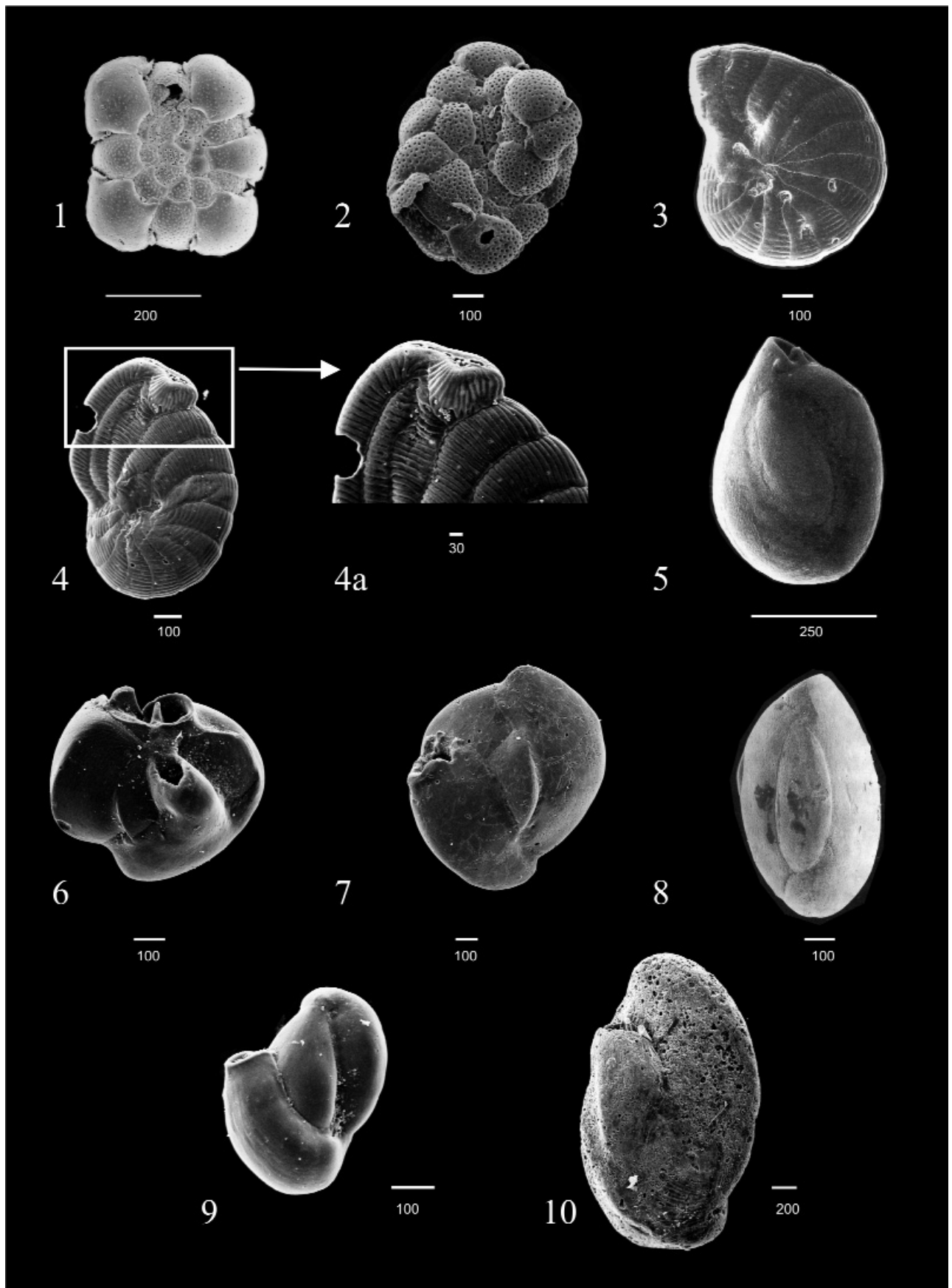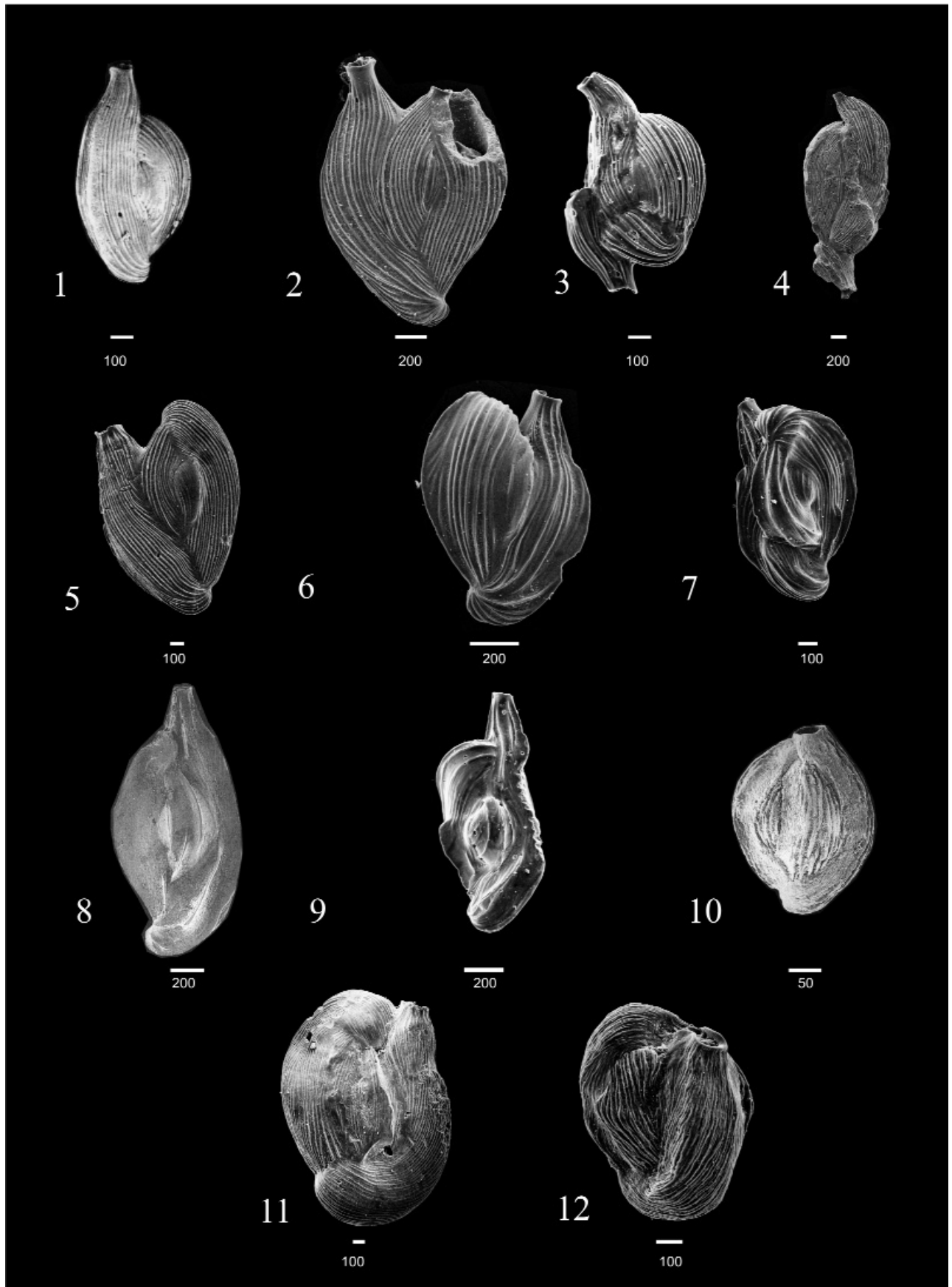
Plate 1

Plate 2

Plate 3

Plate 1

1-5. *Cibicides lobatulus* (Walker & Jacob). Spiral and umbilical side of normal specimen (1-2); spiral view of deformed specimen showing abnormal growth of the last chamber (3) and wrong coiling (4 - 5). PM0, -46 m.

6-8. *Elphidium crispum* (Linneo). Side view of normal specimen (6); deformed specimen with tendency to siamese twin (7) and wrong coiling (7). S33, -70 m.

9-10. *Connemarella rudis* (Wright). Side view of normal specimen (9); deformed specimen exhibiting anomalous protuberance (arrow)(10). S36, - 59 m.

11-12. *Asterigerinata mamilla* Williamson. Spiral side of normal specimen (11); deformed specimen showing high spire giving spiroconvex test (12). S30, - 53 m.

Plate 2

1-2. *Planorbulina mediterranensis* d'Orbigny. Side view of normal specimen (1); spiral side of deformed specimen showing additional chamber (2). PM0, - 46 m; S33_1, - 52m.

3-4. *Peneroplis pertusus* (Forskål). Side view of normal specimen (3); deformed specimen with abnormal growth of the last chamber (4). PM6, - 50 m; PM11, -64 m.

5-7. *Quinqueloculina milletti* (Wiesner). 3 chamber side of normal specimen (5); specimen with additional chamber and double aperture (6), with poor development and wrong coiling of the last chamber (7). PM7, - 48 m.

8-9. *Quinqueloculina seminulum* (Linneo). Side view of normal specimen (8); deformed specimen with poor development of the last chamber (9). S34, -53 m.

10. Example of deformed form of miliolid with aberrant chamber and lack of sculpture. PM24bis, - 37 m.

Plate 3

1-7. *Quinqueloculina* sp.. Side view of normal specimen (1); specimens with double aperture (2-4), specimen with wrong coiling (5-7). PM7, - 48 m.

8-9. *Adelosina pulchella* d'Orbigny. Side view of normal specimen (8); specimen with aberrant shape and size of the last chamber (9). PM27, - 102 m.

10-12. *Quinqueloculina disparilis* d'Orbigny. Side view of normal specimen (10); deformed specimens with wrong coiling (11-12) and aberrant shape of the last chamber (11). PM13, -26 m.