

Living benthic foraminiferal assemblages along a latitudinal transect at 1000m depth off the Portuguese margin

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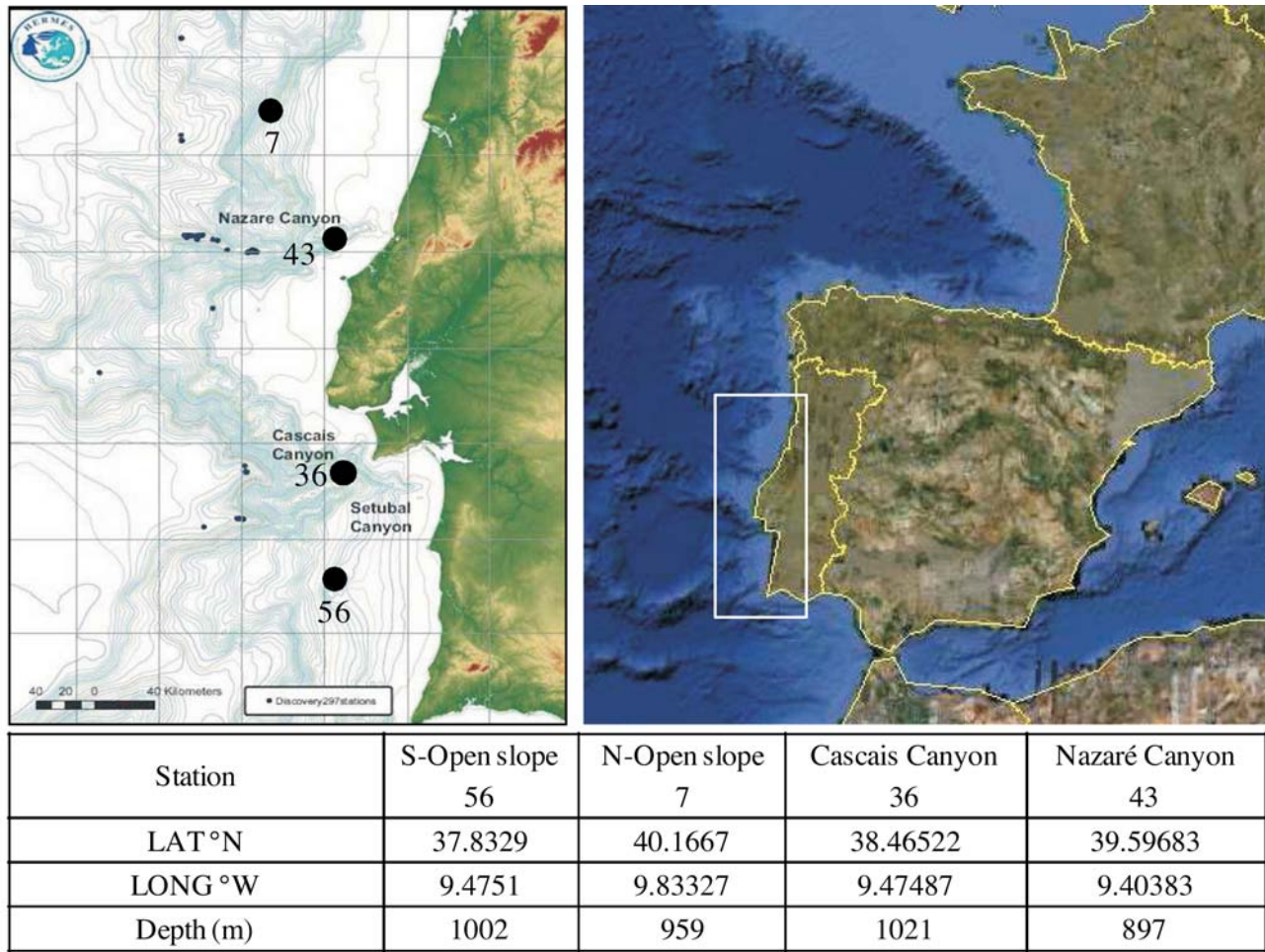
ABSTRACT: The relationships between the quantity and biochemical composition of organic matter and the species diversity and community structure of living benthic foraminiferal assemblages have been investigated at four sites on the Portuguese margin (NE Atlantic). All of the sites are located at approximately 1000m depth. Two out of the four sites are located in the Nazaré and Cascais submarine canyons, while the other two are positioned on the adjacent open slope. The composition and vertical distribution in the sediment of the foraminiferal assemblages have been investigated in the topmost 10cm for the >150µm fraction and in the top cm for the 63-150µm size fraction. Foraminiferal abundance and species richness are related to the quantity and biochemical composition of the sedimentary organic matter, as well as to the stability of the sea floor. The open slope stations are characterised by a relatively low quantity and nutritional quality of organic matter. The faunas of the two open slope stations are much poorer than those found in Nazaré canyon. At both stations, there is a succession of shallow, intermediate and deep infaunal species, suggesting a fairly deep oxygen penetration into the sediment. At the northern open slope station, the faunal density is about two times lower than at the southern station, where the fauna is very largely concentrated in the uppermost half cm. This difference coincides with a lower nutritional quality of organic matter at the northern station. The faunas of the two canyons, where the quantity and nutritional quality of bio-available organic matter are higher, are very different. The rich fauna of Nazaré canyon is characterised by a strong dominance of intermediate and deep infaunal species (e.g. *Melonis barleeanus* and *Chilostomella oolina*) in superficial sediment layers, suggesting a low bottom-water oxygen concentration and a minimal oxygen penetration into the sediment. In Cascais canyon the much poorer faunas of the superficial sediment layers are characterised by the co-occurrence of shallow, intermediate and deep infaunal taxa, again suggesting a rather limited oxygen penetration into the sediment. We suggest that the relatively low densities in the Cascais canyon could reflect an early stage of ecosystem colonisation after a recent turbidite deposition.

INTRODUCTION

One of the main problems of future climate predictions is to adequately model the impact of biological processes on the global carbon cycle. Primary productivity variations in the oceans and the transport of organic matter from the upper water column layers to the sea floor are key processes of the biological carbon pump. The study of the relationships between organic C fluxes and benthic foraminiferal assemblages is important for understanding how the organic matter supply to the sea floor influences the ecology of benthic faunas. On longer time scales (i.e. hundreds to thousands years), observations made in recent ecosystems can be used to reconstruct past organic carbon fluxes to the sea floor based on changes in the density (Herguera and Berger 1991) and composition of fossil benthic foraminiferal faunas (e.g., Jorissen et al. 2007). The measurement of present organic-matter fluxes to the sea bottom is complex, time-consuming, expensive and involves potentially important biases (Lee et al. 1988). In this context, the quantity and composition of the organic matter in superficial deep-sea sediments may provide reliable information on the origin, quantity and composition of organic-matter sinking from the upper part of the water column to the sea floor (Pusceddu et al. 2009).

In deep-sea ecosystems, vertical and advected organic-matter fluxes, oxygen availability and redox conditions in bottom and interstitial waters are among the most important factors controlling the abundance, community structure and distribution of benthic foraminifera (e.g., Altenbach 1988; Altenbach and Sarnthein 1989; Lutze and Thiel 1989; Mackensen and Douglas 1989; Rathburn and Corliss 1994; Jorissen et al. 1995; Rathburn et al. 1996; Jorissen 1999; Schmiedl et al. 2000; Morigi et al. 2001; Fontanier et al. 2005). For instance, some species (e.g., *Chilostomella oolina* and *Bolivina dilatata*) are usually found associated with high organic-matter fluxes, often in combination with dysoxic or even anoxic conditions (Gooday 1994; Sen Gupta and Machain-Castillo 1993; Jorissen et al. 1995; Bernard and Sen Gupta 1999; Schmiedl et al. 2000), whereas others (e.g., *C. pachydermus* and *Cassidulina crassa*) are predominantly found in oligotrophic to mesotrophic ecosystems with well-ventilated bottom waters (De Rijk et al. 2000; Schmiedl et al. 2000).

The two types of environmental settings investigated in the present study, i.e. canyons and adjacent open slopes at about 1000-m depth, are expected to be characterised by different or-



TEXT-FIGURE 1
Study area and geographical position of the four sampling stations.

ganic fluxes to the sea floor. In general, submarine canyons act as sediment traps into which material originating from the continental shelf is conveyed (e.g. Van Weering et al. 2002). This laterally advected organic matter is added to the vertical flux of organic matter from the overlying surface waters. In comparison to the adjacent slope environment, higher sedimentary organic carbon concentrations have been reported from several canyons (e.g., Schmiedl et al. 2000; Epping et al. 2002; García et al. 2003; De Stigter et al. 2007; García et al. 2007, Bianchelli et al. 2008). These increased organic fluxes generally lead to enhanced oxygen consumption rates and a condensed succession of relatively sharp redox boundaries in the superficial sediment (Epping et al. 2002). Therefore, canyon sediments often represent areas of strong organic enrichment, whereas the adjacent continental slope generally is characterised by less eutrophic conditions.

The complex topography of the sea floor on the Portuguese margin, where the slope is incised by several deep-sea canyons (Fiúza et al. 1998), has an important influence on the advected organic-matter fluxes. It is expected that such spatial heterogeneity may also have a profound impact on the abundance and community structure of benthic foraminiferal faunas. With this in mind, we investigated the relationships between the bio-

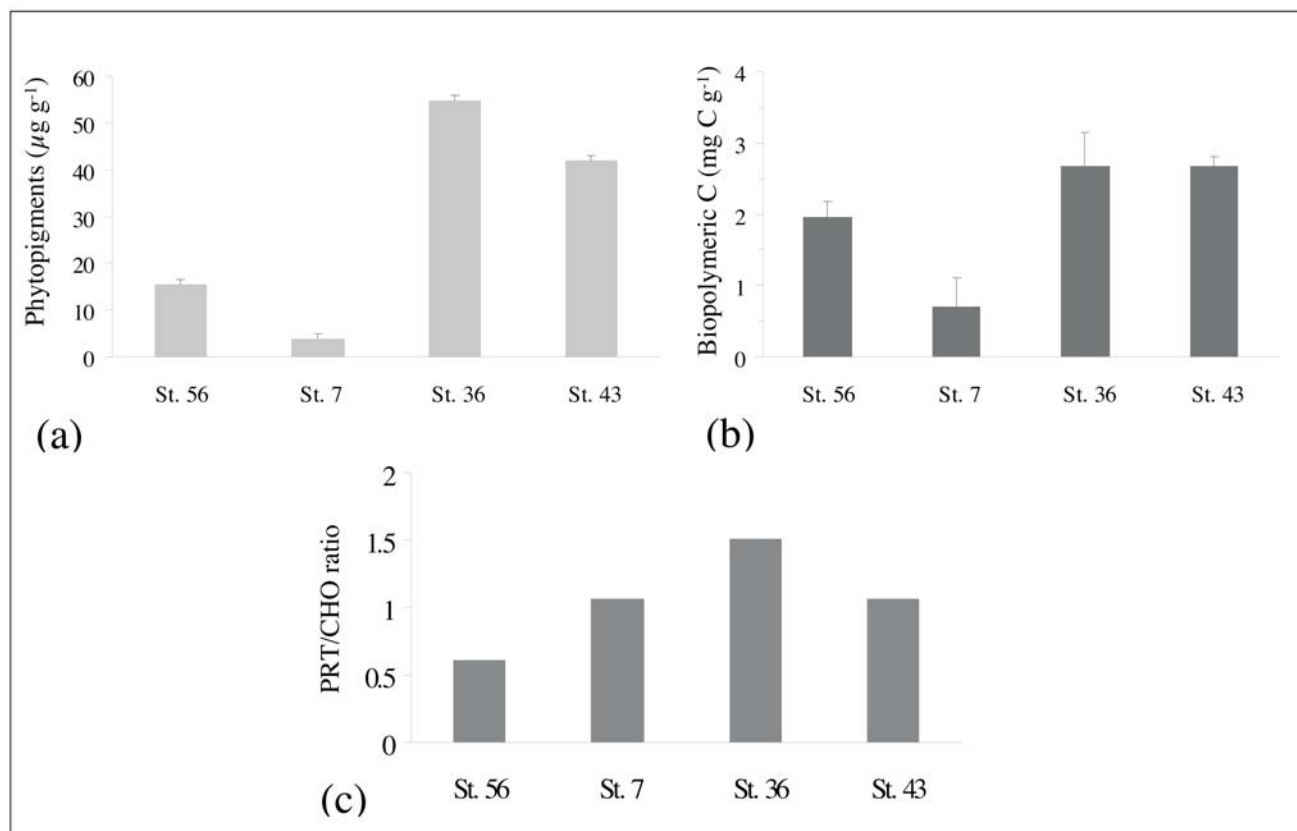
chemical composition (in terms of phytopigment, protein, carbohydrate and lipid contents) of organic matter in the superficial sediment and the abundance and the species composition of benthic foraminiferal faunas.

The study is performed at four middle slope sites located along the Portuguese continental margin at about 1000m depth. The aims of the present study are: 1) to identify differences in the density, species composition and diversity of living benthic foraminifera assemblages occurring in the topmost 10cm of the sediment in two submarine canyons (Nazaré and Cascais) and two adjacent open slope locations, and 2) to assess the possible relationships between abundance, composition and distribution of benthic foraminifera and the biochemical composition of sedimentary organic matter.

MATERIALS AND METHODS

Study area

The Portuguese margin is characterised by the presence of several submarine canyons, separated by relatively narrow open slopes. This area is also characterised by seasonally variable hydrodynamics (Vitorino et al. 2002), which typically leads to upwelling events in summer and downwelling currents in win-



TEXT-FIGURE 2a-c

(a) Concentrations of total phytopigments in sediments from the four stations.

(b) Biopolymeric C content of organic matter.

(c) Values of the protein to carbohydrate ratio.

ter (Vitorino et al. 2002; Huthnance et al. 2002). Primary productivity along the Portuguese margin is fairly high (~ 230 to ~ 360 gCm⁻²y⁻¹; Epping et al. 2002).

The four sampling stations (text-fig. 1) are all located at about 1000m, a depth characterised by the presence of Mediterranean Outflow Waters with a temperature of about 10°C and a salinity of >36.0 (Fiúza et al. 1998). One is located in the Nazaré canyon (station 43), one in the Cascais canyon (station 36) and two on the adjacent northern and southern open slopes (stations 7 and 56, respectively). The Nazaré canyon is one of the largest submarine canyons of the European continental margin (more than 230km long). It is characterised by the accumulation of fine sediments that enter the canyon from the adjacent open slopes through tidal currents and discontinuous advected fluxes (Schmidt et al. 2001). As such, Nazaré canyon can be considered as an “active” submarine canyon (De Stigter et al. 2007). Information on sediment transport activity in Cascais canyon is, in contrast, very scant.

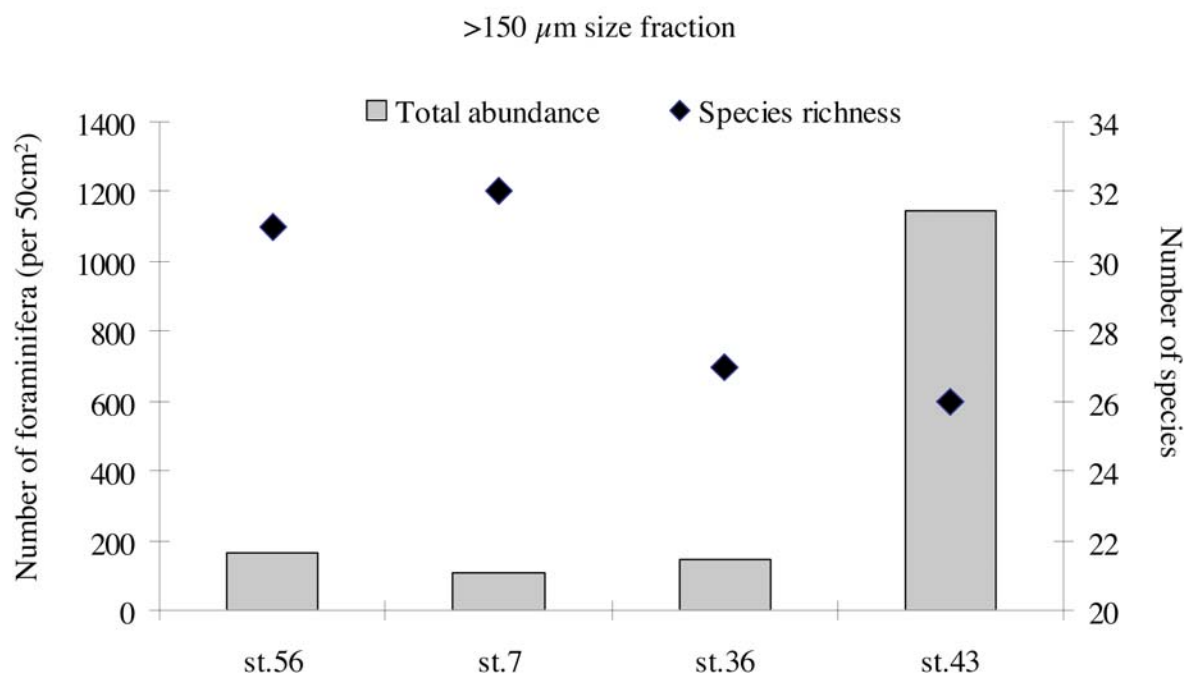
The oceanography of this part of the NE Atlantic Ocean is complex (e.g., Fraga 1981; Haynes and Barton 1990; Frouin et al. 1990; Fiúza, et al. 1998; Vitorino et al. 2002). Different water masses can be identified in the water column along the Iberian margin (Fiúza et al. 1998; Garcia et al. 2003). Eastern North At-

lantic Central Waters (ENACW) occurs beneath the thermocline, and below this, between 600 and 1500m depth, the Mediterranean Outflow Water (MOW) can be distinguished. North Atlantic Deep Water (NADW) occupies deeper parts of the water column (>1500 m). Salinity decreases from 35.8-36 at about 50m depth to a minimum of about 35.6 at 450-500m depth. Below 500m, salinity increases until a maximum value is reached at about 800-1400m depth (about 36.0 at Nazaré Canyon latitude); below 1400m, in the NADW, salinities are low (~ 35) (Fiúza et al. 1998, García et al. 2003).

Foraminiferal study

Sediment samples were collected using a multicorer equipped with four core tubes (6.3cm internal diameter corresponding to a surface of 31cm²), during cruise 64PE252 that took place on board the R.V. *Pelagia* in September 2006. Each core was sliced in 0.5-cm-thick layers, between 0 and 2cm, and in 1.0-cm-thick layers between 2 and 10cm sediment depth. Sediment samples were stained and preserved with about 50mL of a solution of 1.0g L⁻¹ Rose Bengal in 96% ethanol (a staining technique that is an inexpensive and easy to recognize living specimens; Walton 1952; Bernhard 1988, 2000).

In the laboratory, sediment samples were wet-sieved on 150- and 63µm screens and the sieved material was again preserved



TEXT-FIGURE 3

Total foraminiferal abundance (standardised to 50 cm²) and species richness in the >150µm size fraction.

in 96% ethanol. Rose Bengal-stained foraminifera were hand-picked under a stereomicroscope and identified to species level (whenever possible). The foraminiferal fauna was analysed down to 10cm depth for the >150µm size fraction (for a total volume of 310 cm³), and in the topmost cm (0-0.5 and 0.5-1.0cm layers) for the 63-150µm fraction (for a total volume of 31cm³). The study of the 63-150µm was limited to the topmost cm because previous studies (e.g., Gooday 1986; Kitazato et al. 2000; Heinz and Hemleben 2003) have shown that, in deep-sea environments, the topmost sediment layer contains generally about 90% of the total small-sized fauna. Only specimens with all chambers except the last one intensively coloured were considered alive.

For all of the investigated sediment layers and for the two different size fractions, the abundance of living foraminifera was normalized to a standard surface of 50cm². In order to assess the vertical distribution patterns of foraminiferal species, the abundance of foraminiferal specimens in each sediment layer was normalized to a standard volume of 50cm³.

Tubular agglutinated taxa (genus *Hyperammina* and morphologically similar forms) were not included when calculating the abundance and the species richness of the foraminiferal faunas, because they break apart easily when processed in the laboratory, making it impossible to count the number of individuals.

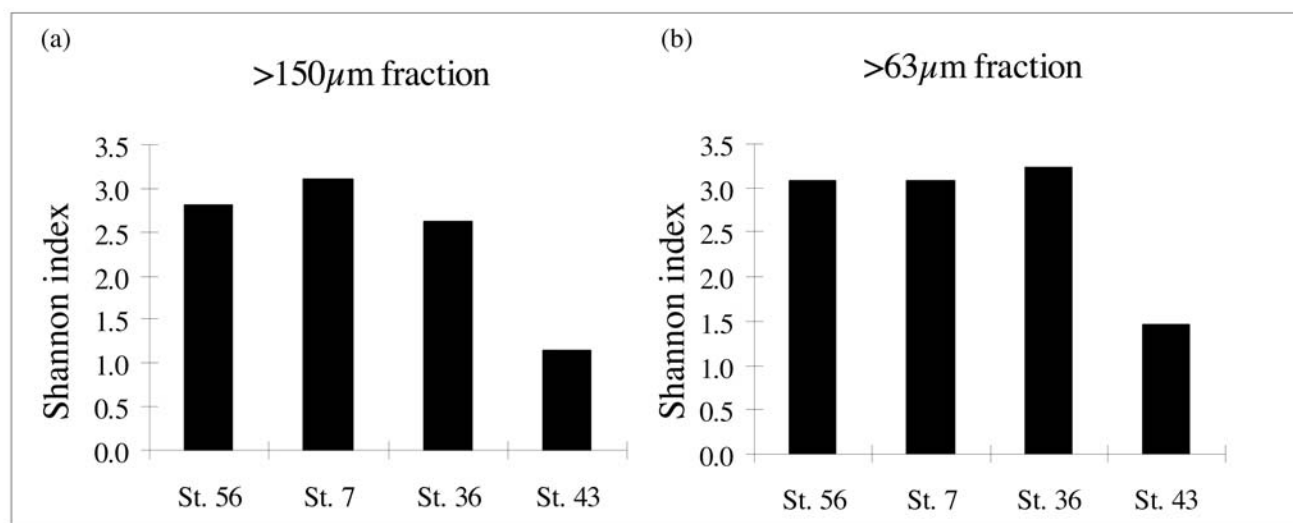
The Average Living Depth (ALD₁₀) of each foraminiferal species, and of the total fauna at each station, was calculated in order to describe vertical distribution of benthic foraminifera in

the sediment, using the relation proposed by Jorissen et al. (1995):

$$ALD_x = \sum_{i=0,x} \frac{n_i \times D_i}{N}$$

where x is the deepest studied level of the core (cm), n_i the numbers of individuals in the interval i, D_i the average depth of the interval i and N the total number of individuals in the whole core. Isolated individuals separated by more than one centimetre from the main population of the taxon were considered to have been accidentally transported by bioturbation and therefore were not considered in the ALD₁₀ calculation.

Species diversity (H') was measured using the Shannon information function (Shannon and Weaver 1949) and the evenness J' (Pielou 1975). The species richness (SR) was calculated as the total number of species collected at each station. All of these indices were calculated using PRIMER v5 (Plymouth Marine Laboratory, UK; Clarke 1993). For the >150µm fraction, the diversity indices are based on faunas from the 0-10cm layer. For the >63µm fraction (combining 63-150µm and >150µm size fractions) they are based on the 0-1cm layer. Below 3cm depth, the faunas become too poor for the calculation of relevant biodiversity indices. Multidimensional scaling analysis was carried out to ordinate the abundance data of foraminifera in the >150µm and >63µm size fractions in the topmost centimetre of the core (0-0.5 and 0.5-1.0cm layers). This was followed by an ANOSIM analysis (using PRIMER v5; Plymouth Marine Laboratory, UK; Clarke 1993) to test statistical differences in the



TEXT-FIGURE 4

Shannon index values calculated for each station (a) for the 0-10cm layer (>150µm size fraction) and (b) for the 0-1cm layer (>63µm fraction).

foraminiferal species compositions between the four sampling stations.

Quantity and biochemical composition of sediment organic matter

Chlorophyll-a and phaeopigment analyses were carried out according to Lorenzen and Jeffrey (1980). At all stations, pigments were extracted (12h at 4°C in the dark) from triplicate superficial (0-1cm) sediment samples (about 1g) obtained from independent deployments of the multiple-corer, using 3-5mL of 90% acetone as the extractant. Extracts were analysed fluorometrically to estimate chlorophyll-a, and, after acidification with 200µl 0.1N HCl, to estimate phaeopigments. Concentrations are reported in µg g⁻¹ DW. Total phytopigments were defined as the sum of chlorophyll-a and phaeopigments and converted into C equivalents using 40 as a conversion factor (Pusceddu et al. 1999). Protein, carbohydrate and lipid sediment contents were analysed spectrophotometrically according to Pusceddu et al. (2004) and concentrations expressed as bovine serum albumin, glucose and tripalmitine equivalents, respectively. For each biochemical assay, blanks were obtained using pre-combusted sediments (450°C for 4h).

Carbohydrate, protein and lipid sediment contents were converted into carbon equivalents using the conversion factors of 0.40, 0.49 and 0.75mg C mg⁻¹, respectively, and their sum defined as the biopolymeric carbon (Fabiano et al. 1995), which is assumed to describe the labile and readily degradable fraction of the organic matter (Tselepidis et al. 2000).

For the purposes of the present study, we used the protein to carbohydrate ratio as a descriptor of the quality of sediment organic matter (Pusceddu et al. 2009). Values > 1 are typically associated with fresher and more recent organic material, which should be more readily available for the nutrition of heterotrophic organisms such as foraminifera (Pusceddu et al. 2000).

RESULTS

Quantity and biochemical composition of sediment organic matter

Table 1 summarises the concentrations of the biochemical compounds determined in the superficial sediments of the four Portuguese margin stations. Concentrations of total phytopigment are higher at the two canyon stations (54.8 ± 13.4 at station 36 and 42.1 ± 2.2 µg g⁻¹ at station 43) than at the open slope stations (15.5 ± 3.2 and 3.8 ± 1.1 µg g⁻¹, at stations 56 and 7, respectively) (text-fig. 2a). Also, the biopolymeric C content of the sediment, considered to represent the quantity of organic available matter to benthic consumers, is higher in the two canyons (2.7 ± 0.4 and 2.7 ± 0.5 mg.g⁻¹, in Cascais and Nazaré Canyon, respectively) than at the open slope stations (0.7 ± 0.1 and 2.0 ± 0.2 mg.g⁻¹, in the N and S slope stations, respectively) (text-fig. 2b). The protein to carbohydrate ratio is higher in the Cascais canyon (1.5) than in the Nazaré canyon (1.1) and the N (1.1) and S (0.6) open slope stations (text-fig. 2c).

Foraminiferal abundance and community structure in the >150µm size fraction

Total foraminiferal abundance and species richness at the four investigated stations are illustrated in text-figure 3. Stations 56, 7 and 36 have rather similar abundances (ranging from 120 to 170 individuals per 50cm²), which are about one order of magnitude lower than those encountered at station 43, in the Nazaré canyon (~1150 individuals per 50cm²). Species richness is not obviously different between the stations (26 to 32 species). However, the very abundant fauna of the Nazaré canyon (station 43) is characterised by minimal species richness, and by the lowest values of the Shannon and Pielou's indices (see text-fig. 4a and 5a), as a consequence of the striking dominance of a single species (*Melonis barleeanus*).

The faunas at the two open slopes (stations 7 and 56) have similar Shannon indices (~3.0) and quite high Pielou's evenness values (~0.8) but they are characterised by rather different

TABLE 1

Concentrations of all of the biochemical compounds of organic matter expressed as C equivalents. Standard deviations are also indicated (sd).

	S-Open slope	N-Open slope	Cascais Canyon	Nazaré Canyon
Station	56	7	36	43
LAT °N	37.8329	40.1667	38.46522	39.59683
LONG °W	9.4751	9.83327	9.47487	9.40383
Depth (m)	1002	959	1021	897
mg Proteins g ⁻¹	0.70	0.35	1.34	1.20
sd	0.12	0.06	0.14	0.09
mg Carbohydrates g ⁻¹	0.93	0.27	0.72	0.91
sd	0.06	0.05	0.17	0.25
mg Lipids g ⁻¹	0.33	0.08	0.62	0.58
sd	0.02	0.01	0.10	0.13
mg Biopolymeric C g ⁻¹	1.96	0.71	2.68	2.68
sd	0.21	0.12	0.40	0.47
Protein/Carbohydrate	0.6	1.1	1.5	1.1
Total phytopigments µg g ⁻¹	15.45	3.84	54.81	42.09
sd	3.186	1.053	13.424	2.209

foraminiferal assemblages (text-figs. 4a, 5a). At station 56 (S slope) *Uvigerina mediterranea* (31%), *Nuttallides umboniferus* (10%), *Cyclammina* sp. (8%) and *Globobulimina affinis* (7%) dominate the foraminiferal fauna (see plates 1 and 2). At station 7 (N slope) *U. mediterranea* is the most abundant taxon (26% of the total foraminiferal abundance), followed by *M. barleeanus* (8%) and *Siphotextularia* sp. (6%).

The fauna of the Cascais canyon (station 36) is characterised by the co-dominance of *C. pachydermus* (26%) and *M. barleeanus* (20%), followed by *N. umboniferus* (9%) and *Chilostomella oolina* (7%). Compared with the Nazaré canyon station, this canyon shows higher values for the Shannon and Pielou's indices (text-figs. 4, 5), more similar to those at the open slope stations.

Assemblages of the Nazaré canyon (station 43) are characterised by the strong dominance of *M. barleeanus* (75%), followed by *C. oolina* (8%).

Statistical comparison of the faunas of the four stations

The multidimensional scaling analysis based on the >150µm-fauna in the topmost cm of the sediment reveals that the four stations are characterised by distinctly different foraminiferal assemblages (text-fig. 6a), with differences between the faunas of the two canyon stations as large as the differences between canyon and open slope faunas. Only the faunas of the two open slope stations are fairly similar. A very similar result is obtained for the >63µm fraction (text-fig. 6b).

The SIMPER analysis of the >150µm fraction (0-1cm layer) reveals that the large differences between the two canyon stations are mostly attributable to the abundance of *M. barleeanus* (accounting for 75% of the total dissimilarity). This species is about 25 times more abundant in the Nazaré than in the Cascais canyon. *Melonis barleeanus* is also the most important contributor (75-79%) to the dissimilarity between the faunas of the Nazaré canyon and of the two open slopes stations. *Cibicides pachydermus* (18%) and *U. mediterranea* (20%) contribute most to the difference between the Cascais canyon and the open slope faunas of stations 7 and 56, respectively. In fact, *U. mediterranea* is more abundant at the open slope stations, whereas *C. pachydermus* shows a higher abundance in the Cascais canyon.

Vertical distribution of “live” fauna and microhabitats

The vertical distribution of the “live” fauna in the topmost 10cm of the sediment is shown in text-figure 7. At all stations,

TABLE 2

Average living depth (ALD₁₀) of foraminiferal species and (in parentheses) the number of individuals on which the calculation is based. Only dominant taxa with a relative proportion ≥5% are shown. Microhabitats patterns are summarised as shallow infaunal (SI), intermediate infaunal (II) or deep infaunal taxa (DI).

Species	ALD ₁₀				Microhabitat
	St. 56	St. 7	St. 36	St. 43	
<i>Bulimina costata</i>	0.25 (5)			0.42 (3)	SI
<i>Bulimina inflata</i>	0.58 (6)	0.50 (2)			SI
<i>Chilostomella oolina</i>			1.13 (6)	2.58 (58)	SI
<i>Cibicides pachyderma</i>		0.50 (2)	0.52 (23)	0.44 (8)	SI
<i>Globobulimina affinis</i>	3.89 (7)	4.83 (3)		3.84 (25)	DI
<i>Clavulina cylindrica</i>				1.80 (24)	II
<i>Melonis barleeanus</i>	1.65 (5)	1.75 (5)	1.14 (18)	0.75 (529)	II
<i>Nuttallides umboniferus</i>	0.50 (10)	0.25 (1)	2.06 (8)		SI
<i>Uvigerina mediterranea</i>	0.71 (31)	0.31 (17)	1.00 (4)		SI
<i>Uvigerina peregrina</i>	1.00 (6)		0.25 (2)		SI
<i>Cyclammina</i> sp.	1.22 (8)		0.25 (1)		SI/II
<i>Siphotextularia</i> sp.		0.24 (4)			SI
ALD ₁₀ of the core	1.04 (101)	1.02 (66)	1.03 (90)	1.07 (709)	

“live” foraminifera show a maximum density in the topmost cm of the sediment and decrease with depth. At stations 56 and 7, the maximum density is found in the uppermost 0.5cm. At station 36 (Cascais canyon), there is a first high peak in the surface layer, and a second, minor density peak at 1.5-2cm depth. Below this layer, there is a clear decrease in density down to the bottom of the core. At station 43 the highest number of living foraminifera is observed in the 0.5-1cm layer.

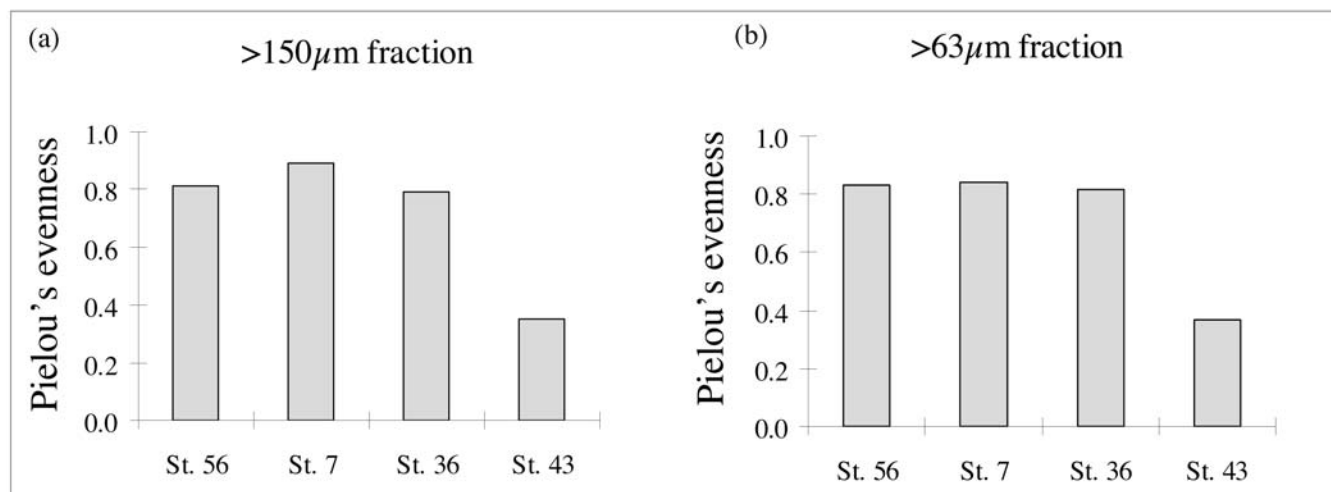
The vertical distribution of the most abundant taxa at each station is shown in text-figure 8 (a-d). The foraminiferal assemblage at station 56 (S slope; text-fig. 8a) shows a well-established microhabitat succession: there is a clear dominance of *U. mediterranea* in the first 1.5cm, where this taxon is accompanied by *N. umboniferus* and *Bulimina costata*. *Melonis barleeanus* is absent in the topmost layer, is present from 0.5 to 3cm depth and reaches a maximum in the 1-1.5cm layer. *Cyclammina* sp. is present in all layers, down to 3cm depth, where *G. affinis* becomes dominant.

At station 7 (N slope; text-fig. 8b) *U. mediterranea* is strongly dominant in the top cm, where it is accompanied by *Siphotextularia* sp., and absent in deeper layers, while a few individuals of *M. barleeanus* and *G. affinis* are present in the 1-3cm and 4-6cm layers respectively.

At station 36 (Cascais canyon; text-fig. 8c), the top 1.5cm of the sediment is characterised by a strong dominance of *C. pachydermus* and *M. barleeanus*, accompanied by *C. oolina*. At 1.5cm depth, a rather poor fauna dominated by *C. pachydermus* and *C. oolina* is replaced by a slightly richer fauna dominated by *N. umboniferus* and *M. barleeanus*. Below 2cm depth the living fauna becomes very scarce.

At station 43 (Nazaré canyon, text-fig. 8d), *M. barleeanus* strongly dominates the fauna down to 2cm, accompanied only by *C. oolina*, which attains a maximum abundance between 1.5 and 3cm, and by *Clavulina cylindrica* in the 0.5 to 2cm interval.

The ALD₁₀ values for the total fauna are rather similar for all stations (ranging from 1.02 and 1.07cm, Table 2). ALD₁₀ values calculated for the main species show that *Bulimina costata*, *Bulimina inflata*, *Cibicides pachydermus*, *Nuttallides umboniferus* and *Siphotextularia* sp. All share a clear preference for the topmost sediment layer. *Nuttallides umboniferus* (a su-



TEXT-FIGURE 5

Pielou's evenness values calculated for each station (a) for the total core (>150µm size fraction) and (b) for the 0-1cm layer (>63µm fraction).

perforated species at station 56) occurs at intermediate depths at station 36. *Melonis barleeanus* behaves like a typical intermediate infaunal taxon, except at station 43, where it is already present with a very high density in the 0-0.5cm layer. Finally, *Chilostomella oolina* and *Globobulimina affinis* occupy deep infaunal niches.

Foraminiferal abundance and community structure in the 63-150µm size fraction

The 63-150µm fraction is composed of juvenile specimens of taxa also found in the >150µm fraction, and some small opportunistic species. The abundance and species richness in the top-most 1cm of the sediment are illustrated in text-figure 9. As in the >150µm fraction, station 43 shows the highest abundance (~875 individuals 50cm⁻²), followed by stations 36 (~325 ind. 50cm⁻²), 56 (~275 ind. 50cm⁻²) and 7 (~125 ind. 50cm⁻²).

At station 56 (S slope), the main species (see text-fig. 10) are *Trifarina bradyi* (19%), *N. umboniferus* (14%) and *Epistominella exigua* (10%). *Uvigerina mediterranea*, which is dominant in the >150µm fraction at this station, is much less important (5.3%). At station 7 (N slope), the main species (see text-fig.10) are *T. bradyi* (11%) and *Trifarina pauperata* (17%). *Uvigerina mediterranea*, abundant in the > 150µm fraction, is absent here. At station 36 (Cascais canyon) only a few species exceed 5% of the foraminiferal assemblage: *Bolivina spathulata* (20%), *Bolivina seminuda* (11%), *Cassidulina carinata* (8%), *Melonis barleeanus* (7%) and *N. umboniferus* (5.3%). Station 43 (Nazaré canyon) shows a strong dominance of *M. barleeanus* (63%), and much lower densities of all other taxa (6% of *Sigmoilina distorta*). Shannon and Pielou's indices based on data obtained by combining the larger (>150µm) and smaller (63-150µm) size fractions for the top cm of each core, are shown in text-figures 4b and 5b. The results are very similar to those obtained for the faunas of the whole cores (0-10cm) of the >150µm fraction.

DISCUSSION

Oxygen concentrations in both bottom and interstitial waters, and the quantity and nutritional value of the sediment organic

matter, are generally considered as the major factors controlling benthic foraminiferal faunas (e.g., Corliss 1985; Altenbach et al. 1999; Jorissen et al. 2007). Turbulence and near-bottom currents can also impact the benthic biota (Schönfeld 2002). All the taxa we found are typical for the observed water depths. However none of the investigated stations yielded the assemblages described by Schönfeld (2002) in the Gulf of Cadiz and at the southern Portuguese continental margin (Schönfeld 1997) as being typical of the high-energy sites influenced by the Mediterranean Outflow Waters (MOW) (e.g., *Cibicides lobatulus*, *Cibicides refulgens*, *Deuterammmina ochracea*, *Planulina ariminensis*). This agrees well with the decreasing velocity of the MOW flow off Cape San Vicente (13cm s⁻¹), described by Nelson et al. (1993).

Open slope and canyon systems along the Portuguese margin were characterised by obvious differences in several environmental variables. This is expected to promote important differences between the benthic foraminiferal assemblages, in spite of the rather similar water depths.

Open slope areas

In open slope areas the supply of organic matter to the sea floor largely depends on superficial primary production and the water column depth (McCave 1975; Billett et al.1983; Lampitt 1985; Bruland et al. 1989; Auffret et al. 1994; Newton et al. 1994). Epping et al. (2002) estimated that only 1.3% to 4.5% of the annual primary production is deposited on the slope (200-2000m) in our study area, and that up to 165 gC m⁻² y⁻¹ are oxidised within the water column, transported by lateral advection, or channelled into the canyons. These authors also noted that sediment resuspension, promoted by tidal currents, internal waves and storms, may prolong the presence of organic matter in the water column overlying the slope. This may increase the consumption of more labile components before deposition, thus further lowering the nutritional quality of organic matter reaching the sea floor. These observations suggest that the open slopes of the Portuguese margin are potentially a source of labile organic carbon for the canyon and the adjacent abyssal plain.

TABLE 3

Main characteristics of the benthic foraminiferal assemblages found at open slopes and canyon areas in some previous studies. All foraminiferal abundances have been standardised to 50cm². Note that in Schmiedl et al. (2000) specimens >125µm have been counted, while in all others studies the reported results concern the >150µm foraminiferal size fraction.

	OPEN SLOPES			CANYONS		
	Dominant species	Total foraminiferal abundances	Nr species	Dominant species	Total fauna abundances	Nr species
This study Portuguese margin (~1000m)	<i>U. mediterranea</i> <i>N. umboniferus</i> <i>M. barleeanus</i> <i>G. affinis</i>	114-171 ind. 50 cm ²	31-32	<i>M. barleeanus</i> <i>C. oolina</i> <i>G. affinis</i> <i>C. pachydermus</i> (Cascais) <i>Bolivina</i> spp. (Cascais)	147-1142 ind. 50 cm ²	27-26
Koho et al. (2008) Portuguese margin (500m)	-	-	-	<i>M. barleeanus</i> <i>C. oolina</i> <i>Globobulimina</i> spp.	603 ind. 50 cm ²	45
Koho et al. (2007) Portuguese margin (927m)	-	-	-	<i>M. barleeanus</i> <i>C. oolina</i>	1583 ind. 50 cm ²	30
Hess et al. (submitted) Bay of Biscay (~500-700m)	-	-	-	<i>Bolivina subaeraniensis</i>	3000-6000 ind. 50 cm ²	38
Fontanier et al. (2002) Bay of Biscay (1012m)	<i>N. umboniferus</i> <i>U. mediterranea</i> <i>C. pachydermus</i> <i>Hoeglundina elegans</i> <i>U. peregrina</i> <i>M. barleeanus</i> <i>G. affinis</i> <i>C. oolina</i>	331 ind. 50 cm ²	40	-	-	-
Fontanier et al. (2006) Bay of Biscay (1000m)	<i>U. mediterranea</i> <i>U. peregrina</i>	125-670 ind. 50 cm ²	-	-	-	-
Fontanier et al. (2008) Bay of Biscay (980m)	<i>U. mediterranea</i> <i>Gyroidinoides orbicularis</i> <i>Rosalina bradyi</i> <i>M. barleeanus</i>	60-100 ind. 50 cm ²	40	-	-	-
Schmiedl et al. (2000) Mediterranean (800m)	<i>U. mediterranea</i>	207 ind. 50 cm ²	51-57	<i>U. peregrina</i> <i>U. mediterranea</i>	516 ind. 50 cm ²	67

The faunas in the > 150µm fraction at our two open slope stations have abundances of about 120 to 170 individuals per 50cm², and are dominated by *U. mediterranea*. Between 1 and 5cm, low numbers of the infaunal taxa *M. barleeanus* and *G. affinis* are found. Stations at a similar water depth in nearby, comparable open-slope settings were studied by Schmiedl et al. (2000) (Mediterranean), Fontanier et al. (2006) (Bay of Biscay) and Fontanier et al. (2008) (Mediterranean Sea; see Table 3 for a comparison of their results). A 1000m- deep site in the Bay of Biscay was sampled ten times between October 1997 and April 2001 to investigate foraminiferal faunas (Fontanier et al. 2006). The foraminiferal abundances in the > 150µm fraction varied from 125 to 670 individuals per 50cm². The densities of our faunas, sampled in September 2006, correspond to the lowest values reported by Fontanier et al. (2006), observed in June and October 1998. Abundances in the 63-150µm fraction (top 1cm) varied from 65 to 1075 ind./50cm²; again our values (125-275 ind./50cm²) are in the lower range of this data set.

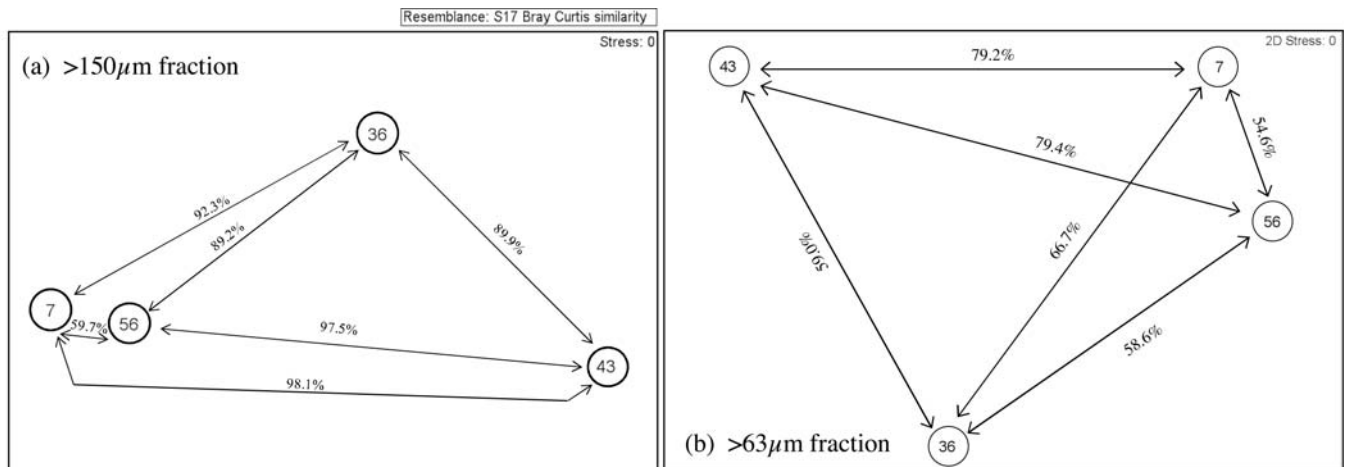
The species assemblages described by Fontanier et al. (2006) were very similar to the one described here for the open slope stations. In the >150µm fraction, the foraminifera are dominated by the superficially living taxa *Uvigerina peregrina*, *U. mediterranea* and *Hoeglundina elegans*. *Globobulimina affinis* is only a dominant species (living deeper in the sediment) during two out of the ten sampling periods.

At 800m depth on the open slope in the Gulf of Lions (Northern Mediterranean Sea), Schmiedl et al. (2000) described an assemblage dominated by *U. mediterranea*, and a poorly developed deep infauna, which according to the authors suggests a rather food-limited area. A rather similar fauna has been described at a 980m-deep station in the same area (Gulf of Lions) by Fontanier et al. (2008). These authors found a density of 60-100 ind./50cm², and a dominance of the shallow-infaunal species *U. mediterranea*, *Gyroidina orbicularis* and *Rosalina bradyi*.

Deeper infaunal species were rare. The environmental characteristics of our study area appear very similar to those reported by Fontanier et al. (2008), with a primary production ranging from 180 to 204g C m⁻² yr⁻¹ (Bosc et al. 2004), and C:N ratios in the sediment is >10, which together suggest that the sediment organic matter is of low nutritional value. Fontanier et al. (2008) suggested that the low sedimentation rates, resulting in long organic matter residence times at the sediment–water interface (via resuspension), could be responsible for an enhanced mineralization of labile organic compounds in the water column and at the sediment–water interface. The hypothesis of Fontanier et al. (2008) is supported by our results, which indicate a low average sediment accumulation rate at the southern open slope (station 56, 0.05g cm⁻² y⁻¹) and also a rather low content of bio-available organic matter and low protein to carbohydrate ratios (≤1). We hypothesize that the low concentration of bio-available organic components limited the foraminiferal abundances at these open slope stations.

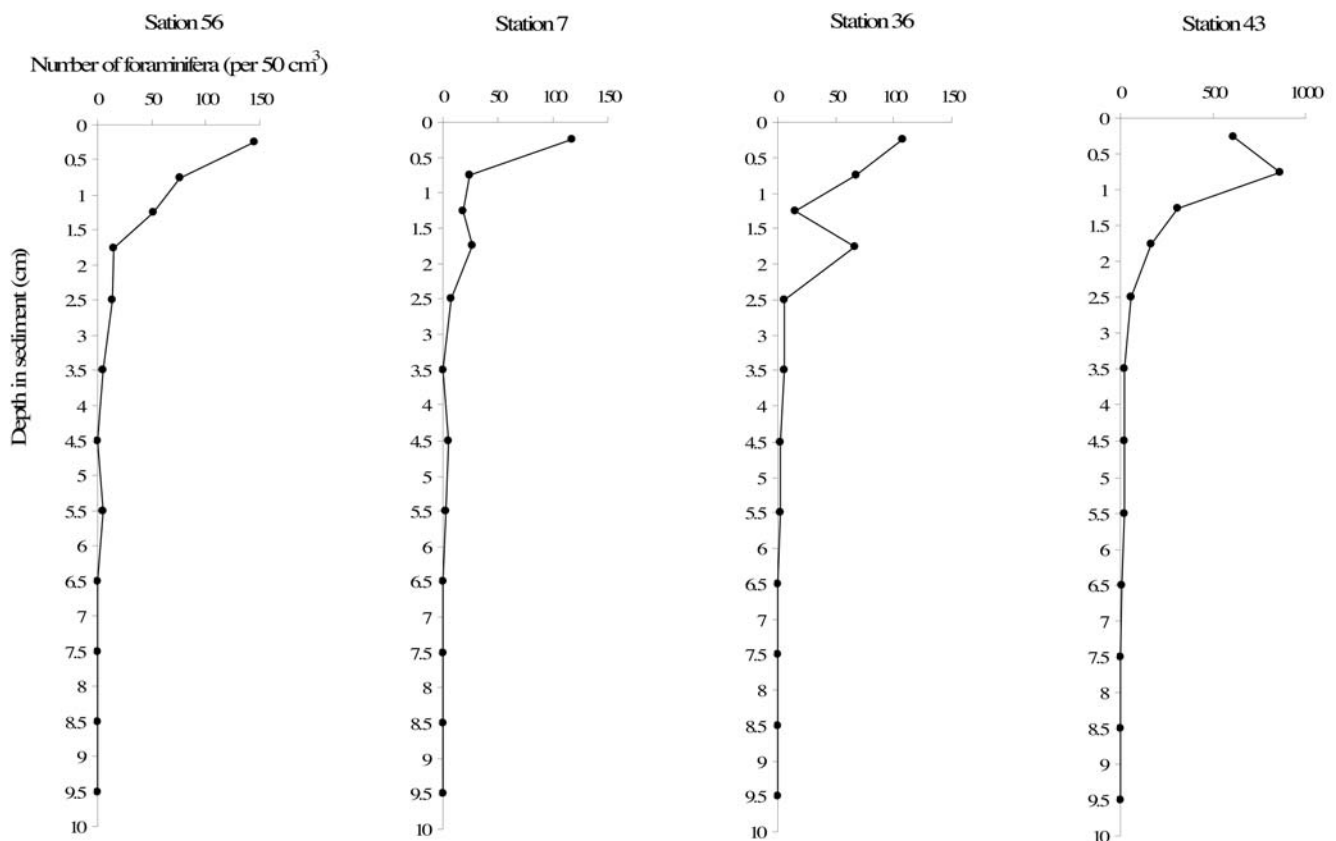
The high relative abundance of *U. mediterranea* at our open slope stations has also been described at open slope stations from similar water depths in the Bay of Biscay and the Mediterranean (Schmiedl et al. 2000; Fontanier et al. 2002; Fontanier et al. 2006; Fontanier et al. 2008). In fact, this species has been described in the western Mediterranean Sea as typical of upper slope environments with a labile organic-matter flux above 2.5gC m⁻² yr⁻¹ (De Rijk et al. 2000). This value agrees with the estimated organic flux values of Epping et al. (2002) for the Portuguese margin. In fact, these authors estimated that organic fluxes to the sea floor on the open slope of the Portuguese margin correspond to 1.3-4.5% of primary production in the euphotic zone (230-360 g m⁻² y⁻¹), or about 3-16 gC m⁻² y⁻¹.

Both open slope stations are characterised by a fairly poor superficial foraminiferal faunas, with a presence of low numbers of intermediate and deep infaunal taxa in deeper sediment lay-



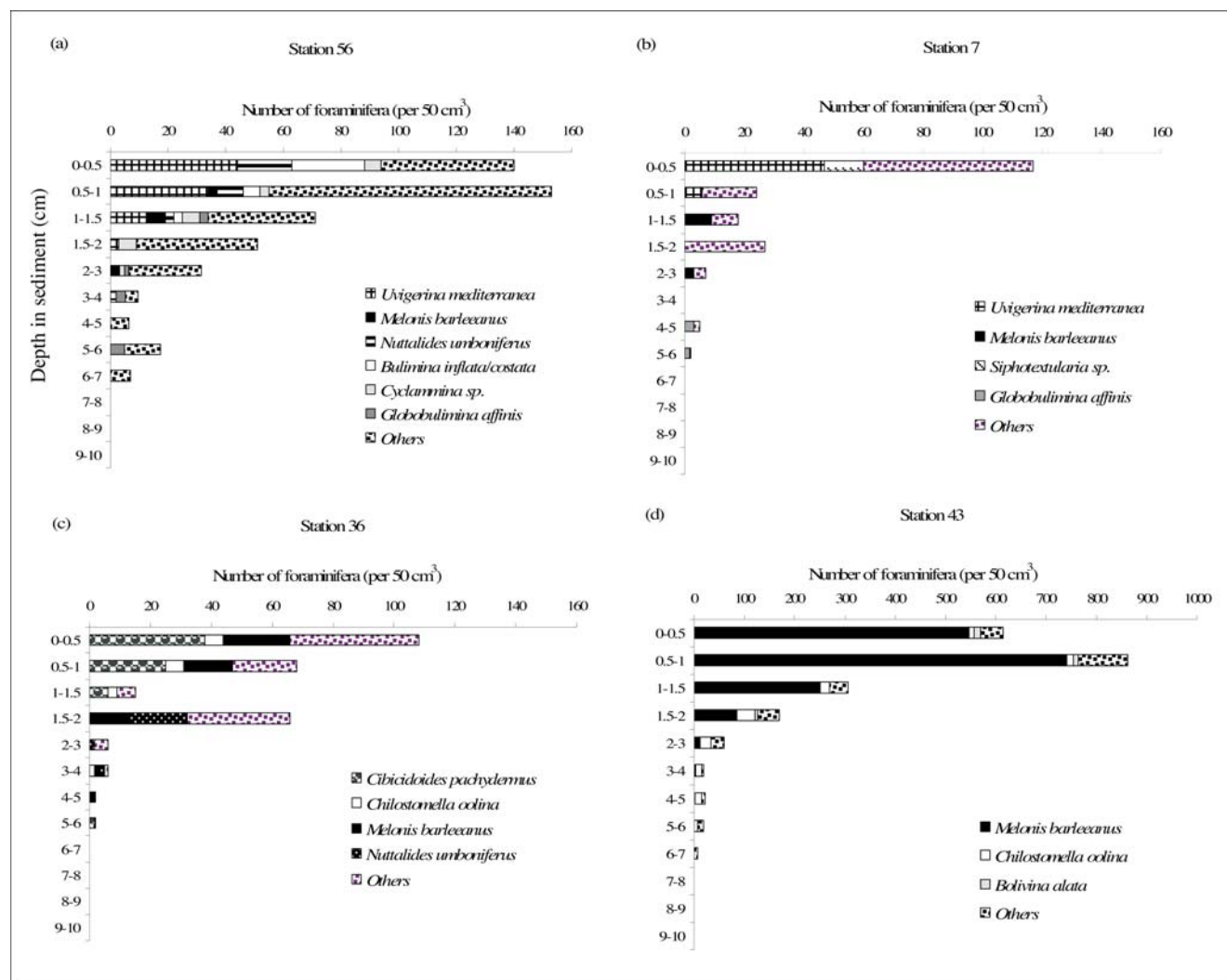
TEXT-FIGURE 6

Multidimensional scaling analysis based on the faunas of the top cm of each core: (a) only $>150\mu\text{m}$ fraction; (b) $>63\mu\text{m}$ fraction. The values on the arrows represent the degrees of dissimilarity between the faunas of the stations.



TEXT-FIGURE 7

Vertical distribution of the total fauna (standardised to 50cm^3) at each of the four sampling stations. Note the different horizontal scale for station 43.



TEXT-FIGURE 8 (a-d)

Vertical distribution of most abundant taxa (>5%) at each station. The number of individuals is expressed per 50cm³. Note the different horizontal scale for station 43.

ers. According to the TROX-model (Jorissen et al. 1995), which synthesises the dependence of foraminiferal microhabitats on food availability and benthic oxygenation, this suggests oligo- to mesotrophic conditions, with a fairly high oxygen penetration into the sediment.

When looking in detail, some differences between our two open slope stations can be observed. First of all, the abundances of both size-fractions are higher at site 56 (southern slope) than at site 7 (northern slope). Furthermore, at station 7, most of the fauna is found in the topmost 0.5cm, whereas at station 56, faunal density remains fairly high down to 1.5cm. These differences suggest a higher trophic status at station 56, which is corroborated by the higher quantity of biopolymeric carbon found at this southern site, indicative of a higher availability of metabolisable organic carbon (Pusceddu et al. 2009).

Submarine canyons

Active submarine canyons are dynamic systems, where large quantities of sediment are transported, together with organic

carbon, from the shelf to the deep ocean (Schmidt et al. 2001; Epping et al. 2002; Van Weering et al. 2002). They are often described as organic-enriched zones (e.g., Epping et al. 2002; Koho et al. 2007; Bianchelli et al. 2008; García and Thomsen 2008), highly influenced by strong physical disturbance (Koho et al. 2007). The faunas of the two investigated canyon stations are very different from those of the open slope stations, but there are also large differences between the two canyon sites. The sample from the Nazaré canyon station (station 43) yielded a very abundant foraminiferal fauna, but the lowest Shannon and evenness values, suggesting rather hostile environmental conditions for most taxa, but very favourable conditions for a few highly opportunistic taxa. Although the Nazaré canyon is an active submarine canyon, affected by important sediment redistribution phenomena (such as turbidites) and a high degree of environmental disturbance (de Stigter et al. 2007; Koho et al. 2007), high organic-matter content and low pore-water oxygen concentrations probably are the major environmental parameters influencing the assemblage of this station. In fact, the fauna we find, which is very close to the assemblages described by

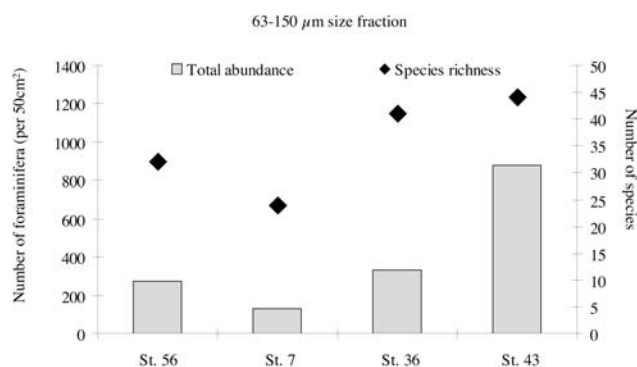
Koho et al. (2007) from the upper canyon terraces, indicates, as these authors suggest, the absence of sedimentary disturbance. This is suggested also by the occurrence of fragile agglutinated taxa, typical of lower-energy settings.

The faunal assemblages of Nazaré canyon are strongly dominated by a single species, *M. barleeanus*. This species generally lives at some centimetres depth in the sediment, in areas of low bottom-water oxygen concentration where nitrate reduction takes place (e.g., Corliss 1985; Jorissen et al. 1995, 1998; Ernst 2002; Fontanier et al. 2002, 2005; Licari et al. 2003; Koho et al. 2008). Its presence at shallow average living depths (uppermost 0.5cm layer) therefore suggests a very limited oxygen penetration of the sediment. Below 2cm depth in the sediment, *M. barleeanus* is replaced by *C. oolina*, a typically deep infaunal species that is adapted to live in strongly dysoxic to anoxic conditions (e.g. Corliss 1985; Mackensen and Douglas 1989; Sen Gupta and Machain-Castillo 1993; Jorissen et al. 1995; Schmiedl et al. 2000), and by *C. cylindrica* and *G. affinis*.

The same species are reported by Koho et al. (2008) at a 500m deep station in Lisbon-Sétubal Canyon (Portugal), sampled in October 2003 (see table 3). They described assemblages dominated by *M. barleeanus*, *C. oolina* and *Globobulimina* spp. (13%, 11% and 8% respectively), with a clear surface maximum of these taxa that normally live much deeper in the sediment. Similar assemblages are also described by Koho et al. (2007) in Nazaré Canyon (~ 1000m). They are characterised by high abundances (~1600 ind. 50cm⁻²) and a strong dominance of *M. barleeanus* and *C. oolina* (18% and 42% of the fauna, respectively), species both living relatively close to the sediment surface (an ALD₅ of 0.6cm and 1.5cm, respectively). Both in our samples and the samples of Koho et al. (2007, 2008), the very high densities of intermediate and deep species in superficial sediment layers, and the low numbers, or absence of the more regular surface-dwelling taxa (*U. mediterranea*, *U. peregrina*, *H. elegans*, etc.), strongly suggest a low-oxygen concentration at the sediment surface, and a low oxygen penetration into the sediment. This is probably the result of a very high sedimentary oxygen demand, due to the massive supply of metabolisable organic matter.

Station 36 in the Cascais canyon is characterised by an unusual mix of shallow (*C. pachydermus*), intermediate (*M. barleeanus*) and deep (*C. oolina*) infaunal species in the superficial sediment layers (0-1.5cm), suggesting a low oxygen penetration depth into the sediment. Deeper in the sediment, the fauna of the 1.5-2cm layer included 6 (out of a total of 21) live specimens of *N. umboniferus*, a normally superficial species (e.g., Corliss 1985; Corliss and Emerson 1990; Corliss 1991; Murray 1991), together with 2 live specimens of *U. mediterranea*. Although the numbers are low, the presence of these near-surface dwelling species deeper in the sediment is surprising, all the more so because *N. umboniferus* is completely absent in more superficial sediment layers.

This anomalous faunal distribution pattern could be the result of the recent, instantaneous deposition of a sediment layer several cm thick, which partially eroded and covered the earlier sediment surface. In our view, the foraminifera in the 1.5 to 2cm layer represent the former surface fauna, which was recently buried by a 1.5cm sediment layer. The fauna in the uppermost 1.5cm would have colonised the sea floor after this sediment deposition. Consequently, this assemblage may still



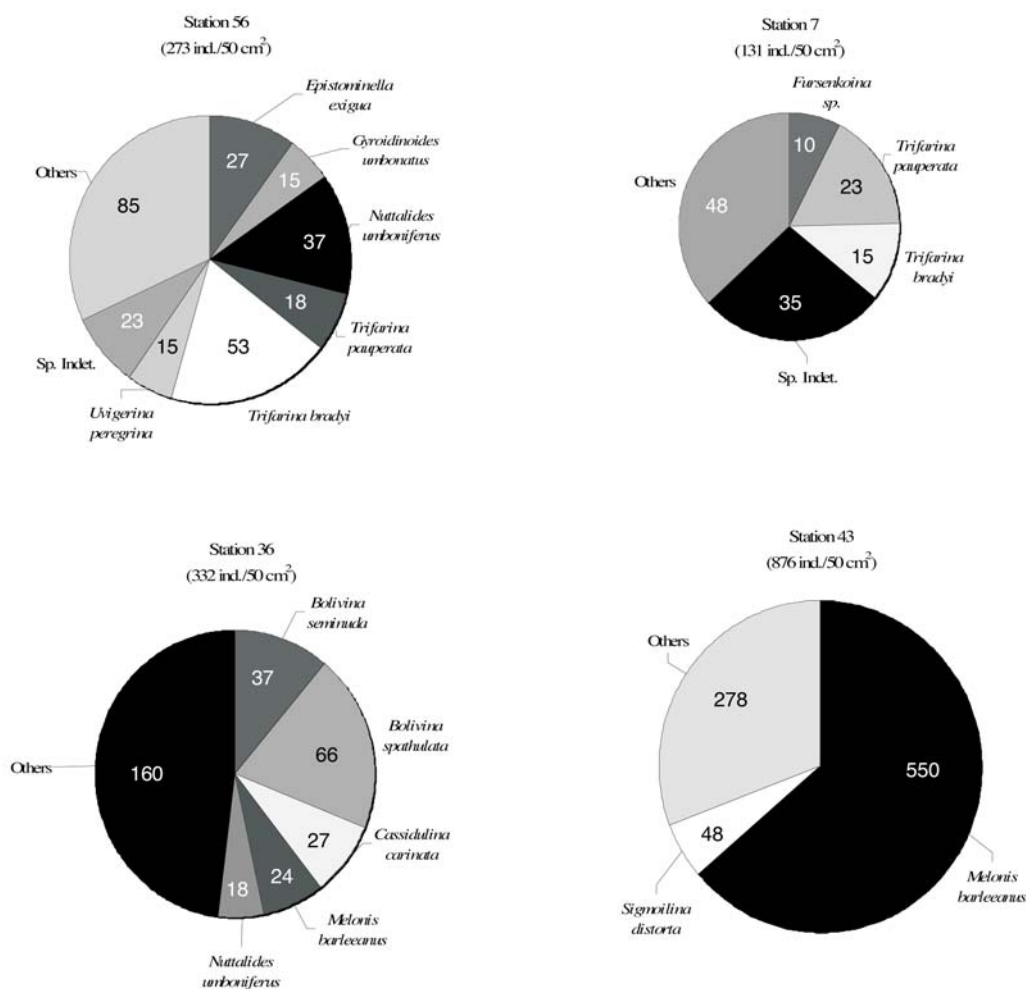
TEXT-FIGURE 9

Total abundance (per 50cm²) and species richness of the 63-150µm size fraction, in the 0-1cm layer.

be in an early stage of sediment re-colonisation. This would explain the fairly low faunal density in the >150µm fraction, which contrasts with the high nutritional value of the upper sediment at this site. Our interpretation is supported by the higher faunal density in the 63-150µm size fraction, which mainly consists of small opportunistic taxa, and the juveniles of larger opportunistic taxa. These could be early colonizers following our putative mass depositional event. According to this hypothesis, the poverty of the >150µm fraction reflects either the time required for the foraminifera to grow to this size, or the fact that more opportunistic species are generally small-sized. Such a situation is similar to that described by Hess et al. (2005), who analysed foraminiferal assemblages following a recent turbidite deposit in the Cape Breton Canyon (Bay of Biscay). They reported the persistence of rose-Bengal-stained foraminifera below an 8 to 18cm-thick turbidite 5 months after its deposition. This stained assemblage probably represented the fauna covered by the turbidite, 5 months earlier.

Our hypothesis is corroborated by the ²¹⁰Pb measurements performed on this core. The total ²¹⁰Pb profile (text-fig. 11) displays a homogeneous surface layer 1.5cm thick, suggesting either intense biological mixing, or the instantaneous deposition of this mud layer. The latter scenario is not unlikely in this canyon setting, especially in view of the high sedimentation rate of 4mm y⁻¹ calculated from the ²¹⁰Pb profile below 1.5cm, and the presence of turbiditic sands below 23cm. However, since the superficial mud layer is homogeneous and has a similar composition and particle size as the underlying sediment, it can not have been deposited by a turbidity current. It could be the result of the sliding of unconsolidated mud from the adjacent slope.

The superficial sediment at the Cascais canyon station displays the highest biopolymeric C concentrations and protein to carbohydrate ratio, which suggest the availability of large amounts of labile organic matter. As indicated earlier, this contrasts with the rather low faunal density in the >150µm fraction, but corresponds well with the dominance of *Bolivina* spp. in the 63-150µm fraction. Bolivinid species are often observed in organic C-rich and low-oxygen environments, which may occur after episodic mass waste depositional events (Sen Gupta and Machain-Castillo 1993; Bernhard and Sen Gupta 1999). High relative abundances of *Bolivina* spp. (in particular *Bolivina*



TEXT-FIGURE 10

Species composition of the 63-150µm size fraction. Only the most abundant taxa (>5%) are shown. Total number of individuals (per 50 cm²) of each species is indicated.

subaenariensis) are also described by Hess and Jorissen (2009) in the low diversity assemblages at 500 to 700m depth in the Cap Breton Canyon. They suggest that these assemblages reflect the strongly food-enriched and non-equilibrium conditions found in this depositional environment, and probably represent an early colonizing stage of a frequently-disturbed environment.

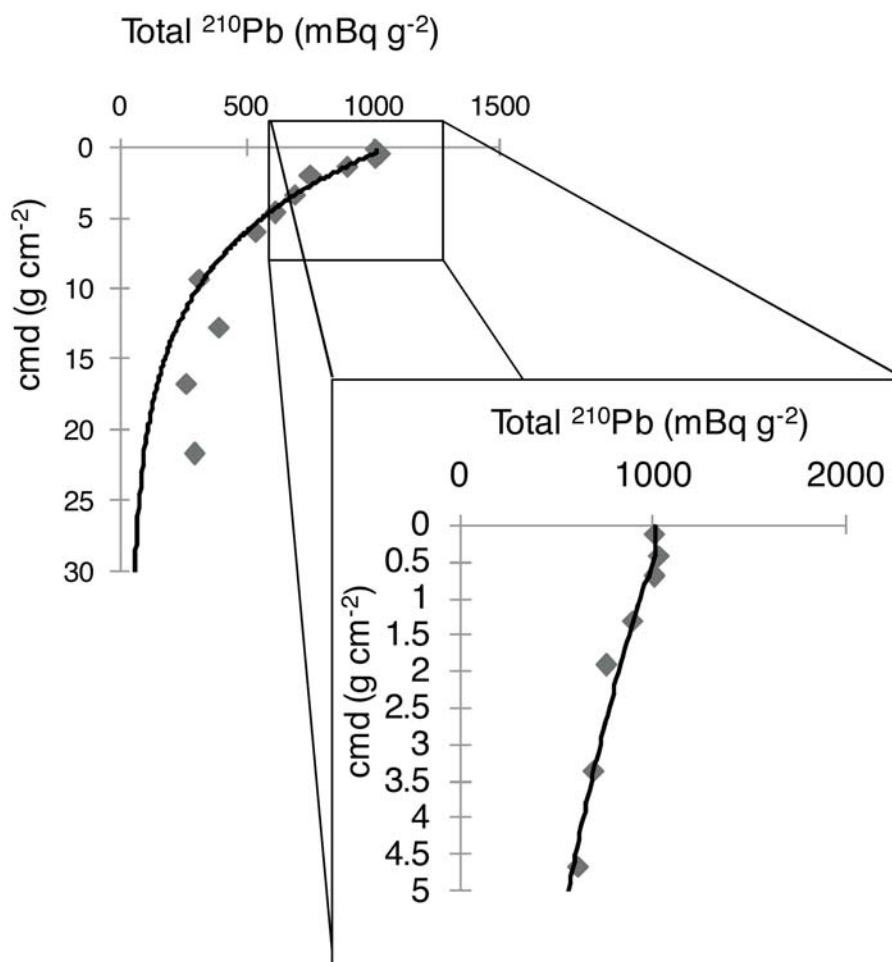
Comparison between open slopes and canyons

The two contrasting settings (i.e. canyons and open slopes) investigated in this study exhibit large environmental differences. In general, the open slope sediments are characterised by a lower quantity and a lower nutritional value of the sedimentary labile organic matter than the two canyons sites. The higher biopolymeric carbon values observed in the Nazaré canyon explain why the abundance of foraminifera is one order of magnitude higher here than at the three other stations. In agreement with previous studies performed in the Nazaré canyon by Epping et al. (2002) and García and Thomsen (2008), the difference in foraminiferal abundance between the Nazaré canyon and the two open slope stations could be explained by the differences in bio-available organic-matter quantity and nutri-

tional quality. Epping et al. (2002) suggest that the high organic-matter concentration in the canyon, and its decrease towards the adjacent open slopes, are the result of repetitive phases of resuspension and downward transport of sediments and organic matter from the open slopes to the canyon.

In contrast, the faunal density is fairly low at the Cascais canyon station, despite the high labile organic content. We think that this contradiction can be explained by a recent mass depositional event. After such an event, the faunas will probably need months to several years to fully re-colonise the site, and attain a maximal density (e.g., Hess et al. 2005). On the basis of a study of benthic foraminiferal faunas in Wilmington canyon, Jorissen et al. (1994) suggested that in case of repetitive mass deposit events, foraminiferal faunas could remain in early stages of ecosystem colonisation, explaining the low densities and poor occupation of deeper microhabitats in their study area.

The composition of the benthic foraminiferal assemblages also shows some remarkable differences between open slope and canyon areas. The two open slope stations are characterised by a high evenness, a strong presence of *U. mediterranea*, and some



TEXT-FIGURE 11
Curve of total ²¹⁰Pb values in the upper 25cm of the sediment of core 36, with a zoom on the first 5 centimetres.

species living in deeper sediment layers. This suggests a relatively well-oxygenated mesotrophic environment, related to a gradual decrease of organic flux towards deeper areas, as suggested by Fontanier et al. (2002; 2006), who found similar assemblages, with a slightly richer intermediate and deep infaunal component at stations on the open slope of the Bay of Biscay. At both investigated canyon stations, however, the assemblages are dominated by intermediate and deep infaunal species (*M. barleeanus* and *C. oolina*, respectively), which are present in the topmost sediment layer. According to the TROX-model (Jorissen et al. 1995), such dominance by deep infaunal taxa in the superficial sediments is indicative of highly eutrophic conditions with an abundance of organic matter, and probably a low bottom-water oxygen concentration and very limited oxygen penetration into the sediment.

The differences between open slope and canyon stations observed by Schmiedl et al. (2000) in the western Mediterranean Sea are much less evident than those reported here. In the canyon axis they found higher standing stocks compared to the open slope station (respectively ~500 and on average ~200 ind.

50cm⁻² of sediment). They explained this as a consequence of higher organic-matter availability in the canyon. On the other hand, they found a higher diversity and a well-developed vertical succession in their canyon station assemblages, suggesting a more stable environment than in our canyons. In fact, high abundances, low Shannon and Pielou's indices value, in Nazaré canyon, and also the peculiar vertical faunal succession in Cascais canyon suggest more hostile environments because of poorly oxygenated conditions at the Nazaré station and perhaps a recent sediment deposit at the Cascais canyon site.

CONCLUSIONS

Foraminiferal assemblages of the two investigated open slope stations are characterised by a fairly low abundance, high species richness and evenness, and the presence of low numbers of infaunal taxa deeper in the sediment. The low biopolymeric carbon contents suggest food-limited conditions for heterotrophic metabolism. Together, the foraminiferal and biogeochemical data indicate a rather stable environment, with oligo- to mesotrophic conditions and well-oxygenated pore waters in the

uppermost centimetres of the sediment. At the Nazaré canyon station, the strong dominance of intermediate and deep infaunal species in the superficial sediments and the very high abundances reflect eutrophic conditions, probably associated with a lower pore-water oxygen concentrations and free oxygen confined to the topmost millimetres of the sediments. These conditions are confirmed by the high biopolymeric carbon concentrations. The different species composition and the peculiar vertical species distribution found at the Cascais canyon station are apparently related instead to a recent depositional event. The fauna, consisting mainly of small opportunistic species, appears to represent a first stage of ecosystem recolonisation.

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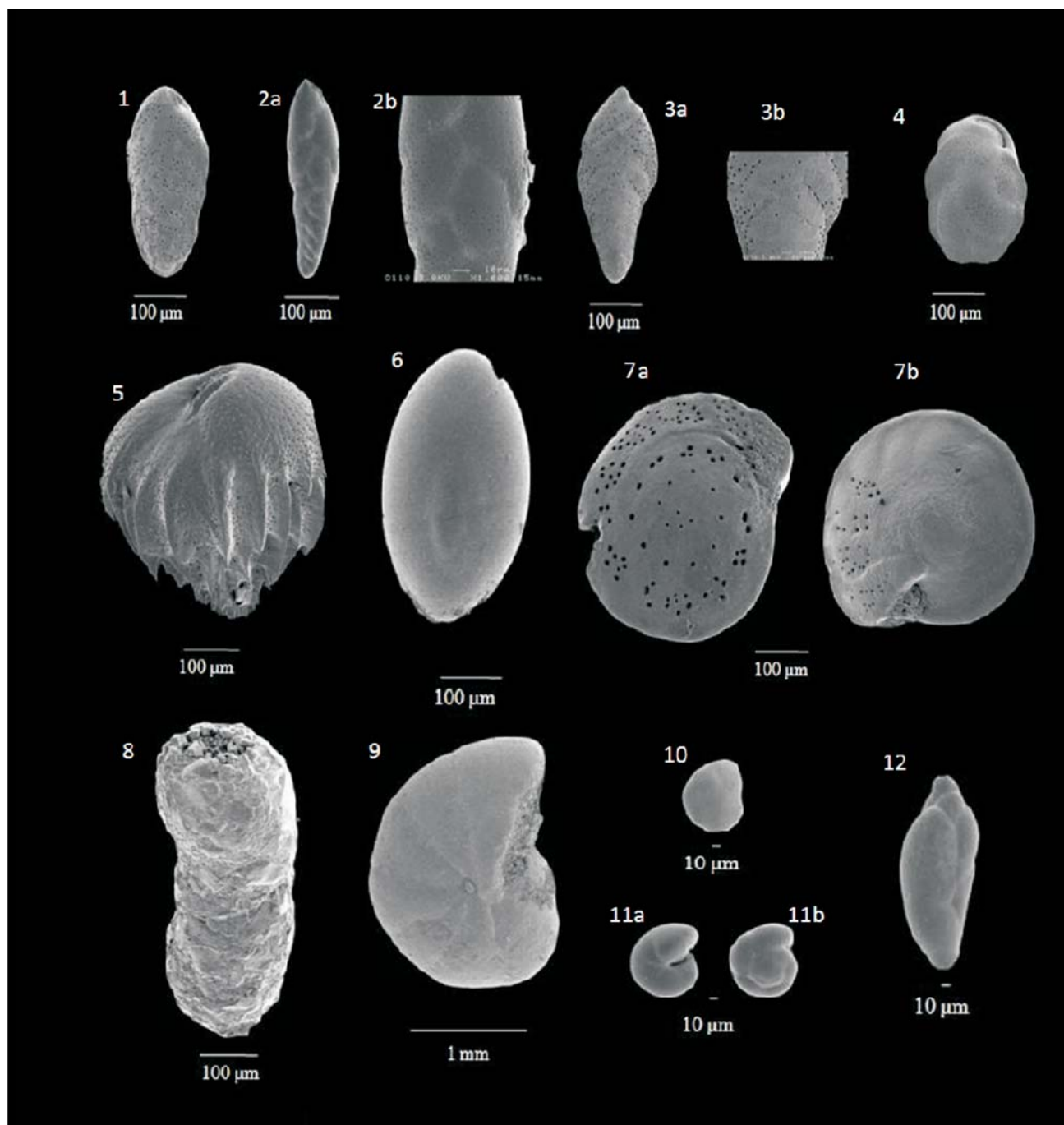


PLATE 1

- | | | | |
|----|--|----|--|
| 1 | <i>Bolivina spathulata</i> (Reuss 1850), ×200 | 7 | <i>Cibicidoides pachydermus</i> (Rzehac 1886), a) dorsal view, ×200; b) ventral view, ×200 |
| 2a | <i>Bolivina seminuda</i> (Cushman 1911), ×200; 2b detail, ×1000 | 8 | <i>Clavulina cylindrica</i> (d'Orbigny 1952), ×80 |
| 3a | <i>Bolivina dilatata</i> (Williamson 1858), ×200; 3b detail, ×1000 | 9 | <i>Cyclammina</i> sp., ×30 |
| 4 | <i>Cassidulina carinata</i> (Silvestri 1896), ×200 | 10 | <i>Epistominella exigua</i> (Brady 1884), dorsal view ×430 |
| 5 | <i>Bulimina inflata</i> (Seguenza 1862), ×200 | 11 | <i>Gyroidina umbonata</i> (Silvestri 1898), a) ventral view, ×400; b) dorsal view, ×400 |
| 6 | <i>Chilostomella oolina</i> (Schwager 1878), ×100 | 12 | <i>Fursenkoina</i> sp., ×400. |

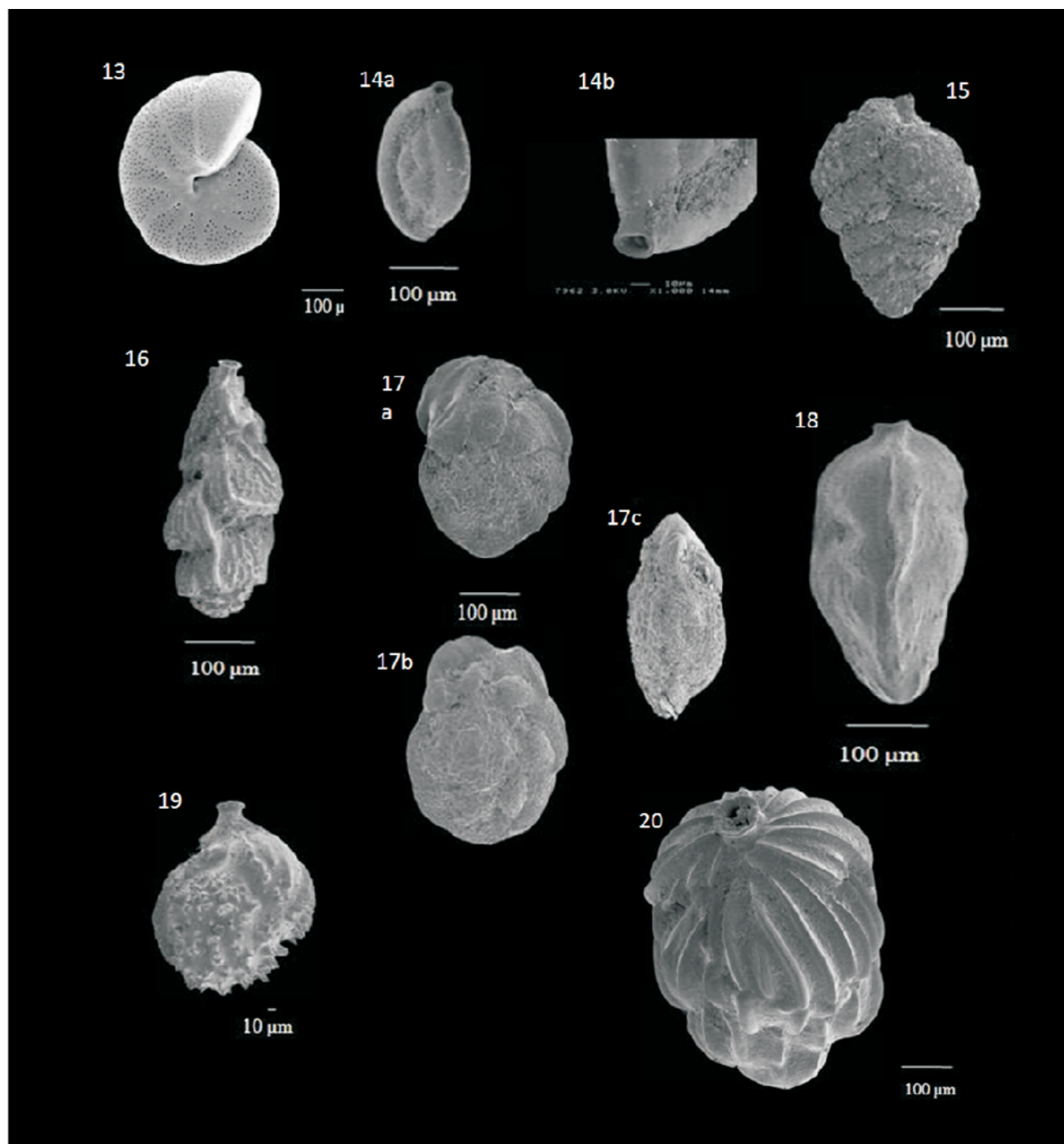


PLATE 2

- 13 *Melonis barleeanus* (Williamson 1858), ×100
 14a *Sigmoilina distorta* (Phleger and Parker 1951), ×250;
 15b. Detail of overture, ×1000
 15 *Siphotextularia* sp., ×200
 16 *Trifarina pauperata* (Heron- Allen & Earland), ×200
 17 *Nuttallides umboniferus* (Cushman 1933), a) ventral
 side, ×200; b) dorsal side, ×200; c) profile, ×200
 18 *Trifarina bradyi* (Cushman 1923), ×200
 19 *Uvigerina peregrina* (Cushman 1923), ×400
 20 *Uvigerina mediterranea* (Hofker 1932), ×200

APPENDIX 1

Census data for live benthic foraminifera in >150µm fraction.

Coe	43	43	43	43	43	43	43	43	43	43	43	43
depth (cm)	0-0.5	0.5-1	1-1.5	1.5-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
size (µm)	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150
<i>Ammonia arginulina</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammonia arginulina</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Amphicoryna scalaris</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina alata</i>	4	6	0	3	0	0	0	0	0	0	0	0
<i>Bolivina dilatata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina earlandi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina spatulata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina subaenariensis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bulinina costata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bulinina inflata</i>	2	1	0	0	0	0	0	0	0	0	0	0
<i>Cassidulina carinata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chilostomella coquina</i>	3	4	6	12	14	7	8	4	0	0	0	0
<i>Cibicides wuellerstorfi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cibicides pachydermus</i>	5	3	0	0	0	0	0	0	0	0	0	0
<i>Dentalina filiformis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gavelinopsis translucens</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina pseudorotundata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina rotundata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globobulimina affinis</i>	0	2	5	1	2	0	4	8	3	0	0	0
<i>Globocassidulina subulosa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gyroidina altiformis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gyroidinoides orbicularis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Hantzswania boueana</i>	0	9	0	0	0	0	0	0	0	0	0	0
<i>Hyalina bulbica</i>	4	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina peregrina</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina vortex</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Melonis barleeanus</i>	175	237	80	27	7	2	1	0	0	0	0	0
<i>Natalitides umboniferus</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Oridorsalis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Planulina ariminensis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Robertinoides</i> sp.1	1	0	0	0	0	0	0	0	0	0	0	0
<i>Rotamorphina involuta</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rotundina elegans</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Siphonina reticulata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Sphaeroidina bulloides</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spirillina</i> sp.	0	1	0	0	0	0	0	0	0	0	0	0
<i>Stilostomella columnaris</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trifarina angulosa</i>	0	0	0	0	0	1	0	0	0	0	0	0
<i>Trifarina bradyi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trifarina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina elongata striata</i>	0	0	1	0	0	0	0	0	0	0	0	0
<i>Uvigerina mediterranea</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina peregrina</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Valvulineria bradyana</i>	0	0	1	6	6	0	0	0	0	0	0	0
<i>Biloculinella cylindrica</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Biloculinella irregularis</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Cyclogyra</i> sp.	0	0	0	0	1	0	0	0	0	0	0	0
<i>Haplophragmoides</i> sp.	0	0	0	0	1	0	0	0	0	0	0	0
<i>Pyrgoella sphaera</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pyrgo bulloides</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pyrgo depressa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Quinqueloculina seminula vulgaris</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammodiscus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammoglobigerina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammoscalaria</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bigenerina nodosaria</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Clavulina cylindrica</i>	2	6	2	7	4	2	0	0	1	0	0	0
<i>Cribrostomoides subglobosum</i>	2	0	0	0	1	0	0	0	0	0	0	0
<i>Cyclammina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Discammina compressa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eggerella</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glomospira charoides</i>	0	2	3	1	0	0	0	0	0	0	0	0
<i>Karreriella bradyi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Paratrochammina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Reophax scorpiurus</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Reophax</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Siphotextularia</i> sp.	0	1	0	0	0	0	0	0	0	0	0	0
<i>Technitella legumen</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Textularia barkeri</i>	1	1	0	0	0	0	0	0	0	0	0	0
<i>Textularia sagittula</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trochaminella</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0
<i>Trochammina</i> sp.	0	1	0	0	0	0	0	0	0	0	0	0
Agglutinant indet.	0	0	0	0	0	0	0	0	0	0	0	0
Total	201	276	98	57	36	12	13	12	4	0	0	0
Arborescent taxa (fragments)	112	102	22	7	3	0	0	0	0	0	0	0
(whole specimens)	14	10	3	1	0	0	0	0	0	0	0	0

core	56	56	56	56	56	56	56	56	56	56	56	56
depth (cm)	0-0.5	0.5-1	1-1.5	1.5-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
size (µm)	> 150	> 150	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150
<i>Ammomarginalina foliaceae</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Amphicoryna scalaris</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Bolivina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina alata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina dilatata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina earlandi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina spathulata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina subenariensis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bulinina costata</i>	5	0	0	0	0	0	0	0	0	0	0	0
<i>Bulinina inflata</i>	3	2	1	0	0	0	0	0	0	0	0	0
<i>Cassidulina carinata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chilostomella oolina</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cibicides wuellerstorfi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cibicides pachydermus</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Dentalina filiformis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gavelinopsis translucens</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina pseudorotundata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina rotundata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globobulimina affinis</i>	0	0	1	0	1	2	0	3	0	0	0	0
<i>Globocassidulina subglobosa</i>	2	0	0	0	0	0	0	0	0	0	0	0
<i>Gyroidina altiformis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gyroidinoides orbicularis</i>	0	0	0	0	1	0	0	0	0	0	0	0
<i>Hanzawaia boueana</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Hyalinea balthica</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina peregrina</i>	1	1	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina vortex</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Melonis barleeanus</i>	0	1	2	0	2	0	0	0	0	0	0	0
<i>Nuttallides umboniferus</i>	6	3	1	0	0	0	0	0	0	0	0	0
<i>Oridorsalis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Planulina ariminensis</i>	2	0	0	0	0	0	0	0	0	0	0	0
<i>Robertinoides</i> sp.1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rotamorphina involuta</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Rotundina elegans</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Siphonina reticulata</i>	1	2	0	0	0	0	0	0	0	0	0	0
<i>Sphaeroidina bulloides</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spirillina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Stilostomella columnaris</i>	0	0	0	0	1	0	0	0	0	0	0	0
<i>Trifarina angulosa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trifarina bradyi</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Trifarina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina elongata striata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina mediterranea</i>	14	11	4	1	0	1	0	0	0	0	0	0
<i>Uvigerina peregrina</i>	1	2	2	1	0	0	0	0	0	0	0	0
<i>Valvulineria bradyana</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bilocalinella cilindrica</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Bilocalinella irregularis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cyclogyra</i> sp.	0	0	0	1	0	0	0	0	0	0	0	0
<i>Haplophragmoides</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pyrgoella sphaera</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pyrgo bulloides</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pyrgo depressa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Quinqueloculina seminula vulgaris</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammodiscus</i> sp.	0	0	1	0	0	0	0	0	0	0	0	0
<i>Ammoglobigerina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammoscalaria</i> sp.	3	0	0	0	0	0	0	0	0	0	0	0
<i>Bigennerina nodosaria</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Clavulina cylindrica</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cribratostomoides subglobosum</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cyclammina</i> sp.	2	1	2	2	1	0	0	0	0	0	0	0
<i>Discammina compressa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eggerella</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glomospira charoides</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Karrerella bradyi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Paratrochammina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Reophax scorpiurus</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Reophax</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0
<i>Siphotextularia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Technitella legumen</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Textularia barkeri</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Textularia sagittula</i>	0	0	0	0	1	0	0	0	0	0	0	0
<i>Trochammina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trochammina</i> sp.	0	0	1	0	0	0	0	0	0	0	0	0
Agglutinated indet.	1	0	1	0	0	0	0	0	0	0	0	0
Total	47	25	16	5	7	3	0	3	0	0	0	0
Arborescent taxa (fragments)	16	37	43	25	7	2	0	0	0	0	0	0
(whole specimens)	0	0	2	0	0	0	0	0	0	0	0	0

core	36	36	36	36	36	36	36	36	36	36	36	36
depth (cm)	0-0.5	0.5-1	1-1.5	1.5-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
size (µm)	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150
<i>Ammomarginulina foliacea</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Amphicoryna scalaris</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina</i> sp.	0	1	0	0	1	0	0	0	0	0	0	0
<i>Bolivina alata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina dilatata</i>	0	0	0	1	0	0	0	0	0	0	0	0
<i>Bolivina earlandi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina spanthulata</i>	0	0	0	4	0	0	0	0	0	0	0	0
<i>Bolivina subaenariensis</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Bulinina costata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bulinina inflata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cassidulina carinata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chilostomella oolina</i>	2	2	1	0	0	1	0	0	0	0	0	0
<i>Cibicides wuellerstorfi</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Cibicides pachyderma</i>	12	8	2	0	0	0	0	1	0	0	0	0
<i>Dentalina filiformis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gavelinopsis translucens</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina pseudorotundata</i>	0	0	0	1	0	0	0	0	0	0	0	0
<i>Glandulina rotundata</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Globobulimina affinis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globocassidulina subglobosa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gyroidina altiformis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gyroidinoides orbicularis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Hanzawaia boueana</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Hyalinea bathica</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina peregrina</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina vortex</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Melonix barleeanus</i>	7	5	0	4	0	1	1	0	0	0	0	0
<i>Nuttallides umboniferus</i>	0	0	0	6	1	1	0	0	0	0	0	0
<i>Oridorsalis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Planulina iriminensis</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Robertinoidea</i> sp.1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rotamorphina involuta</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rotundina elegans</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Siphonina reticulata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Sphaeroidina bulloides</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spirillina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Stilostomella columnaris</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trifarina angulosa</i>	0	0	1	2	0	0	0	0	0	0	0	0
<i>Trifarina bradyi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trifarina</i> sp.	0	1	0	1	1	0	0	0	0	0	0	0
<i>Uvigerina elongata striata</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina mediterranea</i>	2	0	0	2	0	0	0	0	0	0	0	0
<i>Uvigerina peregrina</i>	2	0	0	0	0	0	0	0	0	0	0	0
<i>Valvulineria bradyana</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bilocolinella cilindrica</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bilocolinella irregularis</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Cyclogyra</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Haplophragmoides</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pyrgoella sphaera</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Pyrgo bulloides</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Pyrgo depressa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Quinqueloculina semimula vulgaris</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammosdiscus</i> sp.	1	1	0	0	0	0	0	0	0	0	0	0
<i>Ammoglobigerina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammoscalaria</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bigenerina nodosaria</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Clavulina cylindrica</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cribrostomoides subglobosus</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cyclammina</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0
<i>Discammina compressa</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eggerella</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0
<i>Glomospira charoides</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Karreriella bradyi</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Paratrochammina</i> sp.	0	1	0	0	0	0	0	0	0	0	0	0
<i>Reophax scorpiarus</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Reophax</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Siphotextularia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Technitella legumen</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Textularia barkeri</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Textularia sagittula</i>	1	0	0	0	0	0	0	0	0	0	0	0
<i>Trochammina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trochammina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Agglutinated indet.</i>	0	0	1	0	0	0	0	0	0	0	0	0
Total	32	22	5	21	3	3	1	1	0	0	0	0
Arborescent taxa (fragments)	0	0	0	0	0	0	0	0	0	0	0	0
whole specimens)	0	0	0	0	0	0	0	0	0	0	0	0

N.B. Numbers are not standardised

APPENDIX 2

Census data for live benthic foraminifera in 63-150µm fraction

Core	43	43	56	56	7	7	36	36
depth (cm)	0-0.5	0.5-1	0-0.5	0.5-1	0-0.5	0.5-1	0-0.5	0.5-1
size (µm)	63-150	63-150	63-150	63-150	63-150	63-150	63-150	63-150
<i>Adercotryma glomerata</i>	0	0	0	0	1	0	0	0
<i>Alliatina primitiva</i>	4	6	0	0	2	0	0	0
<i>Anomalina</i> sp.	0	1	0	0	0	0	0	0
<i>Astacolus</i> sp.	0	0	0	0	0	0	2	0
<i>Bolivina alata</i>	0	0	0	0	0	0	0	0
<i>Bolivina albatrossi</i>	1	0	1	0	0	0	0	0
<i>Bolivina dilatata</i>	9	1	2	0	0	0	6	0
<i>Bolivina</i> sp.	1	0	0	0	1	0	1	0
<i>Bolivina seminuda</i>	0	0	0	0	0	0	7	16
<i>Bolivina spathulata</i>	1	1	2	1	0	0	33	8
<i>Bolivina striatula</i>	1	0	0	0	0	0	2	0
<i>Bolivina subaerariensis</i>	6	0	0	0	0	0	2	0
<i>Bulimina costata</i>	2	0	0	0	0	0	0	0
<i>Bulimina inflata</i>	6	0	4	1	0	0	3	0
<i>Bulimina rostrata</i>	0	0	3	1	0	0	1	0
<i>Bulimina</i> sp.	2	0	0	0	0	0	0	0
<i>Cassidulina carinata</i>	0	0	3	0	0	0	15	2
<i>Cassidulina crassa</i>	0	0	0	0	0	0	1	0
<i>Cassidinoides bradyi</i>	2	10	0	0	0	0	8	0
<i>Cassidinoides</i> sp.	0	0	0	0	0	0	0	5
<i>Chilostomella oolina</i>	0	3	0	0	0	0	5	0
<i>Cibicides lobatulus</i>	0	0	1	0	0	0	0	0
<i>Cibicides pachydermus</i>	5	0	0	1	0	0	3	0
<i>Cibicides</i> sp.	0	0	0	0	0	0	2	0
<i>Coryphostoma</i> sp.	0	0	0	1	0	0	0	0
<i>Dentalina advena</i>	0	0	0	0	0	0	1	0
<i>Dentalina intorta</i>	0	0	0	1	0	0	0	0
<i>Dentalina</i> sp.	0	0	0	0	0	0	1	2
<i>Discorbis</i> sp.	0	0	1	0	0	0	0	0
<i>Epistominella exigua</i>	0	0	13	4	0	0	0	0
<i>Fursenkoina</i> sp.	0	0	0	0	0	6	0	0
<i>Gavelinopsis translucens</i>	2	0	0	0	0	0	1	0
<i>Globocassidulina subglobosa</i>	0	0	4	0	1	0	0	0
<i>Gyrodina altiformis</i>	0	0	0	0	0	0	1	0
<i>Gyrodinoides orbicularis</i>	2	0	0	0	0	0	0	0
<i>Gyrodinoides subglobosus</i>	20	6	0	0	0	0	0	0
<i>Gyrodinoides umbonatus</i>	0	0	8	1	2	1	1	0
<i>Hanzawaia bowena</i>	0	1	0	0	0	0	0	0
<i>Hyalinea balthica</i>	6	1	0	0	0	0	0	0
<i>Lagena elongate</i>	0	0	1	0	0	0	0	0
<i>Lenticulina peregrine</i>	0	0	0	0	0	0	1	0
<i>Lenticulina</i> sp.	1	0	0	0	0	0	0	0
<i>Lenticulina vortex</i>	0	0	2	0	0	0	0	0
<i>Melonis barlecanus</i>	118	223	0	7	1	0	12	3
<i>Nonionella iridea</i>	0	0	0	0	0	1	0	0
<i>Nonionella turgida</i>	0	0	0	0	1	0	0	0
<i>Nuttallides umboniferus</i>	0	0	21	2	3	0	8	3
<i>Planulina oriminensis</i>	0	0	0	0	0	0	1	0
<i>Pullenia</i> sp.	12	2	0	0	1	0	4	1
<i>Rosalina</i> sp.1	0	0	4	1	0	0	0	1
<i>Saidovina karreriana</i>	1	0	0	0	0	0	0	0
<i>Trifarina angulosa</i>	1	0	0	0	0	2	0	0
<i>Trifarina bradyi</i>	0	1	24	9	11	0	1	2
<i>Trifarina pauperata</i>	1	0	12	0	14	0	6	2
<i>Uvigerina asperula</i>	0	0	1	0	1	0	0	0
<i>Uvigerina peregrine</i>	0	0	6	3	0	0	5	0
<i>Valvulineria bradyana</i>	1	1	0	0	0	0	0	0
Sp. Indet.	5	0	12	2	21	1	4	0
<i>Biloculinella cylindrica</i>	0	0	1	0	0	0	2	1
<i>Biloculinella inflata</i>	1	0	0	0	0	0	0	0
<i>Biloculinella irregularis</i>	0	0	0	0	0	0	0	1
<i>Cyclogvra</i> sp.	0	0	1	0	0	0	0	0
<i>Quinqueloculina oblonga</i>	5	6	0	0	0	0	0	0
<i>Quinqueloculina</i> sp.	0	0	0	0	1	1	0	0
<i>Sigmoilina distorta</i>	12	18	0	0	0	0	4	0
<i>Ammodiscus</i> sp.	5	0	0	0	0	0	0	0
<i>Ammodiscus globulosa</i>	3	0	0	0	0	0	0	0
<i>Ammodiscus</i> sp.	1	0	0	0	0	0	0	0
<i>Clavulina cylindrica</i>	0	0	0	0	2	0	0	0
<i>Cribrostomoides</i> sp.	1	0	0	0	0	0	5	0
<i>Eggerella</i> sp.	1	0	0	0	0	0	0	0
<i>Haplophragmoides</i> sp.	1	2	0	0	0	0	0	1
<i>Reophax</i> sp.	0	0	1	2	1	1	1	0
<i>Siphonotextularia affinis</i>	0	0	0	0	0	0	1	0
<i>Textularia sagittula</i>	0	0	4	0	1	0	2	1
<i>Textularia</i> sp.	1	2	0	1	1	1	0	0
Agglutinated indet.	3	0	0	0	2	0	2	0
Total	244	293	131	38	64	14	157	49
Arborescent taxa (fragments)	5	2	9	9	0	1	0	0
(whole specimens)	1	0	0	0	0	0	0	0

N.B. Numbers are not standardised

APPENDIX 3

Taxonomic references

SPECIES	REFERENCES
<i>Adercotryma glomerata</i> (Brady, 1878)	Jones (1994), pl. 34, Figs. 15-18
<i>Alliatina primitiva</i> (Cushman and McCulloch, 1939)	Allan Hancock, Pacific Expedition, vol.6
<i>Ammoglobigerina globulosa</i> (Cushman)= <i>Ammoglobigerina</i> (<i>Trachammina</i>) <i>globigeriniformis</i> (Parker & Jones, 1865)	Loeblich & Tappan (1994), pl.22, figs. 1-6
<i>Ammomarginulina foliacea</i> (Brady, 1881)	Jones (1994) <i>Eratidus foliaceus</i> , pl. 33, figs. 20-25
<i>Amphicoryna scalaris</i> (Batsch, 1791)	Jones (1994), pl. 63, Figs. 28-31
<i>Bigenerina nodosaria</i> (d'Orbigny, 1826)	Jones (1994), pl. 44, Figs. 19-24
<i>Biloculinella cylindrica</i> (Todd, 1948)	Sgarrella & Moncharmont Zei (1993), pl. 10, fig. 8
<i>Biloculinella inflata</i> (Wright, 1902)	Sgarrella & Moncharmont Zei (1993), pl. 10, fig.12
<i>Biloculinella irregularis</i> (d'Orbigny, 1839)	d'Orbigny (1839), pl.8, Figs. 20-21
<i>Bolivina alata</i> (Seguenza, 1862)	Schiebel (1992), pl.1, Fig. 2
<i>Bolivina albatrossi</i> (Cushman, 1922)	Schiebel (1992) pl. 1 Figs 1a-1b
<i>Bolivina dilatata</i> (Reuss, 1850)	Schiebel (1992), pl. 1, fig. 4a
<i>Bolivina earlandi</i>	Carballo & Garcia-Gomez (1995)
<i>Bolivina seminuda</i> (Cushman, 1911)	Barmawidjaja et al. (1992), pl. 2, figs. 1-4.
<i>Bolivina spathulata</i> (Williamson, 1858)	Jorissen (1987), pl.1, Fig. 5
<i>Bolivina striatula</i> (Cushman, 1922)	Carnegie Inst., pl. 3, Fig. 10
<i>Bolivina subaenariensis</i> (Cushman, 1922)	Phleger et al. (1953), pl.7, Figs. 24-25
<i>Bulimina costata</i> (d'Orbigny, 1826)	Van Leeuwen (1989), pl.8, Figs. 2-3
<i>Bulimina inflata</i> (Seguenza, 1862)	Van Leeuwen (1989), pl.8, Figs. 4
<i>Bulimina rostrata</i>	Van Leeuwen (1989), pl.8, Fig. 1
<i>Cassidulina carinata</i> (Silvestri, 1896)	Phleger et al. (1953), pl.9, Figs. 32-37
<i>Cassidulina crassa</i> (d'Orbigny, 1839)	Jones (1994), pl. 54, Figs. 4-5
<i>Cassidulinoides bradyi</i>	Sgarrella & Moncharmont Zei (1993), pl. 14, fig. 15
<i>Chilostomella oolina</i> (Schwager, 1878)	Jones (1994), pl.55, Figs. 12-14
<i>Cibicides lobatulus</i> (Walker & Jacob, 1798)	Jones (1994), pl.92, Figs. 10
<i>Cibicides wuellerstorfi</i> (Schwager, 1866)	Van Leeuwen (1989), pl.10, Figs. 1-9
<i>Cibicides pachydermus</i> (Rzehac, 1886)	Jones (1994), pl.94, Figs. 9
<i>Clavulina cylindrica</i> (d'Orbigny, 1952)	Hofker (1932), Figs. 18-19
<i>Cribratostomoides subglobosus</i> (Sars, 1868)	Jones (1994), pl. 34, Figs. 8-10
<i>Dentalina advena</i>	Jones (1994), pl. 63, Fig. 1
<i>Dentalina filiformis</i> (d'Orbigny, 1826)	Jones (1994), pl. 63, figs. 3-5
<i>Dentalina inornata</i> (d'Orbigny, 1846)	Sgarrella & Moncharmont Zei (1993), pl. 11, Fig.11
<i>Discammina compressa</i> (Goës)	Lobegeier & Sen Gupta (2008), pl. 4, figs 3a-3b
<i>Epistominella exigua</i> (Brady, 1884)	Schiebel (1992), pl. 5, Fig. 9
<i>Gavelinopsis translucens</i> (Phleger & Parker, 1951)	Schiebel (1992), pl. 4, Fig. 5
<i>Glandulina rotundata</i> (Reuss, 1850)= <i>Glandulina antarctica</i> (Parr, 1950)	Loeblich & Tappan (1994), pl.168, figs. 9-11= ref. for <i>Glandulina antarctica</i>
<i>Globobulimina affinis</i> (d'Orbigny, 1826)	Phleger et al. (1953), pl. 6, Fig. 32
<i>Globocassidulina subglobosa</i> (Brady, 1881)	Jones (1994), pl. 54, Fig. 17
<i>Glomospira charoides</i> (Jones & Parker, 1860)	Phleger et al. (1953), pl. 5, Fig. 1
<i>Gyroidina altiformis</i> (Stewart & Stewart, 1930)	Jorissen (1987), pl.1, Fig. 11
<i>Gyroidina orbicularis</i> (d'Orbigny, 1826)	Jorissen (1987), pl.1, Fig. 13
<i>Gyroidina umbonata</i> (Silvestri, 1898)	Parker (1958), pl.3, Figs. 19-20
<i>Gyroidinoides subglobosus</i> (Dailey, 1970)	Bolli, Beckmann, Saunders (1994), pl. 13, fig. 2
<i>Hanzawaia boueana</i> (d'Orbigny, 1846)	Jorissen (1987), pl. 3, Fig. 10
<i>Hyalinea balthica</i> (Schroeter, 1783)	Jones (1994), pl. 112, Fig. 1-2
<i>Karrerella bradyi</i> (Cushman, 1911)	Jones (1994), pl. 41, Fig. 1-4
<i>Lagena elongata</i> (Ehrenberg, 1844)	Sgarrella & Moncharmont Zei (1993), pl. 11, fig. 13
<i>Lenticulina peregrina</i> (Schwager, 1866)	Cushman & McCulloch (1950), pl. 39, Fig. 5
<i>Lenticulina vortex</i> (Fichtel & Moll, 1798)	Jones (1994), pl. 69, Fig. 14-16
<i>Melonis barleeanus</i> (Williamson, 1858)	Van Leeuwen (1989), pl. 13, Figs. 1-2
<i>Nonionella iridea</i> (Heron-Allen & Earland, 1932)	Heron-Allen & Earland, 1932, <i>Discovery Rept.</i> , v. 4, pl. 16, Figs. 14-16
<i>Nonionella turgida</i> (Williamson, 1858)	Jones (1994), pl. 109, Figs. 10-11
<i>Nuttallides umboniferus</i> (Cushman, 1933)	Van Leeuwen (1989), pl. 15, Figs. 11-13; pl. 16, Fig. 1-7
<i>Planulina ariminensis</i> d'Orbigny, 1826	Bremer et al. (1980), p. 23, pl. 3, figs. 5-7.
<i>Pyrgo bulloides</i> (d'Orbigny, 1826)	d'Orbigny (1826), p. 297, pl. 16, figs. 1-4.
<i>Pyrgo depressa</i> (d'Orbigny, 1826)	Jones (1994), pl. 2, Figs. 12, 16-17
<i>Pyrgoella sphaera</i> (d'Orbigny, 1839)	Jones (1994), pl. 2, Fig. 4
<i>Quinqueloculina oblonga</i> (Montagu)	Schiebel (1992) pl. 5, Fig. 2
<i>Quinqueloculina seminula</i> (Linné, 1758)	Jones (1994), pl. 5, Fig. 6
<i>Reophax scorpiurus</i> (Montfort, 1808)	Loeblich & Tappan (1988a, b), pl. 44, Figs. 1-3
<i>Rotamorphina involuta</i> (Parker, 1958)	Sgarrella & Moncharmont Zei (1993), pl. 19, fig. 1-3
<i>Saidovina karrieriana</i> (Brady, 1881)	Brady (1884), pl. 53, Figs. 19-21
<i>Sigmoilina distorta</i> (Phleger & Parker, 1951)	Sgarrella & Moncharmont Zei (1993), pl. 9, fig. 5
<i>Siphonina reticulata</i>	Sgarrella & Moncharmont Zei (1993), pl. 19, fig. 7-8
<i>Siphonotextularia affinis</i> (Fornasini, 1883)	Kohl (1985), pl. 2, Fig. 5
<i>Sphaeroidina bulloides</i> (Deshayes, 1832)	Jones (1994), pl. 84, Fig. 1-5
<i>Technitella legumen</i> (Norman, 1878)	Jones (1994), pl. 25, Fig. 8-10
<i>Textularia barkeri</i> (Hofker, 1978)= <i>Sahulita barkeri</i> Loeblich & Tappan, 1994	Loeblich & Tappan (1994), pl.32, Figs. 1-8
<i>Textularia sagittula</i> (Defrance, 1824)	Jorissen (1987), pl. 3, Fig. 12
<i>Trifarina angulosa</i> (Williamson, 1858)	Jorissen (1987), pl. 74, Fig. 17-18
<i>Trifarina bradyi</i> (Cushman, 1923)	Jones (1994), pl. 67, Figs. 1-3
<i>Trifarina pauperata</i> (Heron-Allen & Earland, 1932)	Timm (1992), pl. 6, Fig. 4
<i>Uvigerina elongatastriata</i> (Colom, 1952)	Van Der Zwann et al. (1986), pl. 6, Figs. 1-8
<i>Uvigerina mediterranea</i> (Hofker, 1932)	Jorissen (1987), pl.1, Fig. 2
<i>Uvigerina peregrina</i> (Cushman, 1923)	Van der Zwaan et al. (1986), pl. 1, Figs. 1-6
<i>Valvulineria bradyana</i> (Fornasini), 1900	Jorissen (1987), pl. 4, Figs. 1-2