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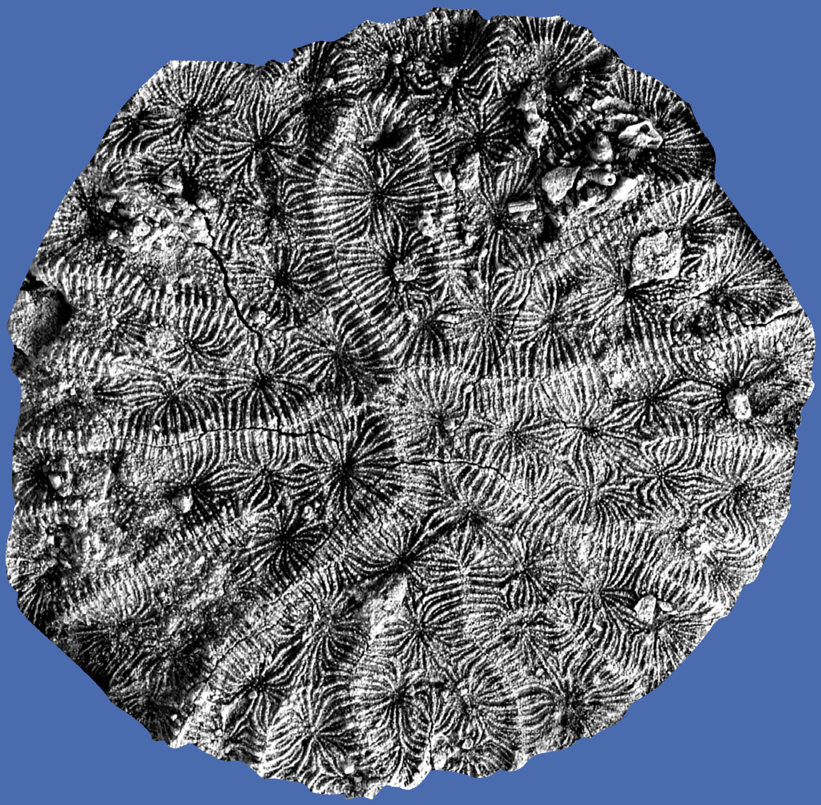

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Cover Illustration: Coral *Collignonastraea meandra* (d´Orbigny, 1850) from the Toarcian (Lower Jurassic) of the Kuh-e-Shisui area (Iran); PIW2004III 40. For details see Pandey & Fürsich: Jurassic corals from the Shemshak Formation of the Alborz Mountains, Iran, pp. 41-74 in this issue.

Umschlagbild: Koralle *Collignonastraea meandra* (d´Orbigny, 1850) aus dem Toarcium (Unterjura) der Gegend um Kuh-e-Shisui (Iran); PIW2004III 40. Für weitere Infomationen siehe Pandey & Fürsich: Jurassic corals from the Shemshak Formation of the Alborz Mountains, Iran, S. 41–74 in diesem Heft.

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Recent benthic foraminifera from the Tagus Prodelta and Estuary, Portugal: microhabitats, assemblage composition and stable isotopes

By
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Abstract

The distribution and microhabitat of living benthic foraminifera (15 calcareous and 6 agglutinated) have been studied in two box cores from the Tagus Prodelta. Stable oxygen and carbon isotopes were analysed for eight different species from six surface samples from the Tagus Prodelta and Estuary. At the two box core stations, most of the living foraminifera were restricted to the oxygenated top cm of the sediment and generally show a shallow infaunal behavior. Those taxa are e.g. *Rectuvigerina phlegeri*, *Stainforthia fusiformis* and species of the genus *Bolivina*, which is the most abundant genus in the Tagus Prodelta. Infaunal species are found down to 10 cm depth, and some infaunal taxa, e.g. *Bulimina marginata*, *Globobulimina auriculata* and *Nonionella turgida*, inhabit the low oxic or anoxic sediments. The deep infaunal species are suggested to feed selectively, on refractory organic matter or on the bacterial stocks, while the opportunistic shallow infaunal species are believed to feed on fresh phytodetritus or labile organic matter. Our data show that there is a close connection between the concentration of foraminifera and the distribution of organic matter in the area. The highest abundance of living benthic foraminifera was found in sediments close to the Tagus river plume, where the sediments have relatively high organic carbon contents. The spatial distribution of the stable isotope values of different benthic foraminifera reflects the distribution of the low salinity and relatively high temperature water with high organic carbon fluxes within the Tagus Estuary.

Key words: Portugal, Tagus, Prodelta, Estuary, benthic foraminifera, microhabitat, stable isotopes

Kurzfassung

An zwei Kastengreifer-Proben aus dem Prodelta des Tejo, Portugal, wurden die Verbreitung und Mikrohabitate von lebenden Benthosforaminiferen untersucht. Fünfzehn kalkschalige und 6 agglutinierende Arten wurden festgestellt. Stabile Sauerstoff- und Kohlenstoffisotope wurden an acht Arten gemessen, wobei 6 Oberflächenproben aus dem Prodelta und Ästuar des Tejo berücksichtigt wurden. In Oberflächensedimenten aus beiden Kastengreifern kommen die meisten lebenden Foraminiferen nur im obersten Zentimeter vor, wo oxische Bedingungen herrschen. Demgemäss zeigt die Mehrzahl der Arten eine flach-infaunale Siedlungsstruktur, wie z.B. *Rectuvigerina phlegeri*, *Stainforthia fusiformis* und Arten der Gattung *Bolivina*, die im Tejo Prodelta am häufigsten ist. Lebende Individuen von Arten der Infauna wurden bis in 10 cm Sedimenttiefe festgestellt. Einige von ihnen, besonders *Bulimina marginata*, *Globobulimina auriculata* und *Nonionella turgida*, besiedeln niedrig oxische bis anoxische Horizonte im Sediment. Diese tiefe Infauna ernährt sich wahrscheinlich von schwer abbaubaren organischen Substanzen oder Bakterien, während sich die opportunistischen Arten der flachlebenden Infauna von frischem Phytodetritus oder leicht abbaubarem organischen Material ernähren. Unsere Ergebnisse zeigen eine enge Beziehung zwischen der Foraminiferenhäufigkeit und der Verteilung von organischem Material im Untersuchungsgebiet. Die höchsten Siedlungsdichten wurden in unmittelbare Nähe der Suspensionswolke im Bereich der Tejo Mündung festgestellt, wo die Gehalte an organischem Kohlenstoff in den Oberflächensedimenten am höchsten sind. Die räumliche Verteilung der stabilen Isotopenwerte aus den Gehäusen der verschiedenen Foraminiferenarten spiegelt die Ausbreitung von niedrigsalinarem und vergleichsweise warmem Flusswasser und seiner mitgeführten Kohlenstofffracht im Tejo Ästuar wieder.

Schlüsselwörter: Portugal, Tagus, Prodelta, Ästuar, Benthosforaminiferen, Mikrohabitat, stabile Isotope

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1. Introduction

The microhabitat of a benthic foraminifera, which is depicted by the vertical distribution of a taxon in the first few cm of sediment, is controlled by the composite action of all physical, chemical and biological processes, and thus varies geographically and seasonally depending on these factors variability (Murray 1991, 2001). Several conceptual models have been advanced to describe the microhabitat of a benthic foraminifera in relation to food and oxygenation. Kaiho (1994, 1999) suggests that the dissolved oxygen and organic carbon flux are the main controlling factors for benthic foraminiferal assemblages. On that basis this author distinguishes three benthic environments, oxic, suboxic and dysoxic, and develops the so-called benthic foraminiferal oxygen index (BFOI). Jorissen et al. (1995) developed the TROX model that explains the microhabitat of benthic foraminifera as a function of the interplay between food availability, trophic conditions, and oxygen concentration. Furthermore, Van der Zwaan et al. (1999) include the redox gradient and degree of foraminiferal competition for labile organic matter in a refined TROX model. It has also been suggested that the quantity and quality of food particles are the most important parameters controlling the vertical distribution of benthic foraminifera (Altenbach &

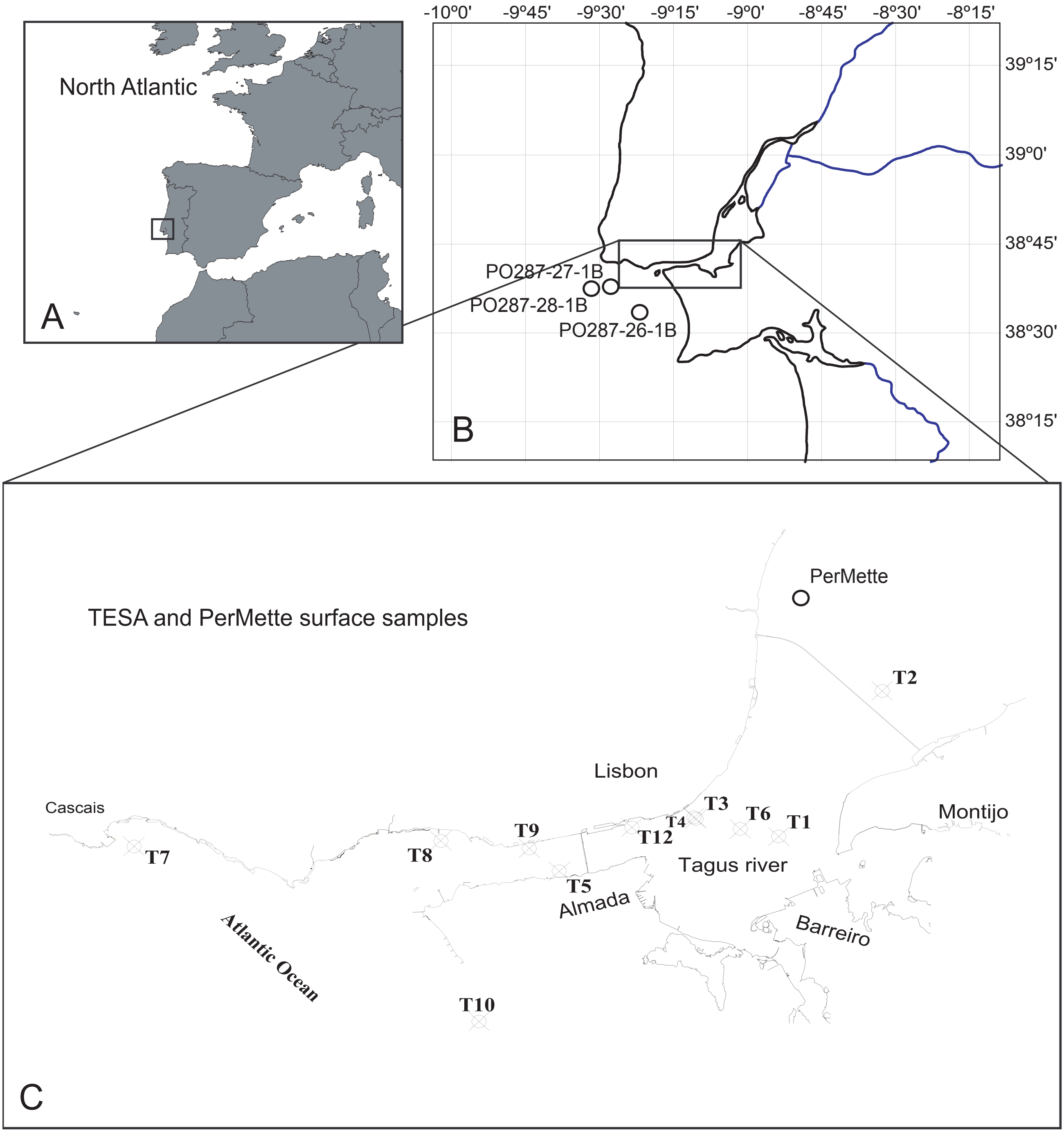

Figure 1: Location of box cores in the Tagus Prodelta (B) and surface samples in the Tagus Estuary (C) on the western Iberian Margin.

SARNTHEIN 1989; JORISSEN et al. 1998; FONTANIER et al. 2002).

The Tagus Prodelta is located in an area where productivity and local oceanography are controlled by the Tagus river input and seasonal coastal upwelling. The Tagus river is the longest river of the Iberian Peninsula, and extreme flood events lead to a major discharge of suspended and bed-load sediments (VALE 1981), especialy during winter months (TRIGO et al. 2002). The sediment deposited in the area is, therefore, characterized by high concentrations of organic matter, 0.1–2.3% in the Prodelta and up to 20% in the Tagus Estuary (GASPAR & MONTEIRO 1977; SIMAS et al. 2001). Furthermore, the Tagus Prodelta is influenced by seasonal (May to September) coastal upwelling, mainly by the Cape Roca upwelling filament (FIÚZA 1983, 1984; SOUSA & BRICAUD 1992; ABRANTES & MOITA 1999). According to ANTOINE & MOREL (1996), the primary productivity rates off Lisbon ranges between 0.6–1.6 g C m^{-2} d^{-1}.

The purpose of this study is to obtain an improved understanding of the benthic foraminiferal species dynamics, their use of different microhabitats and their trophic requirements. The spatial distribution of foraminiferal taxa and their stable oxygen and carbon isotope composition in the Tagus Prodelta and Estuary were studied in order to provide insights into the chemical and physical properties of the water masses as well as the spatial differences of organic carbon flux in the area.

2. Materials and methods

Three box cores PO287-26-1B (38°33.5'N, 09°21.8'W, 96 m depth), PO287-28-1B (38°37.5'N, 09°30.9'W, 105 m depth) and PO287-27-1B (38°38.0'N, 09°27.3'W, 85 m depth) were retrieved in the Tagus Prodelta during the PALEO 1 (287) cruise on the RV POSEIDON in April 2002 (Fig. 1B) (MONTEIRO et al. 2002). The cores were recovered with a giant box corer of 50x50 cm size.

After recovery, a subcorer of 10 cm in diameter was pushed into the box cores. The subcores were cut into 1 cm thick slices and the uppermost 10 cm of cores PO287-26-1B and PO287-28-1B were sampled at 1 cm intervals. In core PO287-27-1B, only a surface sample was taken from the uppermost cm of the sediment with a 50 cm^2 frame sampler. The samples were filled in jars and immediately conserved with 100–200 ml alcohol and Rose Bengal (2 g Rose Bengal/1 liter). The jars were shaken to assure homogeneous mixing and colouring.

Twelve additional surface samples were retrieved during two cruises in May 2003: TESA (T1-T10, T12) on Fisália of the class UAM (Unidade Auxiliar de Marinha) and PerMette on a private vessel. They were obtained with a small cylindrical dredge of 29 cm length and 5 cm in diameter with a 63 µm mesh as diaphragm on the bottom side (HYDROBIOS, Kiel). This dredge retrieves the top 2–3 cm of the surface sediment. These samples were conserved and stained as described above.

2.1 Foraminifera

In the laboratory, the samples were gently washed through 125 and 63 µm mesh screens by using distilled water. The samples were dried and further splits were made in order to reduce the number of living specimen per subsample. The 125 µm fraction was used for benthic foraminiferal analysis, and the assemblages were defined on the basis of the identification and counting of about 300 calcareous and 300 agglutinated specimens. The total assemblage was counted in samples with low concentration of living foraminifera. Most of the foraminifera were identified at species level. A plummer-cell for the reference of 32 taxa is deposited in the Bavarian State Collection for Palaeontology and Geology (Munich, Germany) under accession number BSPG 2006 VIII 1. Appendix A includes taxonomic notes for all of the taxa mentioned in the text as well as additional taxa deposited in the Plummer-cell (Appendix B).

The Rose Bengal staining was used to identify benthic foraminifera that were living at the time of sampling (WALTON 1952; LUTZE & ALTENBACH 1991; MURRAY & BOWSER 2000). One problem of this technique is that Rose Bengal may stain the protoplasm of dead foraminifera. This can be relatively well preserved for a considerable period of time under anoxic conditions that generally prevail deep in the sediment (BERNHARD 1988; CORLISS & EMERSON 1990). Another obstacle for the identification of the living foraminifera is that the shells may be coloured due to algal and bacterial activity. However, the bacterial material is often distinguishable by its relatively patchy dispersion within the test. In general, a specimen has been considered living at the time of sampling if at least one chamber, and preferably the proloculus, is evenly coloured. Due to lack of transparency of some agglutinated foraminifera, particularly the larger forms, only those with a clearly coloured aperture were considered living at the time of collection.

Bolivina dilatata and *Bolivina pacifica* were grouped as *Bolivina dilatata+pacifica* based on the presence of transitional forms between these two taxa. Our *Uvigerina* sp. is determined to the species *Uvigerina* sp. 221 of LUTZE (1986), and this species is hereafter called *Uvigerina* sp. 221.

In order to describe the vertical distribution of the individual living taxa and of the total calcareous and agglutinated fauna, the average living depth (ALD, JORISSEN et al. 1995) was calculated with the following formula:

$$\mathrm{ALD}x = \sum_{i=o,x} (n_i D_i) / N ,$$

where x represents the lower boundary of deepest sample, n_i the number of individuals in interval i, D_i the midpoint of sample interval i, and N the total number of individuals for all levels (Tabs 1, 2).

2.2 Sediments

The organic carbon, calcium carbonate content and grain size distribution were measured at 1 cm intervals in the two box cores PO287-26-1B and PO287-28-1B (Fig. 1B). The total carbon content was obtained with a LECO CHNS-932 elemental analyser, with an error in reproducibility of 0.03%. Samples were dried and grounded to powder. Two sets of samples were run, one for total carbon and one for inorganic carbon after removal of the organic carbon by burning at 400°C. Organic carbon was calculated as the difference between total and inorganic carbon. The nitrogen (total) content was also measured with the LECO CHNS-932 elemental analyser. The grain size (fraction <2 mm) distribution was determined with a Beckman

Table 1: Living foraminiferal taxa in the box core PO287-26-1B (no/86cc) and average living depth (ALD)

Species	Core depth (cm)										
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	ALD
Rectuvigerina phlegeri	917	288	199	259	183	195	120	88	77	60	2.87
Bulimina marginata	32	24	14	26	18	32	26	32	31	18	5.05
Bolivina dilatata+pacifica	1216	128	5	46	33	25	42	8	28	2	1.21
Globobulimina auriculata	53	44	10	6	2	3	2	3	0	0	1.85
Nonion asterizans	139	34	41	14	9	10	1	0	6	1	1.71
Bolivina striatula	309	44	20	29	16	15	6	4	4	5	1.50
Hanzawaia rhodinensis	0	4	1	7	4	5	3	3	2	0	4.74
Stainforthia fusiformis	235	72	2	20	12	0	4	1	1	0	1.14
Globobulimina turgida	11	68	15	11	14	7	2	0	0	0	2.33
Nonionella turgida	64	76	10	10	6	7	3	0	0	0	1.65
Cancris auriculus	21	12	9	8	7	7	5	9	13	3	4.11
Chilostomella ovoidea	96	34	7	13	0	4	1	0	1	0	1.28
Uvigerina sp. 221	11	10	7	3	11	3	1	2	3	0	0.89
Valvulineria bradyana	107	12	6	5	2	3	2	0	4	0	1.25
Cassidulina laevigata	43	4	2	4	12	4	1	0	0	0	1.85
Nouria polymorphinoides	256	29	40	17	4	8	4	1	3	1	1.27
Pseudobolivina fusiformis	320	13	0	2	1	1	1	1	1	0	0.64
Eggerelloides scabrus	40	21	32	15	23	19	23	13	14	25	4.42
Reophax calcareus	24	0	4	2	0	0	0	0	0	0	0.97
Adercotryma glomerata	16	6	4	1	3	1	1	0	0	0	1.75
Cribrostomoides triangularis	48	1	6	1	4	0	1	0	0	0	1.13
Total benthic calcareous	3328	878	359	476	336	328	221	153	173	90	2.17
Total agglutinated	744	87	104	47	48	41	38	26	23	33	1.95

Coulter Laser diffraction Particle Size Analyser LS230 to give the complete particle size distribution, although we are aware that this device ignores particle shape deviating significantly from spheres. Only the sand content (percentage >63 µm) is reported herein. The sedimentological analyses were performed at the Departamento de Geologia Marinha (INETI-DGM) laboratory, Portugal.

2.3 Stable isotopes

Oxygen and carbon isotopes were measured on eight different benthic foraminiferal species from sites PO287-26-1B, PO287-27-1B, PO287-28-1B, T4 (water depth 19.56 m), T9 (18.23 m) and PerMette (5.6 m) (Fig. 1). Species included are *Bolivina striatula*, *Globobulimina auriculata*, *Globobulimina turgida*, *Nonion asterizans*, *Rectuvigerina phlegeri*, *Uvigerina* sp. 221 and *Valvulineria bradyana* from the Tagus Prodelta surface samples (PO287-26-1B, PO287-27-1B and PO287-28-1B; Fig. 1B) and *Ammonia beccarii* from the Tagus Estuary (TESA 4, TESA 9 and PerMette; Fig. 1C). *Ammonia beccarii* was not present in the Tagus Prodelta surface samples. An average number of 10–30 specimens of each species from the >125 μm fraction was used for each measurement. Oxygen and carbon isotopes of the foraminiferal tests were analysed using a Finnigan MAT 251 mass spectrometer at the Department of Geosciences at the University of Bremen, Germany. All samples were measured relative to the VPDB standard, and the reproducibility of the internal "SHK" standard sample was 0.07‰ for $\delta^{18}O$ and 0.06‰ for $\delta^{13}C$ (M. Segl, pers. comm. 2004).

3. Results

3.1 Surface sediments and structures

While sampling, box cores PO287-26-1B and PO287-28-1B had water standing above the sediment surface, and due to core handling, some material, the upper few mm, were in suspension (very fine sediments). Holothurians were dwelling at the surface in both box cores.

The sediment of core PO287-26-1B consists of silt and silty clay. Worm tubes were quite abundant at the surface. The upper 3 cm were moderate olive brown in colour, whereas the underlying sediment was black and olive gray. Some black streaks of pyrite and some plates of mica were also found.

In core PO287-28-1B, the sediment consisted of silty clay. The surface was very soft, moderate olive brown with small worm tubes and small shell fragments. The upper 5 cm were moderate olive grey in colour, and below that the colour changed to olive grey, mottled with few black streaks. It is conceivable that the mottled part once had been of lighter coloured patches, due to burrows in the sediment.

3.2 Foraminifera

A total of 3375 individuals of living foraminifera were found in the entire succession at station PO287-26-1B, while only 1655 individuals were found at PO287-28-1B (see Tabs 1, 2). The species diversity was also higher at PO287-26-1B, with a total of 61 species (39 calcareous and 22 agglutinated),

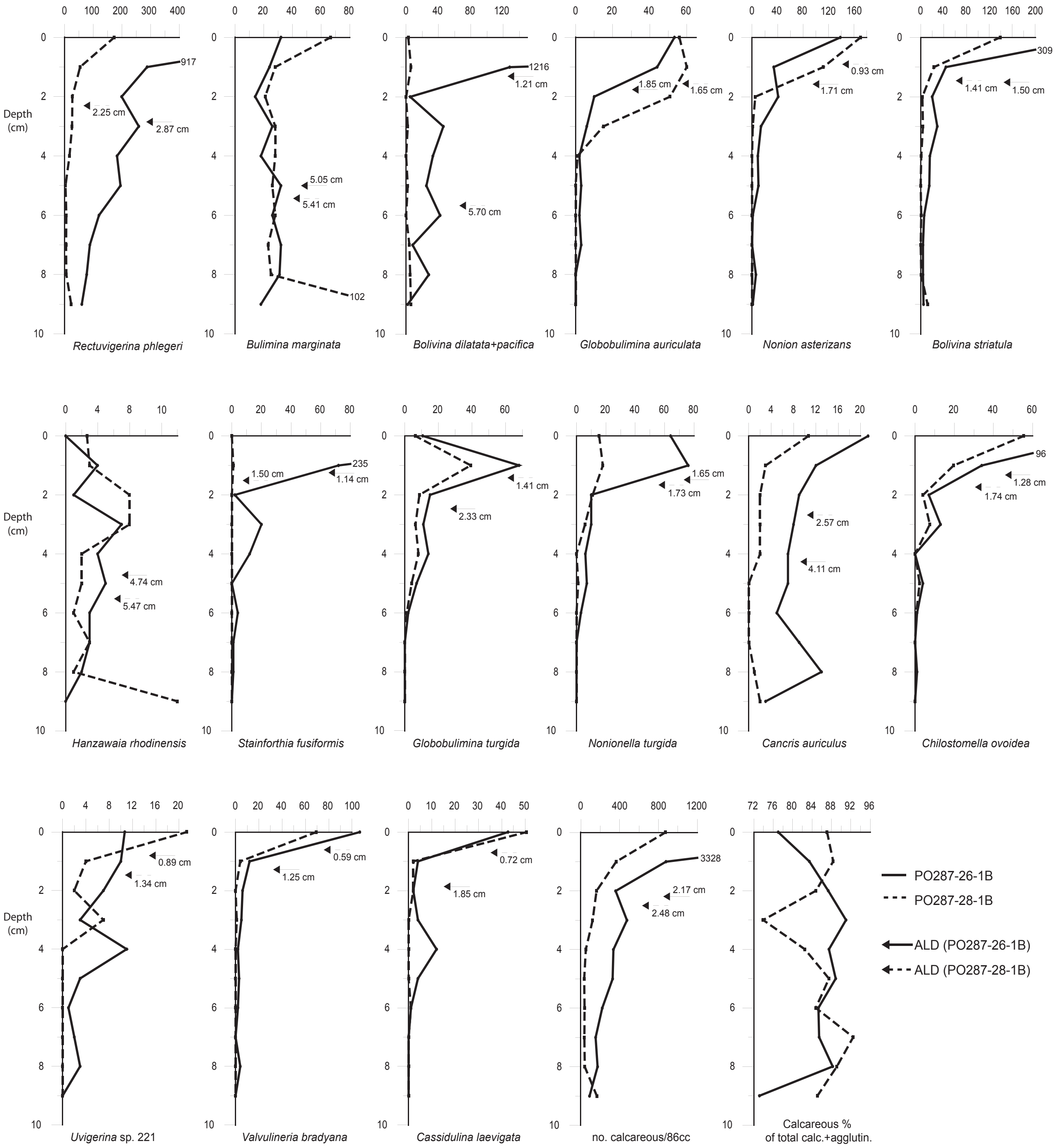

Figure 2: Distribution of 15 taxa of living calcareous foraminifera in the two box cores PO29827-26-1B and PO287-28-1B. The density is shown as number of specimens per 86cc. Average living depth (ALD) is indicated for each taxon in each of the two cores. The last two diagrams show the abundance distribution of the total calcareaous fauna in the cores, including their ALD, and the percentage of calcareous foraminifera of total benthic fauna (calcareous and agglutinated).

than at PO287-28-1B, where a total of 50 living species were found (31 calcareous and 19 agglutinated). Maximum foraminiferal population density was found in the uppermost cm of both cores, i.e. a total of 387/10 cm^3 in core PO287-26-1B and 101/10 cm^3 in core PO287-28-1B. The standing stock decreased rapidly in the second cm (Tabs 1, 2; Figs 2, 3).

Rectuvigerina phlegeri dominates the fauna at station PO287-26-1B with a relative abundance of about 44% of the calcaroues fauna, and it is the second most important species at PO287-28-1B. This species peaks in the first cm of both cores, and its ALD occurs at 2.87 cm in core PO287-26-1B and 2.25 cm in core PO287-28-1B (Fig. 2). *Bulimina*

Table 2: Living foraminiferal taxa in the box core PO287-28-1B (no/86cc) and average living depth (ALD)

Species	Core depth (cm)										
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	ALD
Rectuvigerina phlegeri	173	54	27	26	17	3	6	5	6	23	2.25
Bulimina marginata	67	28	21	28	28	26	28	23	25	102	5.41
Bolivina dilatata+pacifica	3	6	0	2	0	2	0	4	5	6	5.70
Globobulimina auriculata	56	60	51	15	1	0	0	0	0	0	1.65
Nonion asterizans	171	112	5	1	0	0	0	0	0	0	0.93
Bolivina striatula	139	23	3	4	1	0	1	0	1	12	1.41
Hanzawaia rhodinensis	3	3	8	8	2	2	1	3	1	14	5.47
Stainforthia fusiformis	0	1	0	0	0	0	0	0	0	0	1.50
Globobulimina turgida	29	13	10	2	1	0	0	0	1	0	1.41
Nonionella turgida	27	31	19	10	0	2	0	0	0	0	1.73
Cancris auriculus	11	3	2	2	2	0	0	0	1	2	2.57
Chilostomella ovoidea	16	14	4	7	0	0	0	0	0	1	1.74
Uvigerina sp. 221	21	4	2	7	0	0	0	0	0	0	1.34
Valvulineria bradyana	69	4	0	1	0	0	0	0	0	0	0.59
Cassidulina laevigata	51	2	2	0	0	0	1	0	0	0	0.72
Nouria polymorphinoides	101	15	0	3	1	0	0	0	0	4	1.01
Pseudobolivina fusiformis	0	0	0	0	0	0	0	0	0	0	
Eggerelloides scabrus	21	10	8	3	3	0	0	1	1	10	3.15
Reophax calcareus	45	4	2	11	1	0	0	0	0	2	1.46
Adercotryma glomerata	56	0	0	0	0	0	0	0	0	0	0.50
Cribrostomoides triangularis	5	0	0	1	0	0	0	0	0	0	0.97
Total benthic calcareous	872	365	162	122	52	35	39	37	41	166	2.48
Total agglutinated	344	48	29	43	11	5	7	3	5	29	1.77

marginata dominates the fauna at station PO287-28-1B with percentages oscillating around 43.6%. There is a high density of this specis throughout both cores with peak values at the top and bottom of core PO287-28-1B (Fig. 2). The ALD of *B. marginata* is deep in both cores, 5.05 cm (PO287-26-1B) and 5.41 cm (PO287-28-1B). *Cancris auriculus* and *Eggerelloides scabrus* show similar, relatively stable downcore distribution, while *Hanzawaia rhodinensis* fluctuates more. The ALD for these three species is 4.11 and 2.57 cm (*C. auriculus*), 4.42 and 3.15 (*E. scabrus*), 4.74 and 5.47 (*H. rhodinensis*), in cores PO287-26-1B and PO287-28-1B, respectively (Figs. 2, 3).

The *Bulimina dilatata+pacifica* group (3.6 and 12%), *Stainforthia fusiformis* (0 and 2.7%), *Chilostomella ovoidea* (1.4 and 1.5%), *Cassidulina laevigata* (0.8 and 1%) and *Uvigerina* sp. 221 (1 and 1.2%) are most frequent in the topmost cm and exhibit another smaller peak deeper in the sediment. The ALD is higher in core PO287-26-1B than in core PO287-28-1B for all the four taxa (Fig. 2).

Most of the agglutinated and some of the calcareous taxa in both cores PO287-26-1B and PO287-28-1B reach their highest density in the topmost sample; these are *N. asterizans, B. striatula*, *V. bradyana*, *Nouria polymorphinoides, Reophax calcareus, Adercotryma glomerata* and *Cribrostomoides triangularis*. Some of the agglutinated species show a minor peak around 2–4 cm depth. The ALD occurs at a very shallow level in both cores for all these species (Figs 2, 3). The agglutinated species *Pseudobolivina fusiformis* is only found in core PO287-26-1B, and almost all the living specimens occur in the uppermost sample.

Globobulimina auriculata (1.5 and 6.9%) peaks at 1–2 cm in core PO287-26-1B and at 1–3 cm in core PO287-28-1B, and it gradually dissappears below 4–5 cm in both cores. The ALD for this species is 1.85 cm for core PO287-26-1B and 1.65 cm for core PO287-28-1B. *Globobulimina turgida* (1.4 and 6.9%) and *Nonionella turgida* (2.1 and 3.7%) show similar distribution pattern in both cores with highest abundances at 1–2 cm depth (Fig. 2). A minor peak in *G. turgida* is observed at 4–5 cm depth. This species has ALD values of 2.33 cm and 1.41 cm for cores PO287-26-1B and PO287-28-1B, respectively, while the values for *N. turgida* are 1.65 and 1.73 (Fig. 2).

The ALD for the total calcareous foraminiferal fauna occurs at 2.17 cm in core PO287-26-1B and at 2.48 cm in core PO287-28-1B (Fig. 2). The ALD for all agglutinated foraminifera occurs at 1.95 cm in core PO287-26-1B and 1.77 cm in core PO287-28-1B (Fig. 3), which is shallower than for the calcareous foraminifera.

3.3 Sediments

In core PO287-26-1B, the sand fraction generally varies between 3 and 5%, but with a peak value of 12% at 5–6 cm depth. Generally, the values are lower, and fluctuate between 0 and 4.6%, in core PO287-28-1B (Fig. 3). The organic carbon content decreases slightly downcore in PO27-26-1B, while it shows a clearly increasing trend, from 1.6 to 2.1%, in PO287-28-1B. The $CaCO_3$ and the nitrogen contents show downcore decreasing trends in both cores. The Corg/N ratio fluctuates around 9.7 in core PO287-26-1B, while it increases downcore in PO287-28-1B.

Table 3: Stable isotopes of eight living benthic foraminifera in the Tagus Prodelta and Estuary.

Core number	Species	$\delta^{13}C$	$\delta^{18}O$
PO287-26-1B	*B. striatula*	-1,26	0,89
PO287-26-1B	*G. auriculata*	-1,03	1,29
PO287-26-1B	*G. turgida*	-1,87	1,12
PO287-26-1B	*N. asterizans*	-1,70	1,37
PO287-26-1B	*R. phlegeri*	-2,64	0,92
PO287-26-1B	*Uvigerina* sp. 221	-1,14	1,19
PO287-26-1B	*V. bradyana*	-1,34	0,53
PO287-27-1B	*B. striatula*	-1,60	0,98
PO287-27-1B	*G. auriculata*	-1,59	1,29
PO287-27-1B	*G. turgida*	-2,29	1,09
PO287-27-1B	*N. asterizans*	-2,20	1,16
PO287-27-1B	*R. phlegeri*	-3,64	1,08
PO287-27-1B	*V. bradyana*	-2,13	0,63
PO287-28-1B	*B. striatula*	-1,14	1,01
PO287-28-1B	*G. auriculata*	-0,93	1,42
PO287-28-1B	*G. turgida*	-1,43	1,18
PO287-28-1B	*N. asterizans*	-1,52	1,25
PO287-28-1B	*R. phlegeri*	-2,35	1,02
PO287-28-1B	*Uvigerina* sp. 221	-1,21	1,22
PO287-28-1B	*V. bradyana*	-1,23	0,59
TESA9	*A. beccarii*	-5,84	-1,74
TESA4	*A. beccarii*	-4,34	-1,19
PerMette	*A. beccarii*	-8,17	-2,44

3.4 Stable isotopes

Stable isotope values vary considerably, not only from one species to another, but also between different areas of the Tagus Estuary and Prodelta (Fig. 4A, B; Tab. 3). The $\delta^{18}O$ of *B. striatula* (0.89 to 1.01‰) and *G. auriculata* (1.29 to 1.42‰), display the highest values at station PO287-28-1B (Fig. 4A) and lowest at station PO287-26-1B, while *Uvigerina* sp. 221 (1.19 to 1.22‰) has its highest values at PO287-28-1B (not measured at PO287-27-1B). *Rectuvigerina phlegeri* (0.92 to 1.08‰) and *V. bradyana* (0.53 to 0.63‰) show highest $\delta^{18}O$ at PO287-27-1B and lowest at PO287-26-1B, while *N. asterizans* (1.16 to 1.37‰) displays the opposite pattern (Fig. 4A). *Globobulimina turgida* (1.09 to 1.18‰) has its highest $\delta^{18}O$ values at PO287-28-1B and lowest at PO287-27-1B (Fig. 4A; Tab. 3).

The $\delta^{18}O$ values of *A. beccarii* decreases from -1.19 to -2.44, with the highest value in the middle Estuary (TESA 4), and the lowest at the innermost station (PerMette) (Fig. 4B; Tab. 3).

The $\delta^{13}C$ of *B. striatula* (-1.14 to -1.60‰), *G. auriculata* (-0.93 to -1.59‰), *G. turgida* (-1.43 to -2.29‰), *V. bradyana* (-1.23 to -2.13‰), *N. asterizans* (-1.52 to -2.20‰) and *R. phlegeri* (-2.35 to -3.64‰) display the lowest values at station PO287-27-1B and the highest values at PO287-28-1B (Fig. 4A). *Uvigerina* sp. 221 (-1.21 to -1.14‰) has higher $\delta^{13}C$ values at PO287-26-1B than at PO287-28-1B.

The $\delta^{13}C$ values of *A. beccarii* (Fig. 4B) decrease from -4.34‰ and -5.84‰ in the middle and outer part of the Tagus Estuary (TESA 4, TESA 9) to -8.17‰ at the innermost station, PerMette (Fig. 4B; Tab. 3).

The oxygen and carbon isotope values of the water from the sediment-water interface at the two core sites, PO287-26-1B and PO287-28-1B differ substantially from the values obtained from living benthic foraminifera: The $\delta^{18}O$ was slightly lower at PO287-28-1B, 0.66–0.68‰ SMOW, than at PO287-26-1B, 0.65–0.72‰ SMOW. The $\delta^{13}C$ was also lower at PO287-28-1B (0.765‰) than at PO287-26-1B (0.788‰).

4. Discussion

4.1 Microhabitat and environmental indication

At both sites, the living foraminifera are strongly concentrated in the oxygenated sediment top layer, where the labile organic matter is easily consumed. The taxa living in the topmost cm are termed as epifaunal or shallow infaunal (Jorissen 1999). In the present study, these taxa are, e.g., *R. phlegeri*, *B. dilatata+pacifica*, *S. fusiformis*, *B. striatula*, *N. asterizans*, *C. ovoidea*, *V. bradyana*, *C. laevigata* and *Uvigerina* sp. 221, as well as most of the agglutinated taxa, with the exception of only *E. scabrus*.

The most abundant foraminiferal taxon in the Tagus Prodelta is the genus *Bolivina*. The shell structure of this genus, cylindrical or ovate shaped, is common for regions of anoxic, as well as suboxic and hypoxic waters, and/or high flux rates of organic matter (Harman 1964; Bernhard 1986). However, Fontanier et al. (2002) found species of the genus *Bolivina* in the well-oxygenated first half cm. Moreover, as concluded by Barmawidjaja et al. (1992), the ornamented *B. striatula* is limited to the sediment surface, while the unornamented *B. dilatata* is more infaunal. In the Tagus Prodelta, these two taxa both inhabit the topmost cm of the sediment and both are more abundant in sediments closer to the river plume (PO287-26-1B) than at the more oceanic site (PO287-28-1B). This gradient may depict a preference for high flux rates of organic matter.

The dominant species *R. phlegeri* also occupies the topmost cm of the sediment but is found down to a considerable depth in core PO287-26-1B. This might indicate an opportunistic behaviour with a preference for labile organic matter but the capability to use other food resources in relation to altered organic matter. Guimerans & Currado (1999) and Schiebel (1992) relate this species to fine-grained sediments and high organic carbon fluxes, while Schönfeld (2001) recorded it in oxic environments.

Stainforthia fusiformis is found in considerably higher abundance at site PO287-26-1B than at PO287-28-1B, and it occupies the topmost cm of the sediment. This species is opportunistic and has been described as tolerant to low oxic environment (Alve 1994, 2003; Alve & Bernhard 1995; Nordberg et al. 2000).

Nonion asterizans displays its highest density in the top cm of the sediment at both stations, and it favours sediments at the outer station PO287-28-1B. This opportunistic species appears to react to the flux of organic carbon. In the Ría de Vigo, NW Iberian Margin, it – as *Nonion fabum* (Fichtel & Moll, 1798) – behaves opportunistically, blooming during the upwelling season (Diz et al. 2004).

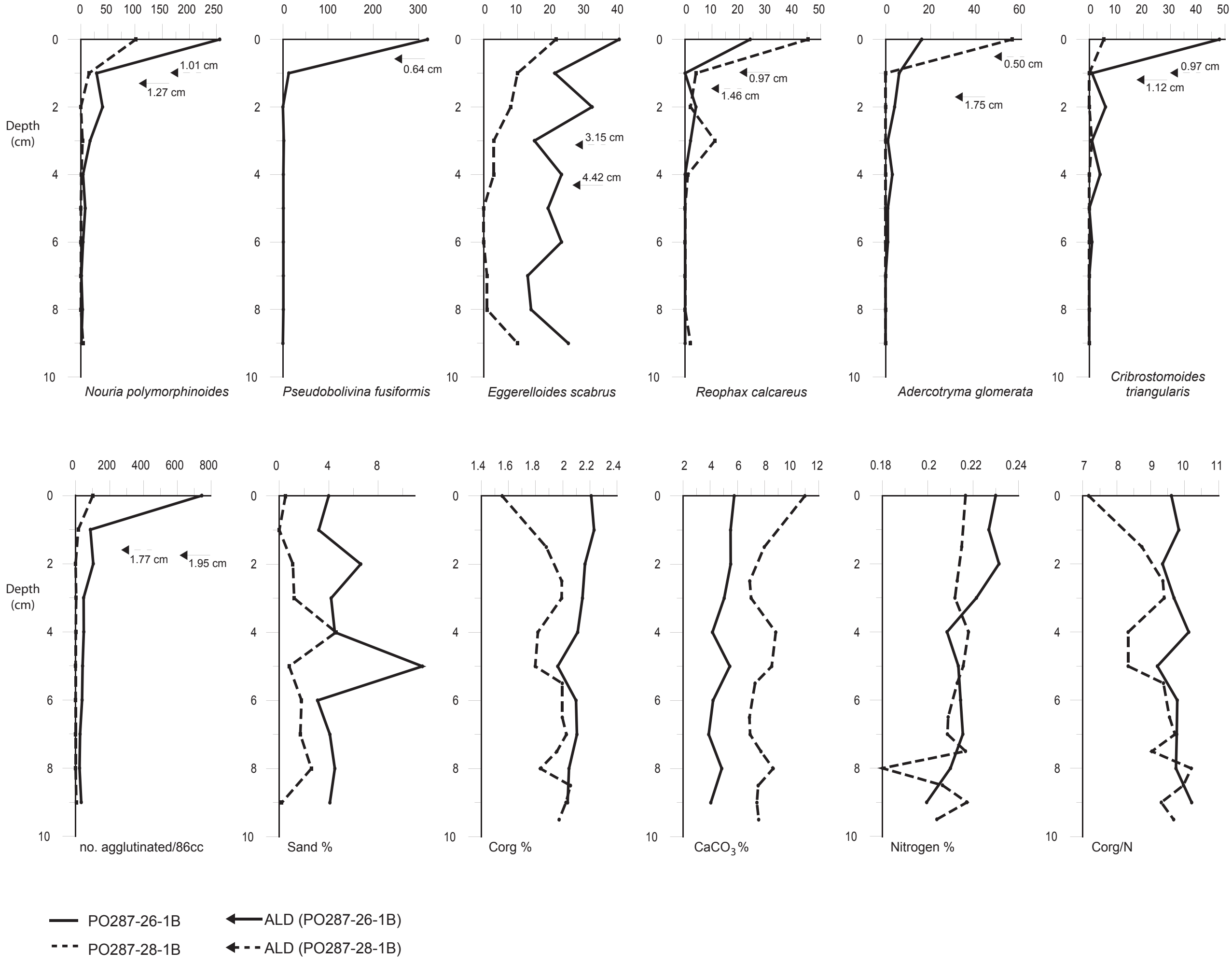

Figure 3: Distribution of six species of living agglutinated foraminifera in the two box cores PO29827-26-1B and PO287-28-1B. The density is shown as number of specimens per 86cc. Average living depth (ALD) is indicated for each species in each of the two cores. The abundance distribution for the total agglutinated fauna in the cores and their ALD are shown in the lower part of the diagram together with grain size distribution (Sand, %), total organic content (Corg, %), calcium carbonate content ($CaCO_3$, %), nitrogen content (%) and the ratio between total organic content and nitrogen (Corg/N).

Uvigerina sp. 221 occurs frequently in the top cm of core PO287-28-1B. The microhabitat of this taxon has been described only from two locations to date. It was recorded inhabiting the uppermost 3 cm of the surface sediment off NW Africa at 200 m water depth (Lutze 1987). *Uvigerina* sp. 221 was found living in the uppermost 2 cm of the surface sediment with an abundance maximum at the sediment surface in the Gulf of Cadiz at 1205 m water depth (Schönfeld 2001). Other species of the genus *Uvigerina* (*U. peregrina* and *U. mediterranea*) have been recorded from well oxygenated shallow infaunal microhabitats (Lutze & Coulbourne 1984; Corliss & Emerson 1990; Fontanier et al. 2002).

Chilostomella ovoidea and the agglutinated taxa *N. polymorphinoides*, *P. fusiformis* and *C. triangularis* all have their highest abundances at station PO287-26-1B, where they occupy the top layer of the sediment. *Chilostomella ovoidea* is regarded as tolerant to low oxygen levels (Bernhard et al. 1997; Ogha & Kitazato 1997).

Globobulimina auriculata, *N. turgida* and *G. turgida* are abundant down to deeper levels in both cores, particularly in PO287-28-1B. These species appear to be relatively resistant to low oxic conditions, and in stressed environments they replace taxa that live more superficially (Rathburn & Corliss 1994). They tolerate conditions at deeper levels in the sediment, where the organic matter is more refractory and where low oxic conditions prevail (Jorissen 1999). *Nonionella turgida* shows a variable depth habitat and has been found as deep infaunal (Corliss & Emerson 1990), as well as epifaunal in shallow waters (Barmawidjaja et al. 1992). In Ría de Vigo, NW Iberian Margin, this species (named as *Nonionella stella* Cushman & Moyer, 1930) exhibits an opportunistic behavior, blooming during upwelling periods (Diz et al. 2004).

Living specimens of *B. marginata*, *C. auriculus* and *H. rhodinensis,* as well as the agglutinated *E. scabrus,* are found down to the bottom sample in both box cores. These species are generally known to live both in sediments at the surface and at deeper levels. *Hanzawaia rhodinensis* is an epibenthic taxon, which inhabits small shell particles or larger quartz grains, and it is commonly found only in the uppermost cm of the sediment (Schönfeld & Zahn 2000). *Bulimina marginata*

Table 4: Stable isotopes of water samples from the Tagus Prodelta.

Core number	Latitude	Longitude	Depth	Date	δ^{18}O	δ^{13}C
PO287-26-1B	38°33.49'N	9°21.84'W	96 m	29.04.2002	0.65	
PO287-26-1B	38°33.49'N	9°21.84'W	96 m	29.04.2002	0.72	0.788
PO287-26-2M	38°33.47'N	9°21.89'W	97 m	29.04.2002	0.69	
PO287-28-1B	38°37.46'N	9°30.87'W	105 m	29.04.2002	0.66	
PO287-28-2M	38°37.45'N	9°30.87'W	106 m	29.04.2002	0.66	
PO287-28-2M	38°37.45'N	9°30.87'W	106 m	29.04.2002	0.68	0.765

has been described in eutrophic and dysoxic environments as well as related to bacterial activity in burrow walls deep in the sediment (Fenchel & Jørgensen 1977; Lutze & Coulbourn 1984; Bernhard & Alve 1996; Fontanier et al. 2002). The microhabitat pattern of *B. marginata* at the present two sites differs, but the abundance of *B. marginata* is high throughout both cores. The increase of this species and a few other taxa, particularly *H. rhodinensis,* in the deepest sample at station PO287-28-1B might be explained by colonisation in macrofaunal burrows or by artificial displacement due to sampling.

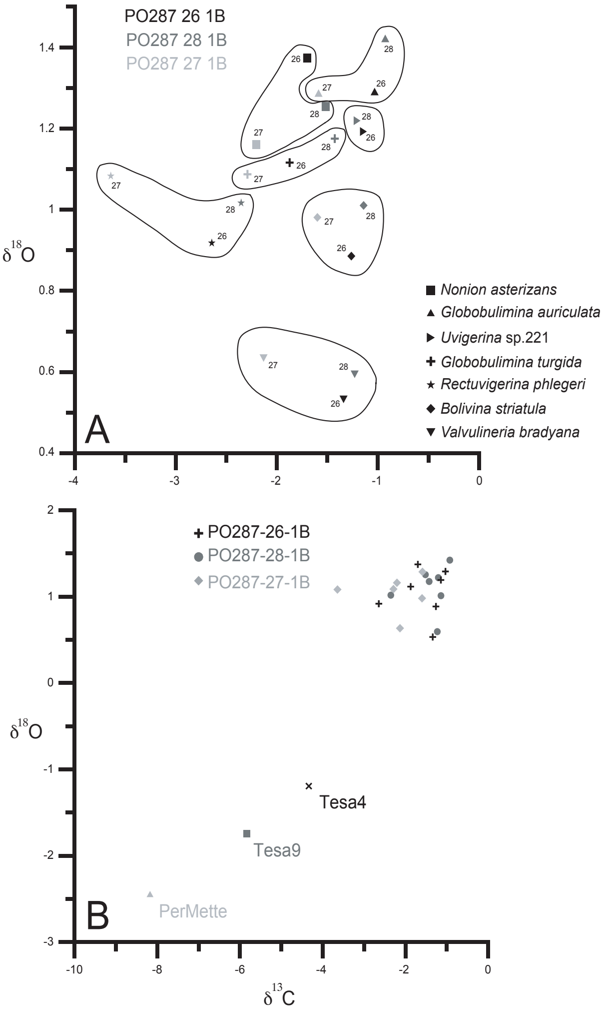

Figure 4A: Relationship between δ^{18}O and δ^{13}C measured on seven different taxa of foraminifera from surface samples at the box core sites PO-287-26-1B, PO287-27-1B and PO287-28-1B in the Tagus Prodelta. **B**: Stable isotope measurements of *Ammonia beccarii* from surface samples in the Tagus Estuary (TESA 9, TESA 4 and PerMette) plotted together with the isotopic measurements from the Tagus Prodelta (**A**).

It is interesting to note that there are comparatively low concentrations of epifaunal species in the living assemblages in the Tagus Prodelta. These are mainly three species, *V. bradyana*, *H. rhodinensis* and *C. auriculus*, which only comprise 6.6% and 4.8% of the fauna in cores PO287-28-1B and PO287-26-1B, respectively. A positive correlation between the amount of epifaunal species and the current velocity has been found in Ría Vigo (Diz et al. 2004) where the epifaunal species comprised more than 75% of the total assemblage in high energy environments. Also Schönfeld (2002) pointed out a relationship between bottom current velocities and live epibenthic foraminifera, and Mendes et al. (2004) link the epifaunal distribution with sedimentary and bathymetric characteristics related to near-bottom water dynamics. In the Tagus Prodelta, the sediments are mostly muddy, with sand contents of 0–10%. The epifaunal species are found not only in the top cm of the sediment, but also slightly deeper. A similar behavior of an epifaunal species has been found on the North Icelandic shelf, where *Cibicides lobatulus* was found at relatively deep levels and not confined to the top part of the sediment (Rytter et al. 2002).

Most of the studied taxa have been found to occupy the sediment-water interface. However, the vertical distribution of the same species can vary during the different seasons (Schönfeld 1997, 2001), and a potential future study in the area would be to investigate the microhabitat of the different taxa for each season.

4.2 Benthic foraminiferal distribution in the Tagus Prodelta and Estuary

There is a high organic carbon flux at both stations, PO287-26-1B and PO287-28-1B, and a clear correlation between the nitrogen content and the organic carbon content of the sediment can be observed (Fig. 3). However, the contents of both nitrogen and organic carbon are higher in the upper part of core PO287-26-1B than in the upper part of PO287-28-1B. Furthermore, the Corg/N ratio is relatively higher in core PO287-26-1B, particularly in the upper part. Due to the fact that plant material contains less nitrogen than animals (Leithold & Hope 1999), this indicates that the organic matter at the latter site is of more terrestrial origin than that at PO287-28-1B. For recent marine sediments of the Tagus river mouth, the Corg/N ratio varies between 1.3 and 20, with trend towards higher values close to the Tagus river plume and the deposition area of core PO287-26-1B (Gaspar & Monteiro 1977).

The foraminiferal faunas at station PO287-26-1B contain over two times more stained foraminifera than those at PO287-28-1B (Fig. 2), and the number of taxa is also higher. A comparison of the density of stained foraminifera in the top cm of the two cores shows that there are more than three times as many foraminifera living at PO287-26-1B than at PO28-28-1B. This is in accordance with the organic carbon contents, which is also much higher at PO287-26-1B (Fig. 3).

Furthermore, the ALD of the total calcareous faunas occurs at shallower depths at station PO287-26-1B than at PO287-28-1B (Fig. 2). The benthic fauna thus evidently responds to the relatively high flux of organic carbon at PO287-26-1B. It has to be noted that the change in the sediment colour, depicting the redox front, is found at 3 cm in core PO287-26-1B, but at 5 cm depth in PO287-28-1B. This also points to a relatively high remineralistaion rate and hence organic carbon flux at core PO287-26-1B. Even if a seasonal variability of this feature can not be ruled out, it is very likely that the benthic foraminifera respond actively and adjust their ALD and vertical distribution in the sediment accordingly.

The two taxa *B. dilatata+pacifica* and *S. fusiformis* are much more abundant at station PO287-26-1B than at PO287-28-1B (Fig. 2), and *B. striatula* and *R. phlegeri* also have their highest densities at PO287-26-1B. Considering the environmental indication of these species, there is also a clear faunal evidence of a higher organic flux to the ocean floor at site PO287-26-1B than PO287-28-1B.

The organic carbon brought to the ocean floor comes from three different sources, i.e. nearshore production of benthic plants as seeweed or benthic diatoms, particulate organic matter of fluvial origin, and production of the coastal phytoplankton or labile organic matter (Loubere & Fariduddin 1999). Benthic foraminifera respond positively to the flux of labile organic matter, but the oxygen content of the pore water, which is yet again controlled by the organic carbon flux, also plays an important role on their distribution. In summary, more organic matter reaches the sea floor at site PO287-26-1B, which is closest to the coast and Tagus river plume, where the organic carbon is probably of fluvial origin.

As posed by Diz et al. (2004), the bottom currents play an important role for the distribution and microhabitat of the benthic community. Increasing current velocities might increase the lateral flux of food particles that can be captured in particular by epibenthic foraminifera. The bottom current velocities are not known at the two studied sites, but the relatively higher sand content (coarser sediment) of core PO287-26-1B might reflect at least occasionally higher bottom currents at that site than at PO287-28-1B.

4.3 Stable isotopes in the Tagus Prodelta and Estuary

The stable isotopic composition in foraminiferal shells can be used for the estimation of the chemical and physical properties of water masses (Zahn & Sarnthein 1987; Mackensen et al. 1993). It has been suggested that influence from surrounding pore water is stongly marked in the stable isotopic values of benthic foraminiferal tests (see also below), and that the isotopic composition of infaunal taxa reflects that of the pore water (Grossman 1987; Rathburn et al. 1996; McCorckle et al. 1997). Therefore, the amount of organic matter input is reflected by the $\delta^{13}C$ of benthic foraminifera (McCorkle et al. 1997). The $\delta^{13}C$ value of benthic foraminifers can also be used as a productivity proxy, because the organic matter is remineralized within the sediment, releasing ^{13}C-depleted CO_2 to the pore waters. Furthermore, the difference between epifaunal and infaunal foraminifera ($\Delta\delta^{13}C$) also serves as productivity proxy. The oxygen isotope composition of the benthic foraminifera is, however, determined by the chemical processes in the ambient water mass where the foraminifera grew and reflect bottom water conditions in terms of temperature and salinity.

It should be mentioned, that there actually is a disequilibrium effect (vital effect) between most of the foraminiferal species and the ambient water both for $\delta^{13}C$ and for $\delta^{18}O$, which is highly species specific (e.g., Duplessy et al. 1970; Grossman 1987; Poole et al. 1995). This isotopic fractionation for the foraminiferal species differs from the oxygen and carbon isotope value of the water at the sediment-water interface. *Valvulineria bradyana* shows $\delta^{18}O$ values close to that of the water at the sediment-water interface (Tabs 3, 4). *Bolivina striatula* also show $\delta^{18}O$ relatively close to that of the water, compared to the other species from the Tagus Prodelta (*G. auriculata*, *G. turgida*, *N. asterizans*, *R. phlegeri* and *Uvigerina* sp. 221).

All the measured species show low $\delta^{13}C$ compared to that of the water at the sediment-water interface. Generally, epifaunal taxa have relatively high $\delta^{13}C$ values, whereas infaunal taxa have rather low $\delta^{13}C$ values (McCorkle et al. 1997; Jorissen 1999). In the Tagus Prodelta, this holds true for some species. For instance, *V. bradyana*, *B. striatula* and *Uvigerina* sp. 221, all considered shallow infaunal, have relatively heavy $\delta^{13}C$, while *R. phlegeri,* which also shows relatively shallow infaunal behavior, displays somewhat lighter values. In core PO287-26-1B, this latter species was found with the highest densities at the sediment-water interface, but it was found down to a considerable depth as well.

The stable isotopic compositions of the benthic foraminifera in the Tagus Prodelta and Estuary vary, not only from one species to another but also geographically (Fig. 4A, B). The lightest $\delta^{13}C$ values were those of *A. beccarii* from the top 2-3 cm of the sediment within the Tagus Estuary (PerMette, T4 and T9). Very depleted values like these, -4.34‰ to -8.17‰, can be caused by anoxic conditions within the sediment as a result of high flux of organic matter to the seabed. The suspended matter of terrestrial material and river phytoplankton, as well as marine phytoplankton in the Tagus Estuary, may originate both from the river drainage basin and from the sea, transported upstream into the Estuary by tidal effects. In Tagus Estuary salt marshes, the organic matter contents varies between 10-20% (Simas et al. 2001). The combined influence of these factors is suggested to have contributed to the low $\delta^{13}C$ values of the benthic foraminiferal shells within the Estuary.

Methane seeps may also cause very strong anomalies in the $\delta^{13}C$ values of infaunal benthic foraminifera (Rohling & Cooke 1999; Rathburn et al. 2003). An example is the gas-hydrate influenced Monterey Bay, California, where the extremely low pore water $\delta^{13}C$ caused a strong depletion of the $\delta^{13}C$ of benthic foraminifera (RATHBURN et al. 2003). For the Prodelta, the lightest $\delta^{13}C$ values were those from core PO287-27-1B, while the heaviest values were those of core PO287-28-1B, a pattern which is suggested to be due to the distribution of organic matter in the area. Site PO287-27-1B recieves a high amount of organic carbon due to its location close to the coast and close to the Capo Roca upwelling filaments (Fig. 1).

The $\delta^{13}C$ value of the water within the Tagus Estuary, which is controlled by the mixing ratio of fresh water and sea water, is not known. It is interesting to note, however, that the relation between $\delta^{13}C$ and $\delta^{18}O$ of benthic foraminifera in the Tagus Estuary show a similar pattern and slope as found for shell carbonates in a Rhine Estuary (Western Scheldt, the Netherlands; cf. MOOK 1971; MOOK & TAN 2006), although the $\delta^{13}C$ values are generally lower in the Tagus Estuary foraminfera (by about 2‰) than in the Rhine Estuary. This indicates similar residence time for the water in the areas, and it also shows that the $\delta^{13}C$ estuary gradient is displayed by the benthic foraminifera.

Relatively light $\delta^{18}O$ values were found within the Estuary (Fig. 4B). This was most likely controlled by the reduced salinity in this area, but relatively high temperatures may also contribute to low $\delta^{18}O$ values at these shallow water sites (5.6–19.6 m) (Fig. 1). In June 2003, temperatures within the Tagus Estuary ranged from 16.6 to 22ºC, while the salinity varied between 32.5 and 16.5‰ (A.P. OLIVERIA, pers. comm. 2005). Instant *in situ* temperatures and salinities in the Tagus Prodelta were around 15–16ºC and 35.8‰ in August-September of 1985 and around 14ºC and 35.7‰ in March 1986 (MOITA 2001). Similar temperatures and salinities were observed in the Cascais Bay, south of Cape Roca, during April 2002 and 2003 (DUARTE-SILVA et al. submitted). Furthermore, satellite-derived values give an average sea surface temperature of 15.5ºC for the winter, and 19.5ºC for the summer. These data clearly indicate the increased temperatures and relatively low salinities in the Tagus Estuary compared to that of the Prodelta, as also reflected in the $\delta^{18}O$ of the benthic foraminifera.

5. Summary and conclusion

The living (stained) benthic foraminiferal assemblages and the microhabitat of 21 different taxa (15 calcareous and 6 agglutinated) have been described for two box cores from the Tagus Prodelta. In addition, the stable isotopic composition of eight different benthic foraminiferal taxa from surface samples in the Tagus Prodelta and Estuary have been discussed in relation to the oceanography of the area.

A major part of the taxa are strongly concentrated in the upper part of the sediment column. The most abundant of these epifaunal and shallow infaunal taxa are species of the genus *Bolivina*. Other important taxa are e.g., *Rectuvigerina phlegeri*, *Stainforthia fusiformis, Valvulineria bradyana* and *Nonion asterizans*. These epifaunal and shallow infaunal taxa feed on fresh and labile organic matter. Infaunal species, living deeper in the sediment, are e.g., *Bulimina marginata*, *Globobulimina auriculata* and *Nonionella turgida*. They are believed to feed selectively on refractory organic matter in some degree of a decaying stage. However, our data only cover one season, the pre-upwelling season, and a seasonal shift in the nutritional distribution can not be ruled out. Borrowing organisms may also have caused some disturbances. Our data show that there is a close connection between the concentration of foraminifera and the organic carbon contents in the sediments. In particular, the density of foraminifera is higher in the core located close to the Tagus River plume (PO287-26-1B) than at the more distant offshore site (PO287-28-1B). The spatial differences in the organic carbon flux is also clearly reflected in the distribution of foraminiferal taxa.

The variation in the isotopic values for the different species is partly controlled by the chemical and physical properties of the water masses and partly by differences in their microhabitats. The spatial distribution of the $\delta^{13}C$ values reflects a relatively high organic flux at site PO287-26-1B, which is closest to the coast and to the Tagus river plume. Low $\delta^{18}O$ values for foraminiferal shells in the Tagus Estuary, compared with the values obtained in the Prodelta, reflect reduced salinity and higher temperatures in the Estuary.

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Appendix A

Benthic foraminiferal taxa.

The original descriptions of the foraminiferal taxa cited in the text and included in the reference plummer-cell (see Appendix B) deposited at the Bavarian State Collection for Palaeontology and Geology (Munich, Germany) under accession number BSPG 2006 VIII 1 are reported in Ellis & Messina (1949 and updates)

Agglutinated taxa (listed alphabetically):

Adercotryma glomerata (Brady) = *Lituola glomerata* Brady, 1878
Cribrostomoides triangularis Saidova, 1961
Eggerelloides scabrus (Williamson) = *Bulimina scabra* Williamson, 1858
Nouria polymorphinoides Heron-Allen & Earland, 1914
Pseudobolivina fusiformis (Chaster) = *Textularia fusiformis* Chaster, 1892
Reophax calcareus (Cushman) = *Proteonina difflugiformis* (Brady) var. *calcarea* Cushman, 1947

Calcareous taxa (listed alphabetically):

Ammonia beccarii (Linné) = *Nautilus beccarii* Linné, 1758
Amphicoryna candei (d'Orbigny) = *Nodosaria candei* d'Orbigny, 1839
Amphicoryna scalaris (Batsch) = *Nautilus* (*Orthoceras*) *scalaris* Batsch, 1791
Asterigerinata mamilla (Williamson) = *Rotalina mamilla* Williamson, 1858
Bolivina alata (Seguenza) = *Vulvulina alata* Seguenza, 1862
Bolivina dilatata Reuss, 1850
Bolivina pacifica Cushman & McCulloch = *Bolivina acerosa* Cushman var. *pacifica* Cushman & McCulloch, 1942
Bolivina striatula Cushman, 1922

Bulimina marginata d’Orbigny, 1826
Bulimina striata d’Orbigny, 1826
Cancris auriculus (Fichtel & Moll) = *Nautilus auricula* var. Fichtel & Moll, 1798
Cassidulina laevigata d’Orbigny, 1826
Chilostomella ovoidea Reuss, 1850
Cibicides lobatulus (Walker & Jacob) = *Nautilus lobatulus* Walker & Jacob, 1798
Elphidium articulatum (d’Orbigny) = *Polystomella articulata* d’Orbigny, 1839
Evolvocassidulina bradyi (Norman) = *Cassidulina bradyi* Norman, 1881
Gavelinopsis praegeri (Heron-Allen & Earland) = *Discorbina praegeri* Heron-Allen & Earland, 1913
Gyroidina umbonata (Silvestri) = *Rotalia soldanii* d’Orbigny var. *umbonata* Silvestri, 1898
Globobulimina auriculata (Bailey) = *Bulimina auriculata* Bailey, 1851
Globobulimina turgida (Bailey) = *Bulimina turgida* Bailey, 1851
Hanzawaia rhodinensis (Terquem) = *Truncatulina rhodinensis* Terquem, 1878
Hyalinea balthica (Schroeter) = *Nautilus balthicus* Schroeter, 1783
Melonis barleeanus (Williamson) = *Nonionina barleeana* Williamson, 1858
Nonion asterizans (Fichtel & Moll) = *Nautilus asterizans* Fichtel & Moll, 1798
Nonionella turgida (Williamson) = *Rotalina turgida* Williamson, 1858
Quinqueloqulina stalkeri Loeblich & Tappan, 1953
Rectuvigerina phlegeri Le Calvez, 1959
Saidovina karreriana (Brady) = *Bolivina karreriana* Brady, 1881
Stainforthia fusiformis (Williamson) = *Bulimina pupoides* d’Orbigny var. *fusiformis* Williamson, 1858
*Stainforthia loeblichi (*Feyling-Hanssen) = *Virgulina loeblichi* Feyling-Hanssen, 1954
Uvigerina sp. 221 Lutze, 1986 (species not formally described)
Valvulineria bradyana (Fornasini) = *Discorbina bradyana* Fornasini, 1900

Appendix B

Tagus Prodelta, Portugal; content of reference plummer-cell BSPG 2006 VIII 1

Core: PO287-28-1B
Location: 38°37.5’N, 09°30.9’W
Water depth: 105 m

Species;

1. *Ammonia beccarii* (Linné, 1758)
2. *Amphicoryna candei* (d’Orbigny, 1839)
3. *Amphicoryna scalaris* (Batsch, 1791)
4. *Asterigerinata mamilla* (Williamson, 1858)
5. *Bolivina alata* (Seguenza, 1862)
6. *Bolivina dilatata* Reuss, 1850
7. *Bolivina pacifica* Cushman & McCulloch, 1942
8. *Bolivina striatula* Cushman, 1922
9. *Bulimina marginata* d’Orbigny, 1826
10. *Bulimina striata* d’Orbigny, 1826
11. *Cancris auriculus* (Fichtel & Moll, 1798)
12. *Cassidulina laevigata* d’Orbigny, 1826
13. *Chilostomella ovoidea* Reuss, 1850
14. *Cibicides lobatulus* (Walker & Jacob, 1798)
15. *Elphidium articulatum* (d’Orbigny, 1839)
16. *Evolvocassidulina bradyi* (Norman, 1881)
17. *Gavelinopsis praegeri* (Heron-Allen & Earland, 1913)
18. *Gyroidina umbonata* (Silvestri, 1898)
19. *Globobulimina auriculata* (Bailey, 1851)
20. *Globobulimina turgida* (Bailey, 1851)
21. *Hanzawaia rhodinensis* (Terquem, 1878)
22. *Hyalinea balthica* (Schroeter, 1783)
23. *Melonis barleeanus* (Williamson, 1858)
24. *Nonion asterizans* (Fichtel & Moll, 1798)
25. *Nonionella turgida* (Williamson, 1858)
26. *Quinqueloqulina stalkeri* Loeblich & Tappan, 1953
27. *Rectuvigerina phlegeri* Le Calvez, 1959
28. *Saidovina karreriana* (Brady, 1881)
29. *Stainforthia fusiformis* (Williamson, 1858)
30. *Stainforthia loeblichi* (Feyling-Hanssen, 1954)
31. *Uvigerina* sp. 221 Lutze, 1986
32. *Valvulineria bradyana* (Fornasini, 1900)

1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56	57	58	59	60