



Living benthic foraminiferal assemblages of a transect in the Rockall Trough (NE Atlantic)

Bianca Lintner^{a,*}, Michael Lintner^a, Patrick Bukenberger^a, Ursula Witte^b, Petra Heinz^a

^a University of Vienna, Department of Palaeontology, Vienna, Austria

^b University of Aberdeen, Institute of Biological and Environmental Sciences, Aberdeen, United Kingdom

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ABSTRACT

Foraminifera are unicellular protists and play a major role in the deep-sea ecosystems. This study focusses on the faunal analysis of living benthic foraminiferal assemblages and their vertical distribution along a transect in the Rockall Trough in the NE Atlantic. Therefore, seven multicorer cores from the Rockall Trough (RT-1 – RT-7), NE Atlantic, were collected at water depths between 1008 and 2205 m on the RRS Discovery cruise DY051 in spring 2016.

Surface sediment samples of the collected material were analysed up to 10 cm sediment depth for living (Rose Bengal stained) benthic foraminifera to gain insight into the recent distribution of the foraminiferal fauna. The cores were sliced from 0 to 3 cm into 0.5 cm intervals and from 3 to 10 cm in 1 cm slices. Sediments were divided into the fractions >125 µm and 125–63 µm by wet-sieving. The analysis showed that stations differed in live assemblages, diversity, abundances and vertical distribution. Standing stock values of 92–168 ind./10 cm² for the total, 54–130 ind./10 cm² for the calcareous and 24–59 ind./10 cm² for the agglutinated assemblages were obtained.

Living deep-sea foraminiferal assemblages differed between the three shallower (RT-1 – RT-3) and the four deeper sites (RT-4 – RT-7), indicating that the different water masses could be a main factor controlling the deep-sea benthic fauna in the Rockall Trough. This area is characterised by two main water masses: the upper more saline Eastern North Atlantic Water (ENAW) and the lower North Atlantic Deep Water (NADW).

Basically, *Nonionella iridea* occurred at all sites, while *Cibicidoides* species (except *C. wuellerstorfi*) and *Melonis barleanus* were limited to water depths between 1008 and 1610 m (RT-1 – RT-3). Soft-shelled foraminifera increased sharply with water depth. *Saccamminid* sp. 1 contributed significantly to this increasing proportion of soft-shelled individuals with its maximum at 1857 m water depth (RT-5). Further characteristics of this transect include a mass occurrence of *Uvigerina mediterranea*, which was only present at 1008 m (site RT-1) or *Globobulimina* sp. 1 with its highest densities at 1610 m (RT-4), where it accounted for 20% of the total living foraminiferal fauna. The general microhabitat preferences were consistent with those of other studies, although the Rockall Trough is a very dynamic region considering food supply or other physical parameters.

1. Introduction

1.1. General introduction

Foraminifera play an important role in marine biogeochemical cycles (e.g. Gooday and Jorissen, 2012). Marine foraminifera inhabit shallow water regions as well as the deep sea. Deep-sea foraminifera rely on the supply of organic matter from the euphotic zone reaching the ocean floor and nutrients transported by water currents (Rowe, 1983; Schaff et al., 1992; Altenbach and Struck, 2001). This transport of biomass into

the deep ocean is called the „biological pump“ (Longhurst and Harrison, 1989; Sarmiento and Gruber, 2006). Organic matter is constantly remineralising on its way down to the ocean floor and nutrients and CO₂ are released into the deep-water masses (Eppley and Peterson, 1979; Jumars, 1993). A higher primary productivity causes high export of organic matter to the deep ocean (Falkowski et al., 2003). Furthermore, seasonality has a high impact on the organic matter flux through the water column and influences benthic foraminiferal assemblages (Loubere and Fariduddin, 1999; Tyler, 1986; Gooday and Hughes, 2002).

Foraminiferal highest abundance in the bathyal and abyssal of the

* Corresponding author.

E-mail address: a1201280@unet.univie.ac.at (B. Lintner).

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Atlantic can be observed during the spring and early summer time (Gooday, 1993), when assemblages profit from phytoplankton spring blooms (Alve and Murray, 1994). This seasonally inputs of relatively labile phytodetritus vary a lot in time and intensity (Pfannkuche et al., 1999). Still, seasonality must not be a controlling factor for vertical distribution in the sediment and the generally high dominance of individuals in the surface few millimeters is probably limited to the presence of microalgal food and burrowing activity of macrofauna (Alve and Murray, 2001) as well as the variability of available oxygen (Murray, 2001). These aspects coupled with different parameters of water masses (see below) lead to the formation of diverse microhabitats for both epi- and infaunal living foraminifera (Corliss, 1985).

Previous studies analysed faunal assemblages in the North Atlantic, and even in the Rockall Trough (NE Atlantic) (e.g. Jones, 1986; Hughes et al., 2000; Gooday and Hughes, 2002; Panieri, 2005). This study focusses on the investigation of living benthic foraminiferal assemblages along a transect in the Rockall Trough (RT) to gain insight into the recent distribution of foraminifera and the influencing factors. For the first time, the vertical distribution of living foraminifera deeper than 1 cm was analysed along a transect in the RT. Changes in abundances, diversity, species composition and vertical distribution along a transect in a very dynamic region can help to characterize a microhabitat and understand the relationship between ecological parameters and foraminiferal communities. Some species of benthic foraminifera respond rapidly to seasonal phytodetritus deposition, especially in RT, making the study of faunal assemblages an important parameter to describe the net flux of organic matter to the ocean floor (Gooday and Lamshead, 1989; Gooday and Rathburn, 1999; Gooday and Hughes, 2002). The following hypotheses we want to test: 1) Foraminiferal communities at RT are strongly influenced by the flux of organic matter. 2) Foraminiferal communities at the RT are strongly influenced by water masses. 3) A shift in organic fluxes or the physical parameters will lead to a shift in the foraminiferal community.

1.2. Influencing parameters

Benthic deep-sea foraminifera are exposed to various environmental factors that influence the faunal composition and abundance. Often, the most important and community limiting parameters are the food flux (C_{org}) and oxygen content (e.g. Jorissen, 1999; Van der Zwaan et al., 1999; Kitazato et al., 2000; Gooday, 2003; Geslin et al., 2004). The organic carbon flux is strongly correlated with the primary production and inversely correlated with water depth. It influences the distribution of foraminifera and the occurrence of certain species. Especially distribution patterns of opportunistic species (e.g. *Alabaminella weddellensis*) are linked to the food supply at the seafloor (Gooday 1988, 1993, 1994; Gooday and Turley, 1990; Gooday and Lamshead, 1989; Lamshead and Gooday, 1990; Heinz et al., 2001). An occasionally supply of organic matter (e.g. from turbidites) may also have an impact on the community (Weaver et al., 1992).

Other environmental parameters, that are believed to influence deep-sea foraminiferal assemblages are a complex set of physical, chemical and biological parameters like water masses (salinities), temperature, sediment type, oxygen content, hydrodynamics of bottom water and the stability of settings or interactions with other organisms (e.g. Weaver et al., 1992; Hall, 1994; Rathburn et al., 1996; Mackensen, 1987; Loubere and Fariduddin, 1999; Culver and Buzas, 2000; Schönfeld, 2002; Murray, 2006; Jorissen et al., 2007).

1.3. Study area

Core samples were collected along a transect in the Rockall Trough (NE Atlantic) about 200 km from the Outer Hebrides (Fig. 1).

The Rockall Trough is an elongated basin with 200–300 km width and consist of thinned continental crust. It developed during the Mesozoic sea floor spreading of the Atlantic and shows a relatively even

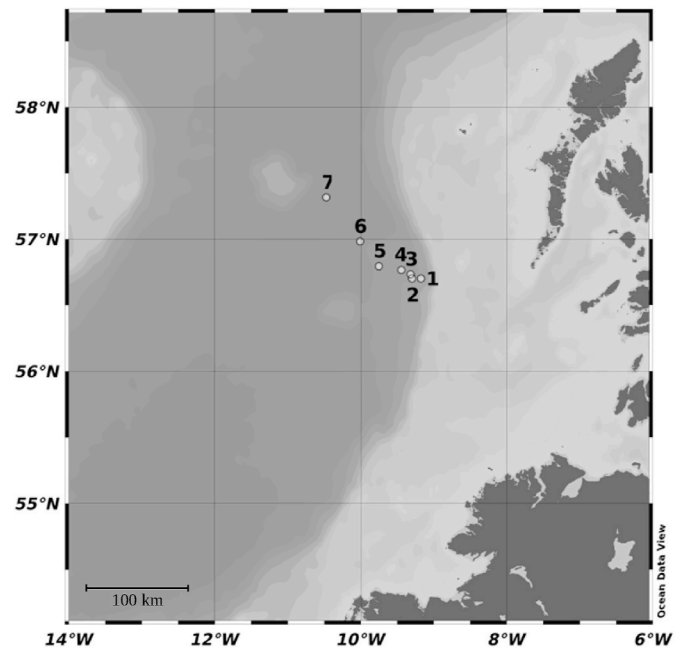


Fig. 1. Location of the study area and position of sites (RT-1 – RT-7) in the Rockall Trough (Schlitzer 2018).

topography (Dorschel et al., 2010). The ocean floor of the northern Rockall Trough is covered primarily by Quaternary sediments and a Holocene sedimentation rate of 6.5 cm kyr^{-1} was determined by radiocarbon dating (Masson et al., 2002; Thomson et al., 2000). The water depth increases from 1000 m in the north to almost 4000 m in the south and the Wyville-Thompson Ridge (at about 500 m water depth) acts as an important oceanographic barrier between the Rockall Trough and the Faroe-Shetland Channel (Masson et al., 2002).

The RT acts like a conduit for saline water masses from the south into the Nordic Seas, where it could affect deep convection and therefore have an impact on the thermohaline overturning circulation (Reid, 1979; New et al., 2001). Basically, it can be distinguished between surface waters and deeper ocean water masses (below 1200 m water depth) (Mienis et al., 2007). Surface waters are derived from two sources: Eastern North Atlantic Water (ENAW) enters the RT from southeast, whereas the Western North Atlantic Water (WNAW) carried by the North Atlantic Current (NAC) flows into the RT from the southwest (Ellett et al., 1986; Holliday et al., 2000; New et al., 2001). Both move northward through the Trough. Sub-Arctic Intermediate Water (SAIW) is also carried by the NAC and brings some fresher waters from the west that partially mix with the saline flows in the southern Trough (Ellett et al., 1986; Pingree, 1993; New et al., 2001). Below this, the deeper water mass, referred to as North Atlantic Deep Water (NADW) by Ellett et al. (1986), consists primarily of Labrador Sea Water (LSW) with some addition of Antarctic Bottom Water (AABW) and a periodic inflow of Norwegian Sea Deep Water (NSDW), and circulates anticlockwise within the RT due to topography (Ellett et al., 1986; Howe, 1995; Holliday et al., 2000; New et al., 2001; Masson et al., 2002). A seasonal cycle in temperature and salinity in the Rockall Trough can be described by the deep convective winter mixing down to 600–1000 m, caused by a weak density gradient (Meincke, 1986; Van Aken and Becker, 1996; Holliday et al., 2000). The oceanography of Irish waters is illustrated in Dorschel et al. (2010) and Sherwin et al. (2012).

1.4. Hydrological setting in the study area

Core samples for this study were collected from areas influenced by SAIW or LSW (Dorschel et al., 2010). SAIW is a water mass with an average temperature between 4 and 7 °C and a salinity below 34.9 PSU

in its formation region, in the Labrador Current (Arhan, 1990). In the Rockall Trough Ullgren and White (2010) identified SAIW between 600 and 1000 m with temperatures of 8–9 °C and salinities of 35.1–35.2 PSU. According to McGrath et al. (2012), the dissolved oxygen in SAIW ranges between 230 and 250 $\mu\text{mol kg}^{-1}$. LSW has been clearly identified between 1600 and 1900 m in the Rockall Trough with a salinity minimum (34.94–34.96 PSU, 3.2–4.1 °C) and a high oxygen content of about 6 ml^*1^{-1} (Lee and Ellett, 1967; Ellett et al., 1986; Ellett and Martin, 1973; Van Aken and Becker, 1996) or 260–270 $\mu\text{mol kg}^{-1}$ (McGrath et al., 2012). In the north of the RT the periodic inflow of NSDW (0.95 °C, 34.94 PSU) over the Wyville Thomson ridge has an impact on the water masses, as its denser than the LSW (Mosby, 1959; Ellett et al., 1986; New et al., 2001). As a result, a deep salinity maximum is formed underneath the LSW minimum (Ellett et al., 1986) usually between 2300 and 2500 m depth (Ellett and Martin, 1973; Van Aken and Becker, 1996).

Studies of vertical flux in the northeast Atlantic have shown that surface biomass (primary production) in the RT can descent at a rate of approximately 100 m/day (Billett et al., 1983). This high settling rate leads to a rapid seasonal signal of primary production (carbon as a food source for deep pelagic and benthic communities) at depth (Deuser et al., 1981; Tyler, 1986). During the sampling period in May 2016, OceanColor data (oceancolor.gsfc.nasa.gov) indicate sea-surface chlorophyll α values of about 2–3 mg/m^3 in the RT. Still, primary production depends strongly on the warming of the water masses and increases rapidly in spring (Zeitzschel, 1986).

2. Materials and methods

2.1. Sampling

Sediment cores were collected during the RRS Discovery Cruise DY051 (project MAC-EXP) from 13 May to June 3, 2016. A transect of seven cores from the Rockall Trough was sampled from the continental slope in the bathyal zone at water depths ranging from 1008 to 2205 m. The cores (Table 1) were collected with a multiple corer (OSIL Maxi Corer) equipped with 8 core tubes having an internal diameter of 10 cm (surface area 78.5 cm^2). On board the cores were sliced into 0.5 cm layers from the top to a sediment depth of 3 cm. The downcore samples were sliced at 1 cm intervals (from 3 to 10 cm). All core samples were preserved in ethanol with Rose Bengal (2 g l^{-1}) and stored in solvent resistant polyethylene jars at room temperature until onshore treatment (March 2018). A solution of Rose Bengal is often used to differentiate the living from the dead foraminiferal fauna (Lutze, 1965; Walton, 1952), because it stains intact cytoplasmic proteins of living specimens. All staining techniques have advantages and disadvantages, but staining with Rose Bengal needs to be handled with caution, as it stains (unspecifically) live or dead proteins and bacteria/symbiotic microalgae on or within the tests of dead foraminifera (Boltovskoy and Lena, 1970; Walker et al., 1974),

2.2. Faunal analyses

In the laboratory, the 91 sediment layers (0–10 cm of each sediment core) were wet-sieved over a 125 and 63 μm sieve. The resulting fractions >125 and 125–63 μm were then dried at 50 °C and filled into glass

Table 1

List of the core stations with location (latitude and longitude) and water depth.

Core station	Lat °N	Log °W	Depth [m]
RT-1	56° 42.10	09° 10.43	1008
RT-2	56° 42.12	09° 17.77	1250
RT-3	56° 44.12	09° 19.02	1382
RT-4	56° 46.03	09° 26.62	1610
RT-5	56° 47.73	09° 45.13	1857
RT-6	56° 58.96	10° 00.45	2056
RT-7	57° 19.02	10° 28.17	2205

vials. It should be noted, that this method of drying the sediment often destroys organic walled foraminifera and makes them unrecognizable (Hughes et al., 2000). Furthermore, each sample was split into halves using a Micropress Europe sample micro-splitter and one of these splits was used for further investigations.

Both fractions were analysed separately and the investigation was based on the analysis of those 182 Rose Bengal stained living benthic foraminifera core samples recorded in the splits. All specimens of benthic foraminifera with stained protoplasm (completely stained specimens except of the last chamber) were picked out with a wet brush under a binocular/stereo microscope for faunal analysis. For the identification of species (alphabetical list in the appendix – Table A), the concepts of Loeblich and Tappan (1988), Jones (1994) and the Catalogue of Foraminifera (Ellis and Messina, 1940) were used. After the identification, both fractions were combined for further analysis and statistical evaluation.

Photographs of gold sputtered foraminifera were taken with the scanning electron microscope JEOL JSM-6400.

Tubular foraminifera, especially *Astrorhizidae* (e.g. *Rhabdammina* or *Rhizammina*) were mainly found fragmented. Several authors have developed methods to semiquantify fragmented species (e.g. Kurbjewit et al., 2000; Heinz and Hemleben, 2003). In this study only fragments larger than 1 mm and those with a proloculus regardless of length were considered as single individuals (Hess, 1998). Smaller fragments were combined to a length of about 1 mm and then counted. With this method we can get a rough estimation of tubular specimens.

For the living benthic foraminifera analysis and the vertical distribution, a standardized surface of 10 cm^2 was used (number of individuals/10 cm^2). For the characterization of the vertical distribution the average living depth (ALD) was calculated for every station after Jorissen et al. (1995) and the oxygen content of the surface layer (0–0.5 cm) was determined using the benthic foraminiferal dissolved-oxygen index (BFOI) after Kaiho (1994). The micropaleontological slides as well as SEM stubs with images are deposited as reference at the University of Vienna, Department of Paleontology.

The statistical evaluation was done using the free software Past3 (Hammer et al., 2001), which calculated rarefaction, the diversity indices Shannon-Wiener $H(S)$, Fisher α and the evenness index E (Fisher et al., 1943; Buzas and Gibson, 1969; Spellerberg and Fedor 2003).

3. Results

3.1. Species richness and diversity

Rarefaction curves show, that the examined sediment amount was sufficient to find all of the expected species (Fig. 2).

The stained foraminiferal assemblages yielded overall 204 species, including 152 calcareous, 50 agglutinated and 2 soft-shelled species. Only 13 species occurred at all studied sites between 1008 and 2205 m:

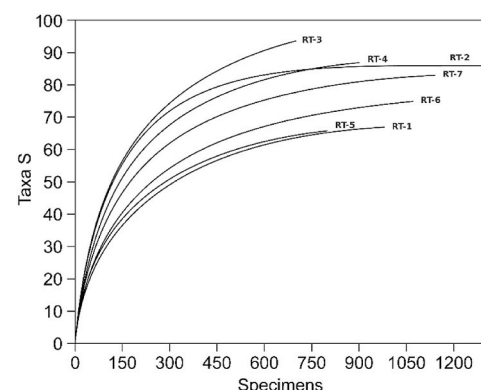


Fig. 2. Rarefaction curves of each core sample site (RT-1 to RT-7).

Alabaminella weddellensis, *Astrononion stelligerum*, *Bolivina difformis*, *Bolivinelina pseudopunctata*, *Bulimina striata*, *Gavelinopsis praegeri*, *Gyroidina laevigata*, *Nonionella iridea*, *Pseudononion* sp. 1, *Pullenia quinqueloba*, *Rhizammina algaeformis*, *Trifarina angulosa* and *Uvigerina peregrina*. About 40% (82 species) of all foraminiferal species occurred only at one single station and always in low abundances (<3 ind./10 cm²). The only exception was *Uvigerina mediterranea* which was abundant (150 individuals) exclusively in RT-1 (1008 m water depth). Eleven of these 82 species were only represented by a single individual. Our results show no demonstrable correlation of simple species diversity (Table 2) with water depth. Generally, the number of living species varied between 66 and 94 species per station. The highest diversity of calcareous foraminifera was found in RT-2 to RT-4. Agglutinated foraminifera encountered between 24 and 30 species at all sites except RT-1 and RT-5 with lower species numbers. Diversity indices Shannon-Wiener *H(S)* and Fisher α are increasing with water depths between 1008 and 1382 m. Afterwards, there is no clear trend of diversity indices anymore. The Shannon-Wiener *H(S)* index varied from 3.069 to 3.945 and the Fisher α values between 16.22 and 28.92. RT-3 showed the highest *H(S)* (3.945) and Fisher α (28.92) values, but the highest evenness value (0.583) was found in RT-2. The strongest dominance (0.103) was recognized in RT-6 at a 2056 m water depth with standing stock values of 138 individuals per 10 cm².

3.2. Faunal analysis of the sediment samples

The seven sediment cores (0–10 cm sediment depth) showed different assemblages of living benthic foraminifera (see Plates I–IV). Total abundances and distributions of Rose Bengal stained benthic foraminifera (both fractions) at different water depths are shown in Fig. 3 and Fig. 4.

The RT-1 sample from 1008 m water depth yielded 993 (= 127 individuals 10 cm⁻²) stained benthic individuals with 67 species recorded. Agglutinated foraminifera accounted for 27.8% of live foraminifera, the rest were calcareous species (including some rare miliolids). The calcareous *Melonis barleeanus* (23.5%) and *Uvigerina mediterranea* (15.1%) were the most abundant species in this core. The most frequent agglutinated species were *Marsipella cylindrica* (6.5%) and *Reophax bilocularis* (6.5%) (Figs. 3 and 4).

Core sample RT-2 came from 1250 m water depth. Here 1316 (= 168 individuals 10 cm⁻²) living benthic foraminifera and 86 species were found. Agglutinated foraminifera made 22.7% of the total foraminiferal assemblage. *Melonis barleeanus* was again one of the most important representatives with 10.3%. Common species included *Cibicidoides bradyi* (6.7%), *Nonionella iridea* (5.2%) and *Lagenammina* sp. 2 (6.4%). *Nonionella iridea* was found exclusively in the fraction 125–63 μm.

In RT-3 (water depth of 1382 m) 717 (= 92 individuals 10 cm⁻²) individuals and 94 species could be identified. Agglutinated specimens amounted to 27.8%. The dominant calcareous species was *N. iridea* (10.2%). *Melonis barleeanus* was represented here with 6.6% and *Cibicidoides bradyi* with 4.5%.

In a water depth of 1610 m RT-4 was obtained. It contained 918 (=

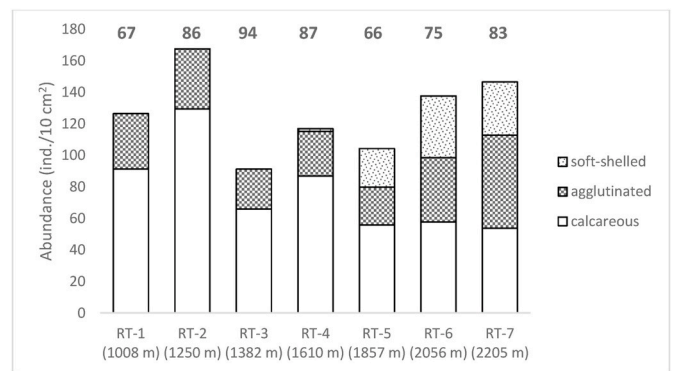


Fig. 3. Abundances of living foraminifera (calcareous, agglutinated and soft-shelled) in the upper 10 cm of sediment at all seven sampling sites (RT-1 – RT-7). Total number of species in bold and water depth in parenthesis.

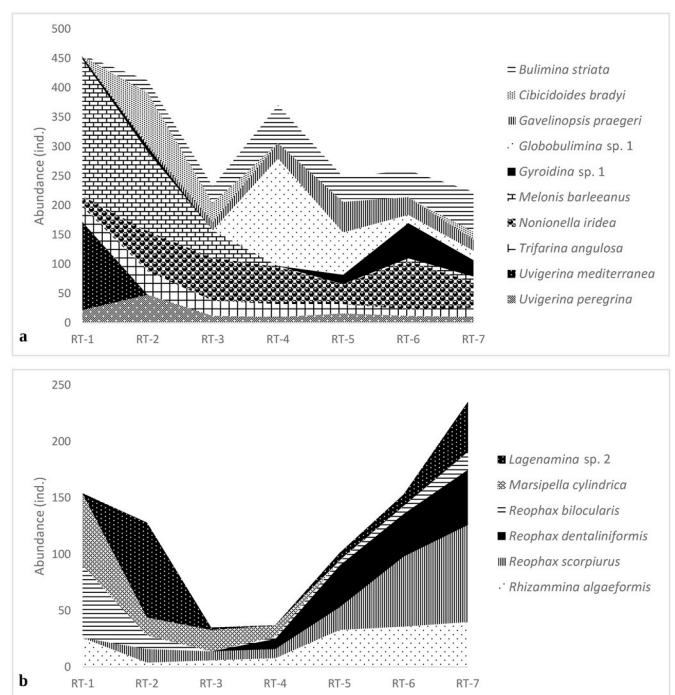


Fig. 4. Distribution of common stained calcareous (a) and agglutinated (b) benthic foraminifera at the studied sites (RT-1 – RT-7).

117 individuals 10 cm⁻²) living individuals and 87 species. A total of 24.2% was made up by agglutinated species. This site is characterised by a high occurrence of the genus *Globobulimina*, that accounted for almost a third (27.1%) of all individuals in RT-4. *Globobulimina* species were not observed at the shallower stations RT-1 to RT-3. *Globobulimina* sp. 1 is

Table 2

Diversity indices: Shannon-Wiener *H(S)*, Fisher α and the evenness index *E*.

Core station	RT-1	RT-2	RT-3	RT-4	RT-5	RT-6	RT-7
Water depth (m)	1008	1250	1382	1610	1857	2056	2205
Species number:							
All species	67	86	94	87	66	75	83
Agglutinated	16	24	25	26	21	27	29
Calcareous	51	62	69	59	44	47	53
Soft-shelled				2	1	1	1
Diversity indices:							
<i>H(S)</i>	3.069	3.915	3.945	3.636	3.201	3.181	3.462
Fisher α	16.219	20.611	28.921	23.600	16.923	18.317	20.519
Evenness <i>E^{H/S}</i>	0.321	0.583	0.551	0.436	0.372	0.321	0.384

with 19.9% the most dominant species here. Also considerable is the presence of *Bulimina striata* (7.0%) and *N. iridea* (6.9%) as well as the first occurrence of soft-shell foraminifera (*Saccamminid* sp. 1 and sp. 2).

RT-5 was collected at 1857 m water depth and contained 819 (= 105 individuals 10 cm⁻²) living individuals from 66 species. Agglutinated foraminifera made up 22.9% of all stained individuals. This site is dominated by soft-shelled foraminifera with the most common *Saccamminid* sp. 1 (23.4%). One of the most important genus of calcareous species was *Globobulimina* (16.1%) with *Globobulimina* sp. 1 (8.8%) and *Globobulimina notovata* (6.1%). Besides, *Gavelinopsis praegeri* (6.4%) and *Bulimina striata* (5.1%) also showed notable amounts.

RT-6 from 2056 m water depth included 1081 (= 138 individuals 10 cm⁻²) living benthic foraminifera and 75 species. The agglutinated foraminifera increased to 29.7% and were dominated by *Reophax* spp. (11.1%). *Saccamminid* sp. 1, the only soft-shelled foraminifera at this site, accounted for 28.4%. The most common calcareous species were *N. iridea* (7.7%), *Gyroidina* sp. 1 (5.6%) and *B. striata* (4.2%).

The deepest investigated station (RT-7) originated from a water depth of 2205 m and yielded a total of 1151 stained individuals (= 147 individuals 10 cm⁻²) and 83 species. A significant increase of agglutinated species (40.2%) was noted with high amounts of *Reophax* spp. (15.6%). Soft-shelled *Saccamminid* sp. 1 (23.1%) was also very abundant. Frequently occurring calcareous species were *B. striata* (5.9%) and *N. iridea* (3.7%).

Soft-shelled foraminifera were only present in RT-4 to RT-7 (Fig. 3). Based on this observation, the core samples of this study can be divided into 2 groups: Group A without soft-shelled foraminifera (RT-1 to RT-3) and Group B including soft-shelled foraminifera (RT-4 to RT-7). RT-4 contained only 14 soft-shelled individuals (2 ind./10 cm²) and their dominant occurrence could be observed in RT-5 to RT-7. They made even 28.4% of the total living benthic fauna in RT-6. To sum up, it can be said, that *Saccamminid* sp. 1 showed up at a water depth of >1610 m and with increasing depth large quantities of this species could be observed. All sites contained between 22.7 and 40.2% agglutinated individuals, with the deepest site (RT-7) reaching the highest percentage of 40.2%.

In contrast, calcareous living benthic foraminifera decreased with depth. Some species are present only at shallower sites and others prefer deeper water depths (Fig. 4).

Melonis barleeanus and *U. mediterranea* were dominating RT-1. However, with increasing water depth their abundances decreased. A different behavior showed *Globobulimina* sp. 1. This species was not present at the first three sites (RT-1 to RT-3) and occurred from a water depth of 1610 m and deeper, with a maximum at RT-4 and RT-5.

Other important foraminifera species occurred at all sites with a similar percentage (e.g. *T. angulosa*) or could not be assigned to a clear trend (e.g. *N. iridea*).

3.3. Vertical distribution

Vertical distribution profiles of stained (calcareous, agglutinated and soft-shelled) benthic foraminiferal abundance down to 10 cm sediment layer are shown in Fig. 5

The highest number of benthic foraminifera occurred in the surface layer (up to 33 individuals 10 cm⁻²), except in RT-1 (18 individuals 10 cm⁻², with maximum of 20 individuals 10 cm⁻² at 2 cm sediment depth). Due to the high abundance of *M. barleeanus* (30 individuals 10 cm⁻²), maximum foraminiferal density in RT-1 was reached in the sediment layer 1.5–2 cm where this species made more than 60% of the total calcareous foraminiferal fauna. Most individuals in RT-1 could be found to a depth of 2.5 cm. The species richness decreased very rapidly with sediment depth. RT-2 was a bit more balanced. The fraction 0–0.5 cm contained the highest number of individuals (33 individuals 10 cm⁻²) and 0.5–1 cm the highest number of species (25 different species). The distribution of living individuals is alternating with increasing sediment depth. RT-3 and RT-4 had a similar pattern. The species richest fraction with 26 individuals 10 cm⁻² for RT-3 and RT-4 was 0–0.5 cm and the number of species decreased with sediment depth. At site RT-4 soft-shelled individuals occurred for the first time, mainly at a sediment depth of 5–6 cm. RT-5 to RT-7 contained high amounts (up to 40 individuals 10 cm⁻²) of soft-shelled foraminifera and had higher number

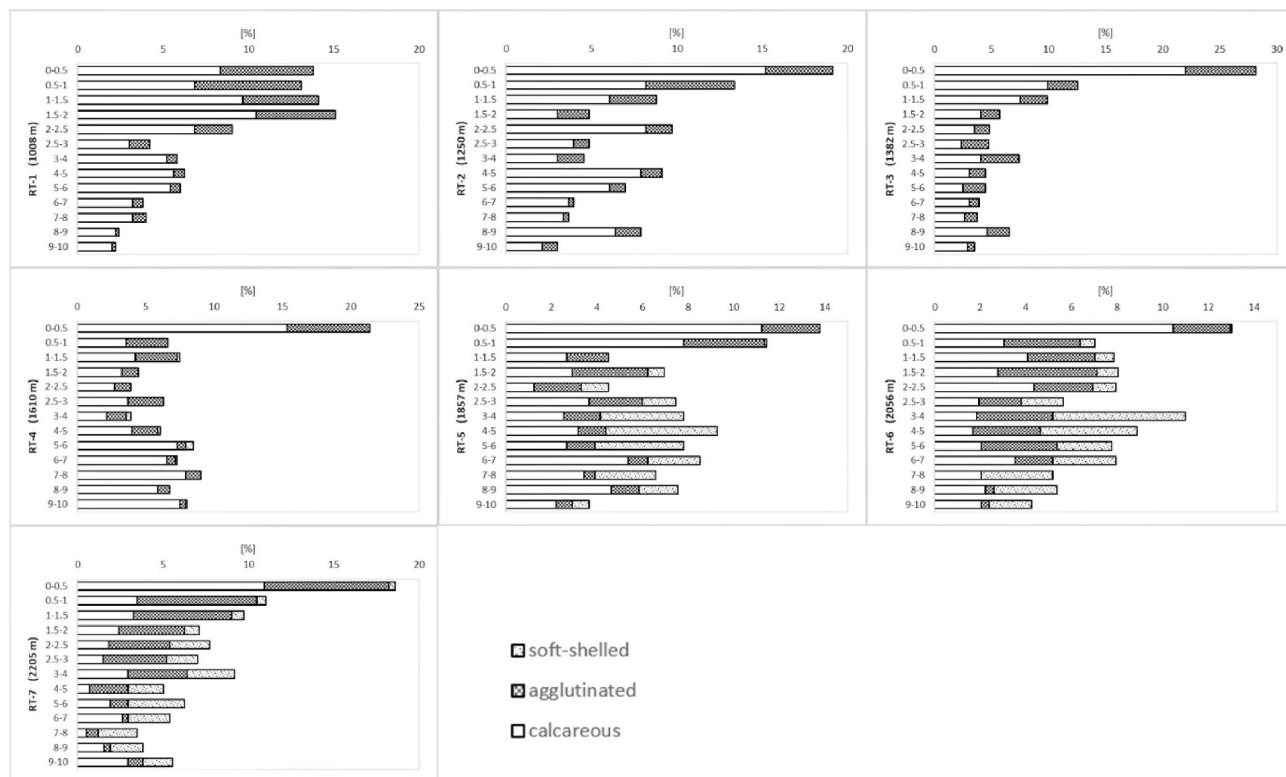


Fig. 5. Vertical distribution of living benthic foraminifera of each core from 0 to 10 cm sediment depth (fraction > 63 μm).

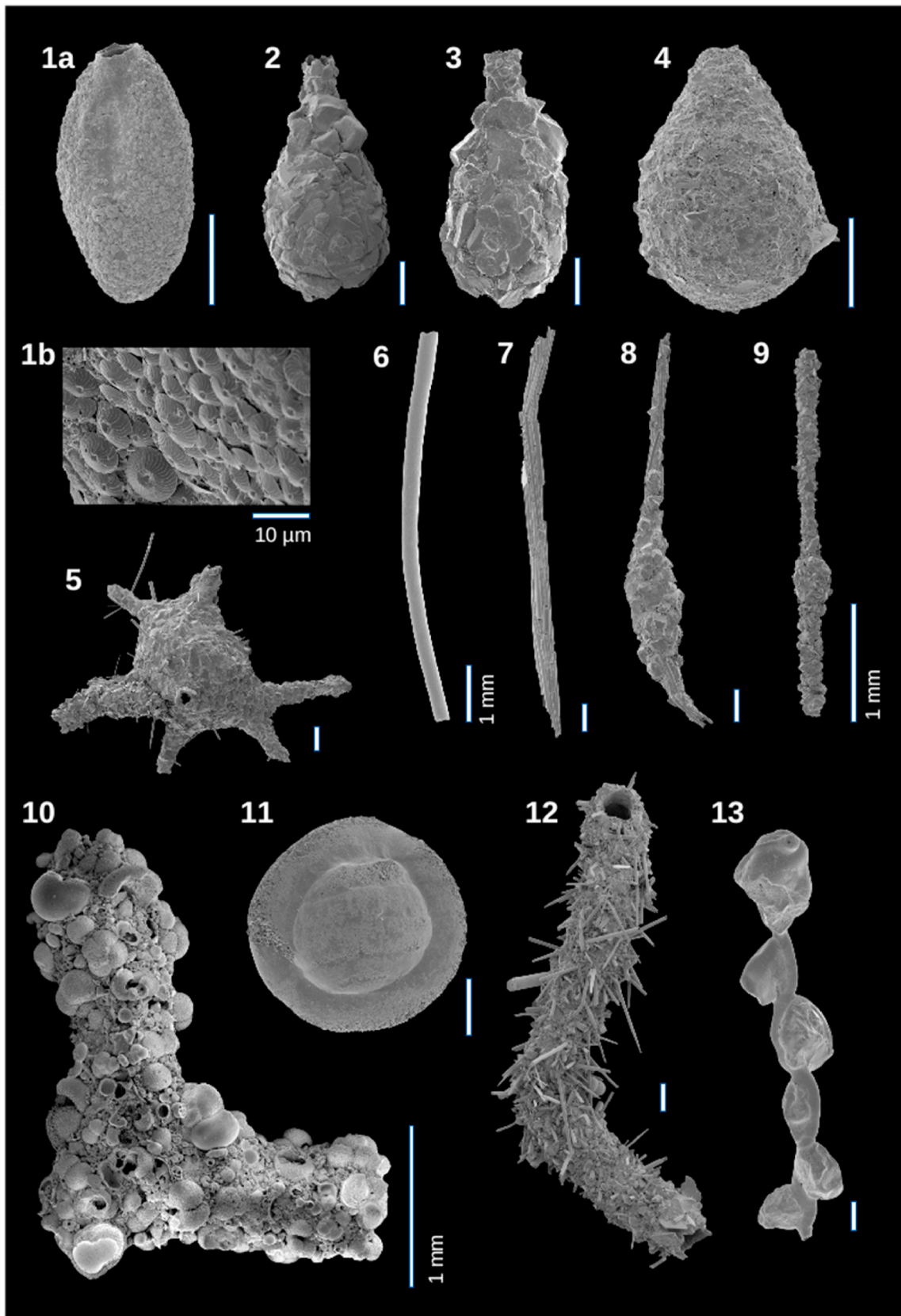


Plate 1. Scanning electron microscope pictures of (1a) *Saccamminid* sp.1, (1b) Test surface of *Saccamminid* sp. 1 in detail, (2) *Lagenammina* sp.1, (3) *Lagenammina* sp.2, (4) *Lagenammina* sp. 3, (5) *Astorhiza limicola*, (6) *Bathysiphon filiformis*, (7) *Marsipella cylindrica*, (8) *Marsipella elongata*, (9) *Rhabdammina linearis*, (10) *Rhammina algaeformis*, (11) *Glomospira charoides*, (12) *Saccorhiza ramosa*, (13) *Ammolagena clavata*. Bar scale = 100 µm, unless stated otherwise.

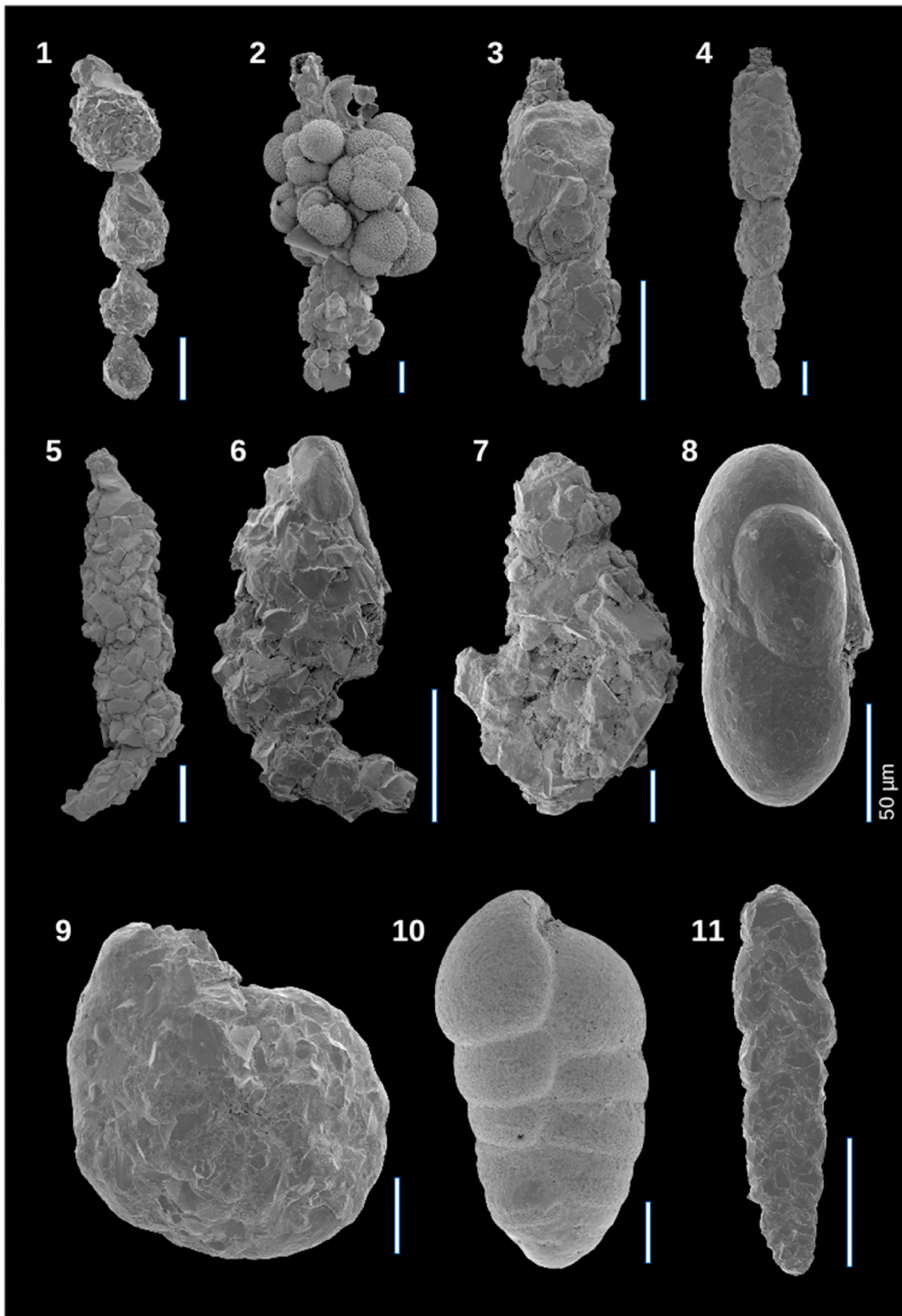


Plate 2. Scanning electron microscope pictures of (1) *Hormosinelloides guttifer*, (2) *Reophax agglutinatus*, (3) *Reophax bilocularis*, (4) *Reophax dentaliniformis*, (5) *Reophax scoriurus*, (6) *Reophax subfusiformis*, (7) *Ammobaculites agglutinans*, (8) *Cystammina argentea*, (9) *Cyclammina cancellata*, (10) *Karrerella bradyi*, (11) *Textularia earlandi*. Bar scale = 100 μm , unless stated otherwise.

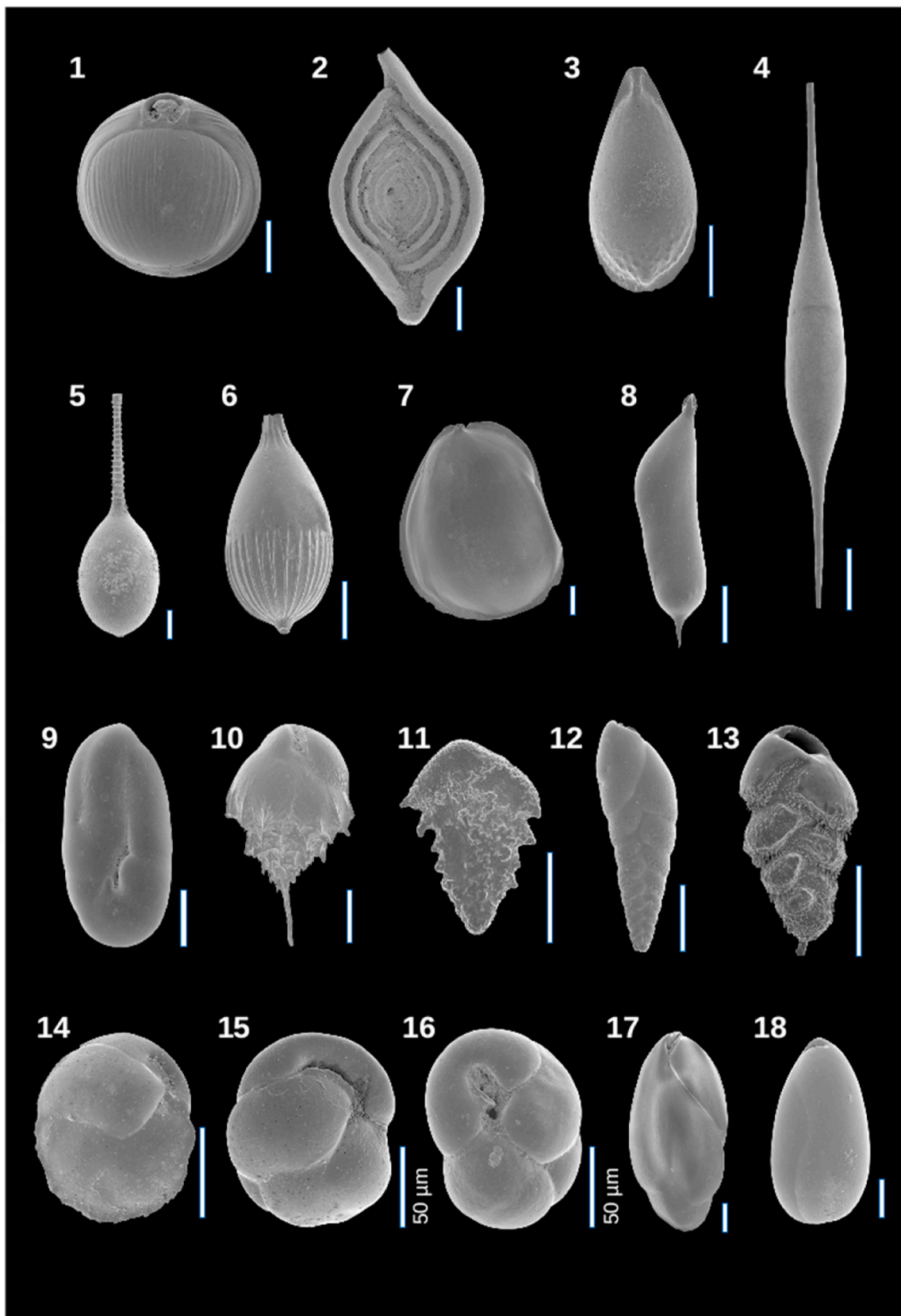


Plate 3. Scanning electron microscope pictures of (1) *Pyrgo comata*, (2) *Spirophthalmidium tenuiseptatum*, (3) *Fissurina cf. aperturaolata*, (4) *Hyalinonetrion gracillimum*, (5) *Lagena crispata*, (6) *Lagena semilineata*, (7) *Neolenticulina variabilis*, (8) *Dentalina trondheimensis*, (9) *Robertina subcylindrica*, (10) *Bulimina striata*, (11) *Bolivina difformis*, (12) *Bolivinelina pseudopunctata*, (13) *Bolivina subspinescens*, (14) *Cassidulina carinata*, (15) *Cassidulina obtusa*, (16) *Globocassidulina subglobosa*, (17) *Globbulimina notovata*, (18) *Globbulimina* sp.1. Bar scale = 100 µm, unless stated otherwise.

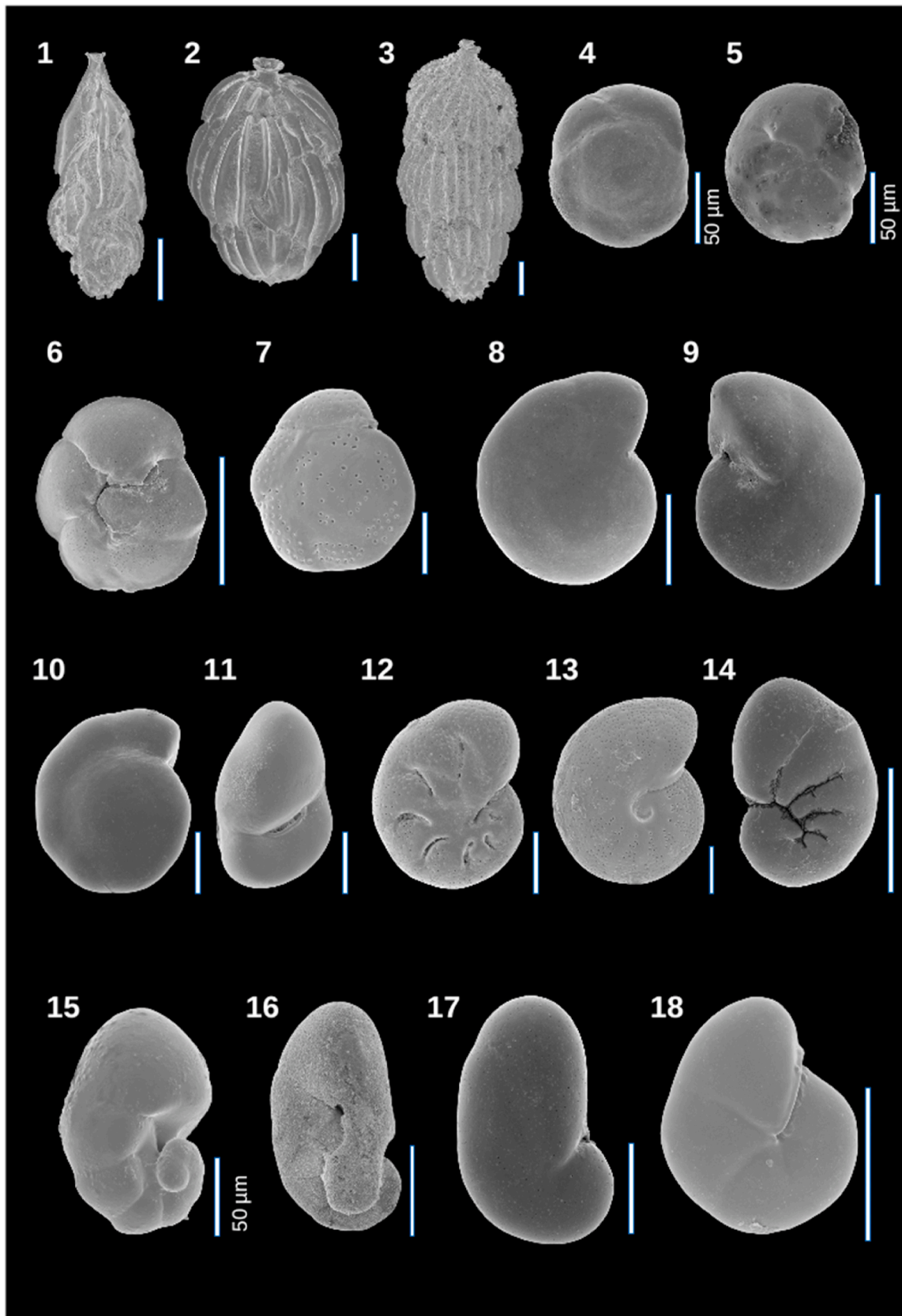


Plate 4. Scanning electron microscope pictures of (1) *Trifarina angulosa*, (2) *Uvigerina mediterranea*, (3) *Uvigerina peregrina*, (4–5) *Alabaminella weddellensis*, (6) *Gavelinopsis praegeri*, (7) *Cibicidoides bradyi*, (8–9) *Gyroidina laevigata*, (10–11) *Gyroidina* sp.1, (12) *Astrononion hamadaense*, (13) *Melonis barleeanus*, (14) *Nonionella auricula*, (15) *Nonionella iridea*, (16) *Nonionoides turgidus*, (17) *Pseudononion* sp. 1, (18) *Pullenia quinqueloba*. Bar scale = 100 µm, unless stated otherwise.

of individuals in sediment depths below 3 cm (>7 individuals 10 cm⁻²). Still, they also showed a noticeable decrease of diversity with sediment depth.

The vertical distribution of abundant foraminiferal species at different water depths are shown in the appendix (Fig. A). Species such as *T. angulosa* or *B. striata* could be found at all sites at any depth. Other species such as *Globobulimina* sp. 1, *Gyroidina* sp. 1 or *Saccamminid* sp. 1 mainly occurred in deeper sediment layers and were not found at all sites. In contrast, *N. iridea* occurred at all stations but only to a sediment depth of maximal 5 cm. RT-1 had the highest amount of *U. mediterranea* and *M. barleeanus*. In some layers these species made up over 40% of all living foraminifera. In cores RT-2 and RT-3 most common foraminifera *M. barleeanus* was found in all depths. *Globobulimina* sp. 1 was the most abundant species in RT-4. In this and in the following stations RT-5 to RT-7 this species appeared in large numbers in the sediment deeper than 5 cm. A similar pattern was shown by *Saccamminid* sp. 1, which was found in RT-4 to RT-7. This species first occurred at a sediment depth of 2–3 cm. From 4 to 8 cm sediment depth *Saccamminid* sp. 1 was present in large quantities in RT-5 to RT-7 and could even account for over 60% of all living benthic foraminifera. From 8 cm sediment depth the quantities of this species decreased with increasing depth.

ALDs of the most common foraminiferal species were calculated. Since the calculation of ALDs is strongly related to the number of living foraminifera in the sediment, values with large amount of foraminifera are more significant than those calculated with smaller amount of living foraminifera (see Table 3). The shallowest station (RT-1, 1008 m) had a ALD of 2.19 for all calcareous foraminifera, whereas the total calcareous ALD of the deepest site (RT-7 2205 m) amounts to 1.08. Thus, a tendency for decreasing ALD of calcareous foraminifera with water depth can be observed. However, RT-4 has an exceptionally high calcareous species ALD of 3.26. This is due to the very high abundance of *Globobulimina* spp., which greatly increases the ALD value. Contrary to this observation, the ALD of agglutinated foraminifera slightly increases with depth. The most important representatives in these core samples can be subdivided as follows:

Epifaunal species (ALD < 0.1): *N. iridea*, shallow infaunal species (ALD 0.1–0.5): *B. striata*, *C. bradyi*, *Gyroidina* sp. 1, *T. angulosa*, intermediate infaunal species (ALD 0.5–1.0): *M. barleeanus* and deep infaunal species (ALD > 1.0): *Globobulimina* sp. 1, *Saccamminid* sp. 1, *U. mediterranea*.

For the calculation of the BFOI, morphological and taxonomic parameters are necessary to divide foraminiferal species in dysoxic, sub-oxic and oxic characters (Kaiho, 1994). Following Kaiho (1994) calcareous benthic foraminifera of this study were divided into dysoxic: *Bolivina* spp., *Chilostomella oolina*, *Dentalina* spp., and oxic indicators: *Cibicidoides* spp., *Globocassidulina subglobosa*, *Pyrgo murrhina*, *Quinqueloculina* spp., *Triloculina* spp. After Kaiho (1994) the foraminiferal assemblage of the first layer (0–0.5 cm) of each sediment core RT-1 to RT-7 reflect high oxic conditions (oxygen index > 83). This corresponds to the dissolved oxygen content of 6 ml*1⁻¹ (Kaiho, 1999).

4. Discussion

4.1. Composition of the foraminiferal assemblages

A clear change in assemblage compositions can be observed along the transect. We can observe a fundamental faunal change between the first three more shallow sites (RT-1 – RT-3, Group A) and the last four deeper sites (RT-4 – RT-7, Group B). This difference may be due to different water masses present at the different sites (Dorschel et al., 2010). Sub-Arctic Intermediate Water (SAIW) extends to a depth of about 1600 m, whereas underneath the Labrador Sea Water (LSW) is present (Dorschel et al., 2010). SAIW (8–9 °C, 35.1–35.2 PSU, dissolved oxygen: 230–250 μmol kg⁻¹) and LSW (3.2–4.1 °C, 34.94–34.96 PSU, dissolved oxygen: 260–270 μmol kg⁻¹) are similar in character and vary mainly in the water temperature and the amount of dissolved oxygen (Van Aken and Becker, 1996; McGrath et al., 2012). Hereby, RT-4 from 1610 m water depth is located at this water mass boundary between SAIW and LSW and may be influenced by both water masses. Sites RT-5 to RT-7 were collected far below this boundary and thus show a different foraminiferal composition compared to the sites RT-1 to RT-3.

In general, RT-1 was dominated by *M. barleeanus* and *U. mediterranea*. Both species accounted for 38.6% of all living foraminifera resulting in the lowest diversity ($H(S) = 3.069$) of all sites. Their highest abundance was observed in a sediment depth of about 1–3 cm, which coincides with those of previous studies (e.g. Gooday and Hughes, 2002) and is also comparable with distribution patterns of these species in other regions (e.g. Sulu Sea, Szarek et al., 2007).

At RT-2 the highest abundance of *Cibicidoides* was recorded (six species of *Cibicidoides* made up 16.9% of all living calcareous foraminifera) compared to other sites. RT-3 was already the deepest site, where *Cibicidoides* (14.5% of stained calcareous foraminifera) and *M. barleeanus* (9.1% of living calcareous foraminifera) occurred in considerable quantities. The fourth site (RT-4) is completely different from the previously considered ones. The dominant species of RT-1 to RT-3 (e.g. *M. barleeanus*, *C. bradyi*) were barely present at this station. The diversity is lower in RT-4 due to an enormous occurrence of *Globobulimina* (36.5% of all living calcareous foraminifera) and in RT-5 and RT-6 due to high amounts of soft-shelled foraminifera (*Saccamminid* sp.1 with 23.4% and 28.4% of the total foraminiferal fauna). Although *Saccamminid* sp. 1 was still dominating RT-7, the diversity was slightly higher ($H(S) = 3.462$) at this site. The *Saccamminid* sp. 1 found in this core samples (RT-4 – RT-7) sparsely resembles illustrated morphospecies found in the bathyal northeast Atlantic (Gooday, 1986a, Fig. 4A). Still, saccamminids occur not only in the RT, but were also found in other areas of the NE Atlantic (Gooday 1986a, 1996, 1998), in the Barents Sea (Gooday et al., 2013) as well as in the abyssal North and Western Pacific (Gooday et al., 2004; Enge et al., 2012) and the Weddell Sea (Cornelius and Gooday, 2004). Sabbatini et al. (2007) discovered 28 different species of Saccamminids in Svalbard, Arctic Ocean, from which *Saccamminid* sp. O bears analogy to our *Saccamminid* sp.1. Comparing

Table 3

ALD of dominant foraminiferal species (after Jorissen et al., 1995). In parentheses: number of individuals that were used for ALD calculations.

Species	ALD						
	RT-1 (1008 m)	RT-2 (1250 m)	RT-3 (1382 m)	RT-4 (1610 m)	RT-5 (1857 m)	RT-6 (2056 m)	RT-7 (2205 m)
<i>B. striata</i>	–	0.08 (25)	0.42 (66)	0.48 (94)	0.49 (68)	0.47 (71)	0.44 (85)
<i>C. bradyi</i>	–	0.14 (71)	0.33 (63)	–	–	–	0.01 (16)
<i>Globobulimina</i> sp. 1	–	–	–	2.07 (260)	1.09 (126)	0.19 (24)	0.19 (30)
<i>Gyroidina</i> sp. 1	0.05 (8)	–	–	–	0.07 (30)	0.38 (78)	0.07 (27)
<i>M. barleeanus</i>	1.07 (269)	0.70 (162)	0.70 (118)	0.02 (5)	–	0.08 (9)	0.04 (12)
<i>N. iridea</i>	0.01 (13)	0.04 (39)	0.07 (61)	0.09 (77)	0.04 (42)	0.06 (68)	0.02 (28)
<i>Saccamminid</i> sp. 1	–	–	–	0.11 (21)	2.04 (318)	2.10 (400)	1.96 (398)
<i>T. angulosa</i>	0.10 (30)	0.14 (35)	0.18 (34)	0.11 (30)	0.06 (25)	0.02 (12)	0.11 (23)
<i>U. mediterranea</i>	1.48 (266)	–	–	–	–	–	–
Total calc. Foram.	2.19 (717)	2.63 (1016)	2.03 (518)	3.26 (682)	1.88 (442)	1.32 (452)	1.08 (422)
Total aggl. Foram.	0.50 (276)	0.55 (300)	0.73 (199)	0.58 (222)	0.64 (188)	0.86 (320)	0.86 (463)

saccamminids with other studies is difficult, because often species are not illustrated or mostly photographed using reflected and transmitted light. Gooday et al. (2005) and Sabbatini et al. (2007) described some saccamminids with their wall composed of plate-like particles (e.g. Sabbatini et al., 2007, Plate 2L and 2N), but none of them mentioned coccoliths as a test compound. *Saccamminid* sp. 1 of this study is almost entirely covered with coccoliths. Foraminifera selectively encasing themselves with coccoliths are known since the cretaceous age (Thomson and Rasmussen, 2008) and nowadays foraminifera such as *Trochamminopsis pusillus* or *Spiroplectammina tenuissima* can still be found covered selectively and completely with coccoliths (Wollenburg, 1992). Therefore, we can assume that *Saccamminid* sp. 1 could be a new (not now in detail described) species, but further studies are necessary to clarify this aspect.

Although deep-sea foraminiferal studies have been carried out in the Rockall Trough and the nearby situated Porcupine Seabight (Weston, 1985; Gooday, 1986; Gooday and Lamshead, 1989; Murray, 1991; Hughes et al., 2000; Gooday and Hughes, 2002), most of them were just investigating the uppermost 1 cm of sediment (e.g. Gooday and Hughes, 2002; Panieri, 2005) and Gooday (1986) sampled only the upper 5 cm of sediment. No study dealing with the vertical distribution (deeper than 1 cm) of foraminifera along a transect at different water depths in the RT has yet been published. The seven sites (RT-1 to RT-7) of this study showed a high diversity, but they differed in their abundances and evenness (Table 2). The highest number (1316 ind.) of living benthic foraminifera with $H(S) = 3.915$ was found in RT-2 (1250 m water depth). In contrast, RT-3 (1382 m water depth) showed a similar diversity ($H(S) = 3.945$), but possessed the least total number of stained foraminifera (717 ind.). Generally, there are few dominant species and the high diversity is due to a large number of rare species. This pattern is typical for deep-sea foraminiferal assemblages in well-oxygenated settings (Douglas and Woodruff, 1981). Comparisons with previous studies from this RT-area have to be treated with caution, since different methodologies were used. For instance, Hughes et al. (2000) found in wet-sorted samples (sampled in August 1997 from 1926 m depth, > 125 μm , 0–1 cm) 190 live individuals/10 cm^2 for the total and 25 live individuals/10 cm^2 for the calcareous assemblage, while our results (sampled in May 2016, RT-5 from 1857 m and RT-6 from 2056 m, > 63 μm , 0–1 cm) reached 24–25 stained individuals/10 cm^2 for the total assemblage and 19–20 calcareous individuals/10 cm^2 . These large differences can occur, since wet-sorted samples include delicate soft-bodied and agglutinated forms that are destroyed by drying (Brodniewicz 1965), like the organic-walled and divers allogromiids (Gooday et al., 1998). In our study we do not use wet-picking methods because the focus was set on calcareous species. Besides, analysis of different size fractions can lead to changes in species number and therefore diversity (Schönfeld, 2012). Another aspect are the seasonal changes in population density as shown by Gooday and Hughes (2002) who found different mean densities of *N. iridea* in May (40 ind./10 cm^2) and July (326 ind./10 cm^2) at 1920 m water depth. In our study the mean density of *N. iridea* (6 ind./10 cm^2 in May, calculated from RT-5 and RT-6, 0–1 cm) was lower than this obtained by Gooday and Hughes (2002). Not comparable are also the results of Panieri (2005) who used almost identical methods, but was investigating the total foraminiferal fauna (dead and live). In dried samples (sample C43 from about 1000 m depth, > 63 μm , 0–1 cm) Panieri (2005) found a total of 23 ind./10 cm^2 and in our sample (RT-1 from 1008 m, > 63 μm , 0–1 cm) we reached 52 ind./10 cm^2 for the total living foraminiferal assemblage. Still, in our study living (Rose Bengal stained) benthic foraminifera displayed standing stocks of 92–168 ind./10 cm^2 for the total, 54–130 ind./10 cm^2 for the calcareous and 24–59 ind./10 cm^2 for the agglutinated assemblages.

Generally, standing stocks of deep-sea foraminiferal assemblages are often comparable low at continental slopes and in the range of 20–200 ind./10 cm^3 (Murray, 2006). These densities can be found not only in the Atlantic and Southern Ocean, but also in the Arctic Ocean. Similar

densities can be found at abyssal sites (197 ind./10 cm^2 ; Gooday, 1996) or even at shallower sites near Explorers Cove, Antarctica (137 ind./10 cm^2 ; Bernhard, 1989).

4.2. Microhabitat preferences of benthic foraminifera

The vertical distribution of foraminifera is varying between the studied sites. In RT-1 to RT-4 and in RT-7 a typical epifaunal to shallow infaunal lifestyle of foraminifera could be observed. RT-5 and RT-6 showed an additional increase in population density with increasing sediment depth due to the high abundances of *Globobulimina* sp.1 and *Saccamminid* sp. 1 in deeper sediment layers. At all sites the diversity of foraminifera decreases with sediment depth. On the average across all seven stations, the upper sediment fraction (0–0.5 cm) contained 38 genera, whereas at a depth of 10 cm only 9 genera were present. Following the TROX model of Jorissen et al. (1995), food supply and oxygen concentration influence the foraminiferal vertical distribution. Therefore, most foraminifera species are present in the upper sediment layers, since food limitation plays an important role and occurs with deeper sediment depths (Jorissen et al., 1995). The graphs in Figure A (appendix) show a maximum occurrence of *Saccamminid* sp. 1 at a sediment depth of about 4–6 cm and then the proportion of this species decreases again with increasing depth. For other species such as *U. mediterranea* (only in RT-1) or *Globobulimina* sp. 1 (occurring especially in RT-4 from 4 to 10 cm sediment depth) the examined 10 cm sediment cores were not sufficient deep enough to detect their maximum occurrence. Based on the strong increase of *Globobulimina* sp. 1 with sediment depth, it can be assumed that this species can also be found living deeper than 10 cm. The discovery of *Globobulimina* species in deeper sediment layers has been discussed several times (Gooday and Hughes, 2002; Nomaki et al., 2005, 2006; Szarek et al., 2007). According to Jorissen (1999), *Globobulimina* spp. can also be found at shallower sediment depths, if the sediment has only a thin top layer of oxygenated sediment. The vertical distribution of *Globobulimina affinis* in relation to the oxygen content was also experimentally investigated by Geslin et al. (2004). Since *Globobulimina* spp. showed a high abundance in our core samples from a depth of 5–6 cm, it seems that the sampling area is well oxygenated. This can be also supported by the calculated BFOI (0–0.5 cm of each sediment core), which implies high oxic conditions (oxygen index >83) for all seven cores. Furthermore, *Globobulimina affinis* (seasonal-phytophagous) consumes preferentially older organic detritus and therefore avoids areas with high oxygen content that would decompose organic matter (Kitazato, 1994; Nomaki et al., 2006). However, observations by Rathburn and Corliss (1994) showed that the presence of high organic flux to the bottom is more important for the species dominance of some *Globobulimina* and *Uvigerina* species than the oxygen concentration. This coincides with the calculated amount of dissolved oxygen in the RT by McGrath et al. (2012). *Globobulimina* sp. 1 is more abundant at deeper sites RT-4 to RT-7, which contained slightly more dissolved oxygen (273 $\mu\text{mol kg}^{-1}$ in LSW at 1500–2000 m, 2010) than in RT-1 to RT-3 (248 $\mu\text{mol kg}^{-1}$ in SAIW at 700–1000 m, 2010) (McGrath et al., 2012). Export production may also have an influence on the organic food flux at the deeper sites. In RT-1 to RT-3 the absence of *Globobulimina* spp. could indicate a better ventilation of the sediment or a lower organic flux. A high concentration of biomass in this region has been known for some time and is directly related to turbiditic and high primary activity (Gage, 1979). This implicates, that the oxygen concentration is probably the decisive factor in the investigated core samples, as the ALDs of *Globobulimina* sp. 1 decrease with increasing water depth (Table 3).

Uvigerina mediterranea plays a special role, as this species only occurred in core RT-1. Jorissen et al. (2018) correlated the relative abundance of some foraminiferal species to the amount of total organic carbon (TOC) and assigned this foraminifer to “indifferent species”, meaning that this species often occurs in areas with low TOC. Therefore, the enormous occurrence of *U. mediterranea* in core RT-1 indicates a

lower TOC content at this site, and leads to the assumption that the TOC content might be higher at the other sites (RT-2 to RT-7). A similar pattern is drawn by the occurrence of *Melonis barleeanus*. This common foraminifer is classified in the group of “third order opportunists” after Jorissen et al. (2018) and tolerates/responds opportunistic to higher organic enrichment, but is absent in areas with maximum enrichment. In our study, mass occurrences of *M. barleeanus* could be observed only at the shallower sites RT-1 and RT-2 and the low abundance at deeper sites indicates again changing organic carbon content with depth. Basically, *M. barleeanus* occurred in large numbers at sediment depths of 2–3 cm and 6–7 cm in RT-1 to RT-3. An occurrence of *M. barleeanus* in these sediment depths is also known from literature (Heinz et al., 2002; Jannink et al., 1998). Comparing our ALD data (1.07 (269) at 1008 m) with literature (e.g. Fontanier et al. (2003) ALD of *Melonis barleeanus*: 1.1(40) in June 1998 at 550 m), similar values can be observed indicating an infaunal to deep infaunal lifestyle of this species. According to Jannink et al. (1998), *M. barleeanus* occupies a special position, as this species may live epifaunal to deep infaunal depending on the availability of food. In our core samples, *M. barleeanus* was found up to the maximal sediment depth of 10 cm. Past investigations have shown, that in some areas typical shallow to intermediate infaunal living species migrate deeper into the sediment while searching for food (Szarek et al., 2007). Migrations through the sediment (up and down) are also induced by seasonal fluctuations of food supply and the corresponding changes of the oxygenated layer (Goody, 2003). However, *M. barleeanus* was highly abundant in our core samples at several sediment depths, which led to a conclusion, that sufficient food was present over the entire sediment depth investigated. According to Caralp (1989) this species consumes both fresh and altered organic matter and the appearance of *M. barleeanus* is an indicator for food availability (Jannink et al., 1998). It tolerates high concentrations of organic matter (Fontanier et al., 2002) and is also indicative of deep mesotrophic conditions (Jorissen et al., 1995). Since this species dominated up to 3 cm sediment depth, it can be assumed that the available food decreases below 3 cm. This can be also confirmed by the occurrence of *N. iridea*. The top cm of the sites (except RT-1) showed a high abundance of *N. iridea* in the fraction 125–63 μm . According to Duffield et al. (2015), *N. iridea* can occur in large quantities in the upper layers of a sediment. *Nonionella iridea* was present in our core samples only to a depth of 2–3 cm and is regarded as an indicator for primary production, because of its opportunistically response to phytodetritus (e.g. Mackensen et al., 1990; Goody and Hughes, 2002; Duchemin et al., 2005, 2008). This species occurred mainly in the uppermost 0.5 cm and can also indicate lower temperatures and salinities (e.g. in the northern Gulf of Cadiz, Mendes et al., 2012). This extreme epifaunal lifestyle can be described very well with the large number of individuals and yet very low ALDs. *Nonionella iridea* occurred in the core samples RT-1 to RT-7 with abundances of 3–11 ind./10 cm² exclusively in the fraction 125–63 μm . Goody (1986) discovered juvenile and adult individuals of *N. iridea* in the fraction 45–63 μm and 1/3 of foraminifera were found in this fraction. For our study this means, that probably not all individuals were recorded.

Also, *Saccamminid* sp. 1 was only present in the smaller fraction (125–63 μm) with its highest abundance between 3 and 10 cm sediment depth in RT-4 to RT-7. The mass occurrence of monothalamous foraminifera in marine sediments is a discussed aspect (e.g. Goody, 2002; Cornelius and Goody, 2004). However, the identification of saccamminids is difficult and it is likely to underestimate their true diversity (Lecroq et al., 2011). Difficult taxonomic identification, large distribution areas and probably high diversity make it hard to formulate a clear statement about their preferred habitat (Goody, 1986; Cornelius and Goody, 2004), since they have been found in deep-water anoxic settings (Bernhard et al., 2005) as well as in areas with high oxygen concentrations (Goody et al., 2000). Enge et al. (2011) demonstrated in in-situ feeding-experiments, that saccamminids do not prefer freshly deposited food and Goody (2002) suggested even a bacterivory lifestyle or ingestion of refractory organic material (Goody et al., 2008). Since

the species *Saccamminid* sp. 1 occurred in our core samples from 3 cm sediment depth and deeper, it can be stated that this foraminifera prefers the infaunal lifestyle. In general, they appear to be less opportunistic than most calcareous species (Goody et al., 2001). In this study, a high population density of saccamminids from RT-5 (water depth of 1857 m) could be determined. This mass occurrence of saccamminids might have a close relation to the absence or low abundance of prominent phytodetritus-associated species (e.g. *Alabaminella weddellensis*). This way, available food is not consumed by opportunistic epifaunal species and reaches deeper sediment layers. Enge et al. (2012) described a similar setting, where some saccamminids were abundant in samples from September and after the phytodetritus pulse in spring less individuals were observed. Therefore, we can assume that our samples were not collected right after a phytodetritus pulse.

5. Conclusions

We studied 182 Rose Bengal stained sediment samples collected from seven multiple-core sampling sites (RT-1 – RT-7) in the Rockall Trough. The following conclusions were drawn from analysis of stained benthic foraminiferal assemblages:

- The investigated sites differed in assemblages, diversity, abundances and vertical distribution. The core samples (down to 10 cm) yielded 204 species of benthic foraminifera, including 152 calcareous, 50 agglutinated and 2 soft-shelled species. The standing stock values (92–168 individuals 10 cm⁻² at RT-1 – RT-7) the high diversity and calculated BFOI characterize well-oxygenated conditions in the Rockall Trough. Because of the foraminiferal faunal composition, the sites can be divided into two groups, which mainly differentiate in the absence or presence of soft-shelled taxa: Group A without soft-shelled foraminifera (RT-1 (1008 m) to RT-3 (1382 m)) and Group B including soft-shelled foraminifera (RT-4 (1610 m) to RT-7 (2205 m)). Although, site RT-4 contained only 14 soft-shelled individuals (2 ind./10 cm²) and their dominant occurrence could be observed in RT-5 to RT-7, they made even 28.4% of the total living benthic fauna in RT-6 (2056 m). The soft-shelled taxa were dominated by *Saccamminid* sp. 1, which is entirely covered with coccoliths and may be a new (no yet described) species, but further investigations are necessary to clarify this aspect.
- In general, calcareous living benthic foraminifera decreased with water and sediment depth. Some species were present only at shallower sites (e.g. *U. mediterranea* at site RT-1) and others prefer deeper water depths (e.g. *Globobulimina* spp.). Most foraminiferal fauna was present in the very top of the sediment (upper sediment layers), but a clear vertical distribution within the cores was observed. Epifaunal species (e.g. *N. iridea*) were present as well as deep infaunal species like *Globobulimina* sp. 1.

In contrast, agglutinated individuals accounted between 22.7 and 40.2% at all sites and reached their highest abundance of 40.2% at the deepest site (RT-7 (2205 m)).

- Some species were very abundant (e.g. *Saccamminid* sp. 1) and their mass occurrence might be influenced by the food supply and the oxygen content. Opportunistic species such as *Melonis barleeanus* were very abundant at the shallower sites and its vertical distribution implies an intermediate to deep infaunal lifestyle with ALDs comparable to literature. Still, due to the low abundance of opportunistic species (e.g. *Alabaminella weddellensis*), we can conclude that our cores were not collected right after a phytodetritus pulse.
- Differences of living foraminiferal assemblages between the sites can probably be explained by increasing water depth and the change in influencing water masses. RT-1 to RT-3 are surrounded by the Sub-Arctic Intermediate Water (SAIW) that extends to a depth of about 1600 m (Dorschel et al., 2010). Underneath the Labrador Sea Water

(LSW) is located (Dorschel et al., 2010). As a result, RT-4 was collected at this water mass boundary between SAIW and LSW and may be influenced by both water masses. Sites RT-5 to RT-7 were surrounded by the LSW and thus show a different foraminiferal composition compared to the sites RT-1 to RT-3.

In summary, this study once again illustrates the diversity of foraminifera in different water depths. The changing foraminiferal assemblages allowed to gain insight into the prevailing environmental parameters that influenced the faunal composition in this area. The transect can be summarized as an area of high productivity with a high diversity of foraminifera and good oxygen conditions in the uppermost cm of the sediment, where the high food supply allows to inhabit deeper sediment layers.

Appendix

Table A

Abundance of Rose Bengal stained benthic foraminifera (calcareous, agglutinated and soft-shelled species) in the >125 µm and 125–63 µm fraction for all 7 cores (numbers not standardized for sediment volume).

calcareous species	RT-1 (1008 m)		RT-2 (1250 m)		RT-3 (1382 m)		RT-4 (1610 m)		RT-5 (1857 m)		RT-6 (2056 m)		RT-7 (2205 m)	
	>125 µm	125-63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm
<i>Alabaminella weddellensis</i>		1		8		8		5		9		6		7
<i>Alliatina primitiva</i>				28		2		4						2
<i>Amphicoryna scalaris</i>	2													
<i>Anomalina</i> sp. 1						1								
<i>Articulina</i> sp. 1					2									
<i>Astrononion hamadaense</i>		5	8			7		5		4		24		19
<i>Biloculinella cylindrica</i>					2									
<i>Bolivina alata</i>			4											
<i>Bolivina difformis</i>		12		4		4		3		2		3		1
<i>Bolivina</i> sp. 1						1								
<i>Bolivina spathulata</i>				4										
<i>Bolivina subspinescens</i>		2		12		1		1						3
<i>Bolivinelina pseudopunctata</i>		6		12		2		5		1		1		3
<i>Bulimina marginata</i>	2													
<i>Bulimina striata</i>		1	20		28		62	2	42		44	1	68	
<i>Cassidulina laevigata</i>		8		4		7	6	14		4		1		
<i>Cassidulina carinata</i>			8	32	2	13	6			2			2	1
<i>Cassidulina obtusa</i>	2	38	12	20		12	8	2				1		2
<i>Cassidulina teretis</i>			12	8		5		3						
<i>Chilostomella oolina</i>	8		8	4	4		6		2				6	
<i>Cibicidoides bradyi</i>			84	4	30	2							12	1
<i>Cibicidoides lobatulus</i>			20	4	4	1								
<i>Cibicidoides robertsonianus</i>			12		4									
<i>Cibicidoides</i> sp. 1			12		2									
<i>Cibicidoides</i> sp. 2			12		12									
<i>Cibicidoides</i> sp. 3			28		20									
<i>Cibicidoides wuellerstorfi</i>							4				10		8	3
<i>Cornuspira involvens</i>	4					1				1				
<i>Dentalina albatrossi</i>											4			
<i>Dentalina mutabilis</i>					2									
<i>Dentalina trondheimensis</i>						4								
<i>Epistominella exigua</i>		4										2		2
<i>Eilohedra vitrea</i>						1		2		3	2	10		5
<i>Favulina hexagona</i>								2						2
<i>Favulina melo</i>								2						
<i>Fissurina (trigono) tenuistratiformis</i>												1		
<i>Fissurina</i> cf. <i>aperturoalata</i>												2		
<i>Fissurina foliiformis</i>					4									
<i>Fissurina</i> sp. 1					4									
<i>Fissurina spinosiformis</i>								1		2				
<i>Fissurina tenuistratiformis</i>												2		
<i>Francisita advena</i>														2
<i>Franciscia</i> sp. 1														2
<i>Gavelinopsis caledonia</i>						4		7				4		
<i>Gavelinopsis praegeri</i>		1		4	4	10	12	14	12	40	12	18	8	11
<i>Glandulina laevigata</i>	2													
<i>Glandulina ovula</i>	28		4		4									

(continued on next page)

Table A (continued)

calcareous species	RT-1 (1008 m)		RT-2 (1250 m)		RT-3 (1382 m)		RT-4 (1610 m)		RT-5 (1857 m)		RT-6 (2056 m)		RT-7 (2205 m)	
	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm
<i>Glandulina</i> sp. 1			4											
<i>Globobulimina affinis</i>							18		6		2			
<i>Globobulimina notovata</i>							42		48	2				
<i>Globobulimina pacifica</i>							4							
<i>Globobulimina</i> sp. 1							134	49	72		14		16	
<i>Globobulimina</i> sp. 2							2							
<i>Globocassidulina crassa</i>							2							
<i>Globocassidulina subglobosa</i>		48	4	16						1	4			2
<i>Globulina</i> sp. 1							2							
<i>Globulotuba</i> sp. 1													2	
<i>Guttulina</i> sp. 1				8										
<i>Gyroidina altiformis</i>	2		4		4		6						2	
<i>Gyroidina laevigata</i>	2		4			5	2	1		2		1		9
<i>Gyroidina</i> sp. 1	4			8					16		58	2	28	
<i>Hansenisca soldanii</i>			28				2				6			
<i>Hoeglundina elegans</i>		4											10	
<i>Hyalinonetrion gracillimum</i>		1	4				2			2				2
<i>Islandiella norcrossi</i>				12		5		3						
<i>Laevidentalina advena</i>			8											
<i>Laevidentalina ariana</i>						1								
<i>Laevidentalina haueri</i>	2					1								1
<i>Laevidentalina subsoluta</i>					2									
<i>Lagena crispata</i>	2													
<i>Lagena hispida</i>		1												1
<i>Lagena hispidula</i>							8			4	2			
<i>Lagena</i> cf. <i>semiinterrupta</i>			4											
<i>Lagena</i> sp. 1						1								
<i>Lagena striata</i>			4											
<i>Lagena semilineata</i>	2													
<i>Lagena sulcata</i>					2									
<i>Lenticulina gibba</i>						1		1						
<i>Lenticulina glabrata</i>														3
<i>Lenticulina orbicularis</i>	4		4						2	1				
<i>Marginulina obesa</i>														
<i>Melonis barleeanus</i>	136	97	124	12	22	25	2				4		10	
<i>Melonis pompilioides</i>	2		44								4		6	
<i>Miliolinella</i> sp. 1					2									
<i>Neoponoides</i> sp. 1						1								
<i>Neolenticulina variabilis</i>	10	1	8											
<i>Nodosaria</i> sp. 1	2													
<i>Nodosaria</i> sp. 2		4								1				
<i>Nonionella auricula</i>						10	7	2	1					
<i>Nonionella iridea</i>		18		68		73	63		34		83			43
<i>Nonionella</i> cf. <i>auricula</i>						2					2			9
<i>Nonionellina labradorica</i>						2		2						
<i>Nonionoides turgidus</i>				8		1	2							
<i>Nuttallides umbonifer</i>											2			
<i>Oolina borealis</i>			4											
<i>Oolina globosa</i>			4											
<i>Oolina</i> sp. 1			4											
<i>Parafissurina lateralis</i>						1			1		1		2	1
<i>Parafissurina</i> sp. 1											1			
<i>Parafissurina tectulostoma</i>			4											
<i>Planularia magnifica</i>			4											
<i>Planularia ariminensis</i>	2													
<i>Planulina</i> sp. 1						1								
<i>Polymorphina</i> sp. 1			4											
<i>Proemassilina</i> sp. 1	2				2			1						
<i>Protoglobulimina pupoides</i>			4				14		4					
<i>Pseudohauerina fragilissima</i>					2									
<i>Pseudononion</i> sp. 1		2		8		24		29		12		17		3
<i>Pseudosolenina wiesneri</i>					2									
<i>Pullenia bulloides</i>			4	8			10		2		6		10	2
<i>Pullenia quinqueloba</i>	2		32	4	6	1	12	3	10	3	26	11	6	3
<i>Pullenia</i> sp. 1							2		2				6	
<i>Pyrgo comata</i>	6													
<i>Pyrgo depressa</i>	2										8			
<i>Pyrgo murrhina</i>			8		4				2					
<i>Pyrgo serrata</i>														2
<i>Pyrgo</i> sp. 1	2													
<i>Pyrgo williamsoni</i>	4	1												6
<i>Pyrogella irregularis</i>							4							2

(continued on next page)

Table A (continued)

calcareous species	RT-1 (1008 m)		RT-2 (1250 m)		RT-3 (1382 m)		RT-4 (1610 m)		RT-5 (1857 m)		RT-6 (2056 m)		RT-7 (2205 m)	
	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm
<i>Pyralina fusiformis</i>														6
<i>Quinqueloculina lamarckiana</i>											2			
<i>Quinqueloculina oblonga</i>										6		1		
<i>Quinqueloculina seminula</i>	4		4				6			1	4			6
<i>Quinqueloculina</i> sp. 1				4		1		1						
<i>Quinqueloculina</i> sp. 2										9				
<i>Quinqueloculina</i> sp. 3		3										3		
<i>Quinqueloculina</i> sp. 4														4
<i>Robertina subcylindrica</i>			4			1								1
<i>Robertinoides bradyi</i>										2		4	2	2
<i>Rosalina bradyi</i>				4										
<i>Rutherfordoides rotundata</i>								2						
<i>Sigmoilopsis schlumbergeri</i>			4	8	8		2				2			2
<i>Siphonoperta</i> sp. 1					2									
<i>Spirillina</i> sp. 1								1						
<i>Spirophthalmidium tenuiseptatum</i>	6		8		2									
<i>Stainforthia concava</i>								5		4				2
<i>Stainforthia fusiformis</i>		5		8		6		9		7		3		
<i>Stainforthia</i> sp. 1												1		
<i>Stomatorbina concentrica</i>						1								
<i>Tosaia hanzawai</i>							2		4		2			4
<i>Trifarina angulosa</i>	2	24	4	36	2	24	2	20		16		11		16
<i>Triloculina tricarinata</i>			8		2			2		8		3		8
<i>Triloculina trigonula</i>							2	1	2					
<i>Uvigerina bradyana</i>					2									
<i>Uvigerina hispidocostata</i>	4				30		10		8					
<i>Uvigerina mediterranea</i>	150													
<i>Uvigerina peregrina</i>	22		48		12		10		16		12			10
<i>Uvigerina</i> sp. 1		4			2	6		2	2		4			
<i>Vaginulina spinigera</i>	2													
<i>Vaginulinopsis</i> sp. 1														2
<i>Valvulinera minuta</i>				20										
agglutinated species	RT-1 (1008 m)		RT-2 (1250 m)		RT-3 (1382 m)		RT-4 (1610 m)		RT-5 (1857 m)		RT-6 (2056 m)		RT-7 (2205 m)	
	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm
<i>Ammobaculites agglutinans</i>	10		4		6						24			38
<i>Ammoglobigerina globigeriniformis</i>											4			
<i>Ammolagena clavata</i>	2													
<i>Ammoscalaria tenuimargo</i>	4				4		12		2		10			
<i>Astrorhiza granulosa</i>														12
<i>Astrorhiza limicola</i>					14		16		20		24			16
<i>Bathysiphon filiformis</i>	12	4	12		14		2		2					
<i>Bigenerina</i> sp. 1														4
<i>Cribrostomoides jeffreysii</i>				4		19	2	11						
<i>Cribrostomoides subglobosus</i>					4						6			6
<i>Cyclammmina cancellata</i>											8			
<i>Cystammmina argentea</i>						15			1					
<i>Dendronina arborescens</i>							4							2
<i>Deuterammmina rotaliformis</i>				4										
<i>Eggerella bradyi</i>			12		10		8							
<i>Globotextularia anceps</i>											4			
<i>Glomospira charoides</i>											4			6
<i>Glomospira gordialis</i>						1					2			
<i>Haplophragmoides</i> sp. 1			4						2	14	8	8		
<i>Hormosinella</i> sp. 1				4		2	2	2						
<i>Hormosinelloides guttifer</i>	4													1
<i>Hyperammmina elongata</i>	4		12				4		2		2	4		6
<i>Jaculella acuta</i>			8		4				2					7
<i>Jaculella obtusa</i>	4										6			6
<i>Karrerella bradyi</i>	14		12		16		2							4
<i>Lagenammmina</i> sp. 1	30				10						4		26	3
<i>Lagenammmina</i> sp. 2			84		2				6		10		38	6
<i>Lagenammmina</i> sp. 3							16							
<i>Lagenammmina</i> sp. 4										3				
<i>Marsipella cylindrica</i>		64	16		16	3	2	8		1				
<i>Marsipella elongata</i>	4		12		12		22		6					8
<i>Portatrochammmina murrayi</i>								1						
<i>Psammosiphonella discreta</i>			8		4		8							8
<i>Recurvoides</i> sp. 1				4	2						4			8

(continued on next page)

Table A (continued)

calcareous species	RT-1 (1008 m)		RT-2 (1250 m)		RT-3 (1382 m)		RT-4 (1610 m)		RT-5 (1857 m)		RT-6 (2056 m)		RT-7 (2205 m)	
	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125- 63 µm	>125 µm	125-63 µm	>125 µm	125-63 µm
<i>Reophax agglutinatus</i>				8		20		8		4				6
<i>Reophax bilocularis</i>	52	12	12					2	4		7			16
<i>Reophax dentaliniformis</i>								9	12	25	12	26		26
<i>Reophax pilulifer</i>							2		4					23
<i>Reophax scorpiurus</i>			12	8		8		16	4	38	24			36
<i>Reophax subfusiformis</i>				20		9		5		4		9		50
<i>Rhabdammina abyssorum</i>			12											22
<i>Rhabdammina linearis</i>											4			8
<i>Rhizammmina algaeformis</i>	26	4		6		8		30	3	36				34
<i>Rhizammmina cf. indivisa</i>		16		4		10		2		4				2
<i>Saccammmina sphaerica</i>	2	4		2		10	4	2		2				
<i>Saccammminid sp. 1</i>							12		192		307			266
<i>Saccammminid sp. 2</i>							2							
<i>Saccorhiza ramosa</i>	12		8		4		6			14				10
<i>Textularia earlandi</i>		16						8		13		7		9
<i>Thurammmina papillata</i>			12				8							4
<i>Trochammmina sp. 1</i>											1			4
<i>Veleroninoides scitulus</i>														2

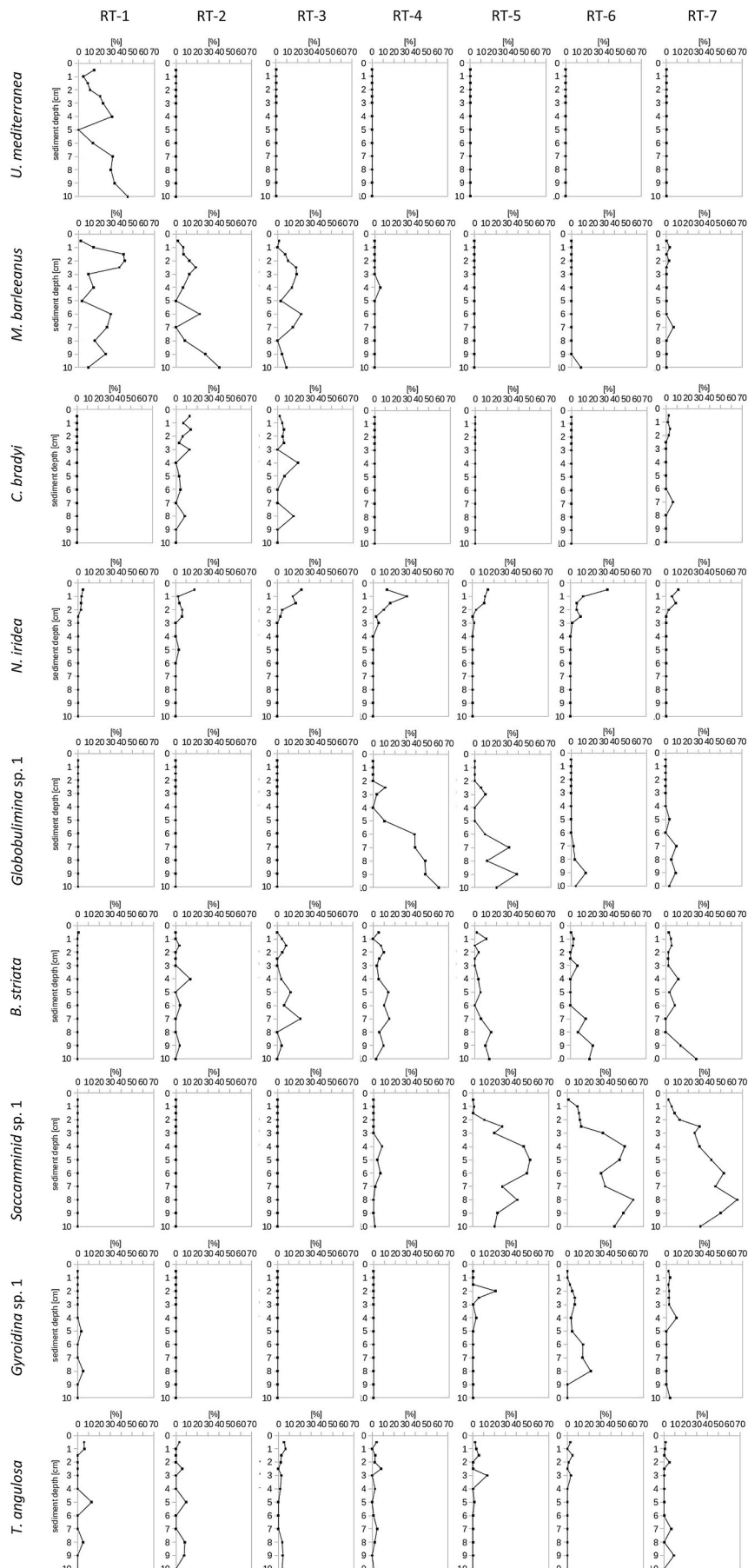


Fig. A. Vertical distribution of selected foraminifera species in relation to water depth: *U. mediterranea*, *M. barleeanus*, *C. bradyi*, *N. iridea*, *Globobulimina* sp. 1, *B. striata*, *Saccamminid* sp. 1, *Gyroïdina* sp. 1, *T. angulosa*.

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