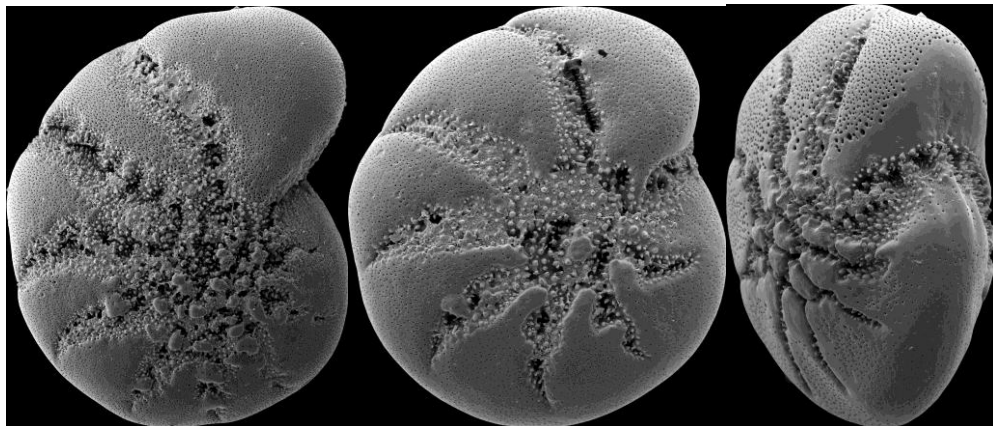**Master Thesis in Geosciences**

Benthic foraminifera as a proxy for natural versus anthropogenic environmental change in the German Bight, North Sea

A record over the last 1000 years

Anniken B. Rotstigen

UNIVERSITY OF OSLO
FACULTY OF MATHEMATICS AND NATURAL SCIENCES

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Abstract

The Helgoland mud area in the German Bight is one of few sediment depocenters in the North Sea. It is therefore a suitable site to study long-term effects of anthropogenic pollution and/or natural environmental change. The high sedimentation rate in the area provides a high resolution for historical reconstructions. A five meter long core from the Helgoland mud area in the German Bight, North Sea, covering approximately the last 1000 years was investigated for benthic foraminifera. A pre- anthropogenic fauna, dominated by *Nonion* cf. *depressulum*, existed in the interval prior to the 19th century. It was intercepted by opportunistic species in periods with extremer conditions caused by lower or higher salinity levels. These opportunistic assemblages were found to be dominated by either *Ammonia tepida* or *Elphidium excavatum*. Since the beginning of the 19th century the fauna, indicating anthropogenic changes in river- runoff and nutrient fluxes, is dominated by *Elphidium excavatum*. During these last 200 years a much higher percentage of abnormal test deformation and indications for eutrophication caused by increasing organic matter content were found.

Contents

1 Introduction

The Helgoland mud area in the German Bight is one of few sediment depocenters in the North Sea. Even though the waters in average are shallow (< 30 meter depths), the topmost sediments give a continuous and high- resolution record, thus allowing the reconstruction of regional paleoenvironmental conditions since 400 AD (Hebbeln et al. 2003). There are many pathways for pollution to find its way into the North Sea. Rivers transport wastewater from sewage treatment plants and industrial facilities as well as fertilizers and pesticides into the sea. Wind transports exhaust fumes from cars, waste incineration plants and power stations over big distances. Many of the contaminants that reach the ocean water (mercury, lead, cadmium, pesticides and plasticisers) are persistent and can accumulate in organisms harming them in different ways. Nutrients, i.e. nitrate, phosphor and ammonia are naturally present in an environment and limit the growth while being necessary for productivity. Excessive input therefore forces an unbalance in the environment by causing oxygen depletion and changing the species composition (Sündermann et al. 2002).

The North Sea is considered to be one of the most productive marine regions of the world. To the countries situated around it, the North Sea plays a great economical value and it has proved itself necessary to preserve the natural regeneration capacity of the ecosystem (Sündermann et al. 2002). To predict the effect which human activity could have on ecosystems in the future, the relationship between different kinds of pollution and natural climatic variability in ecosystem- functioning should be investigated. Therefore environments where humans already have made an influence can be useful to give an insight in the interaction between natural variability and ongoing human activity on the ecosystems functioning (De Nooijer 2007).

Anthropogenic pollution produces many biological effects and diseases in plant and animal species (Sen Gupta 2002). Foraminifera, one celled organisms producing carbonate, aragonite or agglutinated tests, have a great advantage over most other biological indicators. They occupy almost every marine habitat, occur in relative high abundance, leave behind a record in the sediments giving opportunities to reconstruct the environmental history and

they are easy to access and prepare (Scott et al. 2001). Foraminifera especially, but also other protozoa, play a significant role in global biochemical cycles of inorganic and organic compounds. Their tremendous taxonomic diversity gives them a potential for diverse biological responses to pollutants and the short reproductive cycles (from 6 months to 1 year) and rapid growth makes the community structure responsive to environmental change. Thus, foraminiferal species have a great potential for monitoring pollution from diverse sources (Sen Gupta 2002).

The separation of natural properties from pollution effects in coastal marine environments can be difficult. The ecosystems of the environment often have many different adaptations to complex hydrographical and physical conditions. Thus, it is important to compare the natural, pre-pollution assemblage with the present day assemblage (Alve 1995). Commonly studies where biological monitoring is used to assess the anthropogenic influence on aquatic ecosystems usually cover only the last 20 years. In this time period the anthropogenic influence was already manifested. Long time series covering the background or "normal" ecological setting are usually not available. The application of benthic foraminifera to reconstruct the paleoenvironment can therefore make an important contribution (Tsujimoto et al. 2008).

Although the North Sea is known to be influenced by both natural and anthropogenic environmental change, few studies have been carried out in the area describing the effects from changes in the environment. To investigate anthropogenic influence and other interventions in coastal ecosystems centuries- spanning datasets should be analyzed (Nooijer 2007). Thus, the pre- anthropogenic interval can be investigated and compared with what have happened in the same region the last 200 years. Studying a five meter long core giving a 1000 year history record, high- resolution foraminiferal data from the Helgoland mud area will here be reported. The major target is to find relation between the foraminiferal fauna and test morphology and pre- anthropogenic and anthropogenic environmental changes.

2 Study area

2.1 General setting

The North Sea, with a surface area of 750.000 km^2 and a catchment area of 841.500 km^2, where around 184 million people live in twelve different countries (Lozán et al. 2003), is a marginal sea of the Atlantic Ocean on the north-western European shelf. The southern part of the North Sea has depths up to 50 meters while the northern part has a depth up to 200 meters (Figure 1a). The Skagerak has down to 700 meters depths (Sündermann et al. 2002). The North Sea is characterized by high tide and energy levels where resedimentation is a predominant process. Thus, the hydrography and morphology of the North Sea restrict continuous sedimentation at very few depocenters. Skagerak is the most prominent depocenter, but there is also the Helgoland mud area in the German Bight, southeast of the island Helgoland. Here sediments accumulate due to small scale eddies induced by currents, river runoff from the Elbe and tidal dynamics (Scheurle et al. 2004) with an average sedimentation rate of 1,6 mm/year (Hebbeln et al. 2003).

In its natural state, the North Sea undergoes strong external forcing with 12 hour cycles of tides, big storm events, seasonal changes, and fluctuations over years and decades. The most important driving mechanism is the North Atlantic Oscillation (NAO), an oscillating air pressure gradient between the Azores High and the Iceland Low, with periods of several years (Sündermann et al. 2002). Temperature measurements from the German Bight exist for the last 130 years and these values show a general increase in the water temperatures through this time. The surface water temperature close to Helgoland has increased around 0,6 to 0,8 °C during the last 120 years (Scheurle et al. 2004).

There are several major river systems, i.e. Elbe, Thames and Rhine, which are draining catchments in central and northern Europe and providing runoff to the North Sea. Their runoff strongly affects the salinity pattern. On a larger scale, the inflow of Atlantic water through the English Channel as well as between Norway and Scotland determine the salinity distribution in the North Sea (Scheurle et al. 2004).
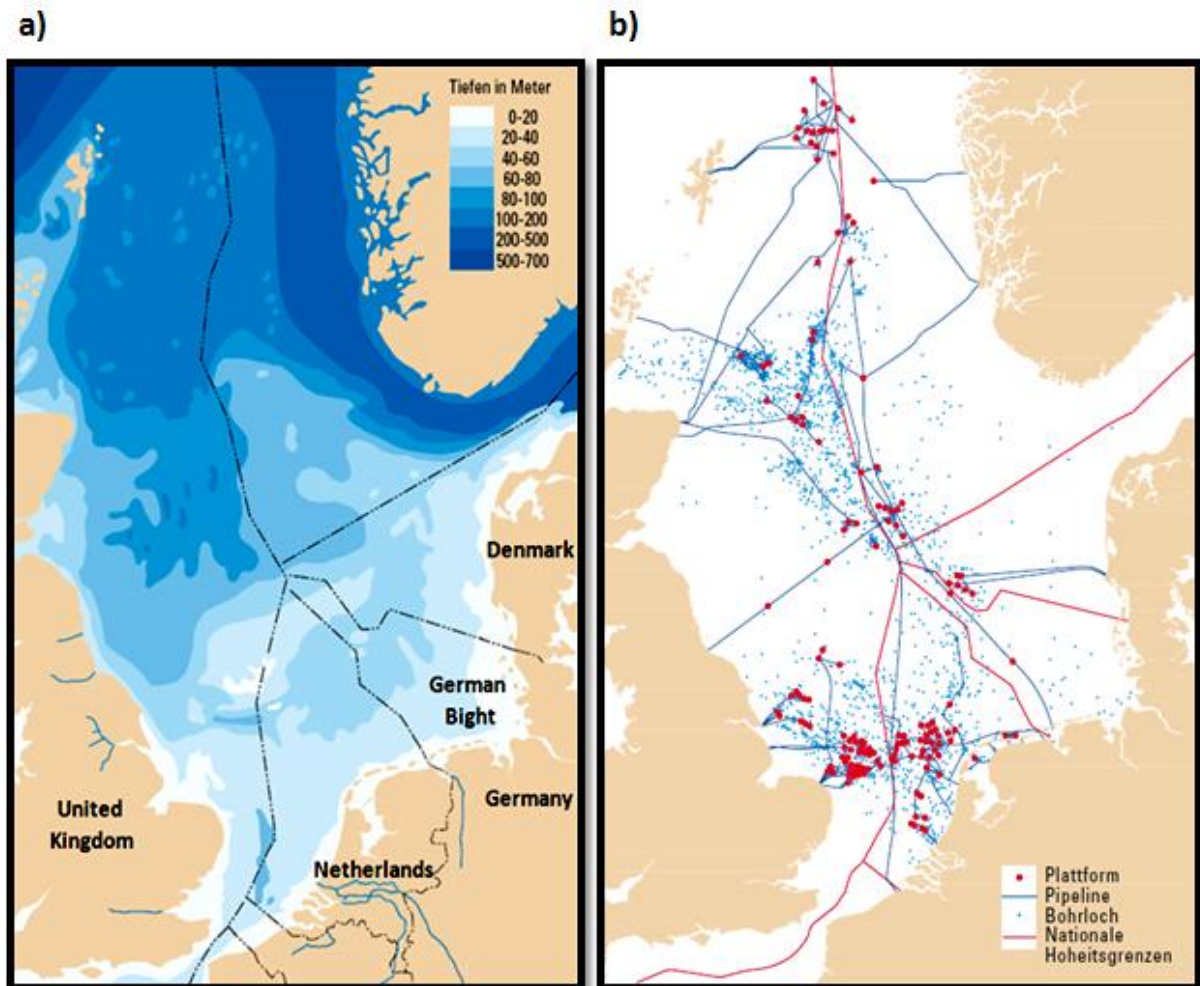
Figure 1: a) Map of the North Sea showing the country borders and the water depths. b) Overview of the over 500 oil and gas production sites in the North Sea and the network of 10 000 km of pipelines (Sündermann et al. 2002).

2.2 Sediment history

The Helgoland mud area extends over around 500 km^2 with a mean water depth of 20 meter. This sediment filled depression containes up to 30 meter depth of Holocene sediments (Figure 2). In the western parts the sediments consist mainly of mud (clayey silt) and towards the eastern parts the sand content increases. Hebbeln et al. (2003) studied the depositional history of the Helgoland mud area from around 400 AD. The record revealed a big shift in sedimentation rate around 1250 AD when the sedimentation rate dropped from more than 13 to only 1,6 mm / year. After the shift there is a continuous and high- resolution paleoenvironmental record in the sediments showing natural events like storm – flood activity as well as human activity on both local and global scales. The sedimentation is

strongly controlled by the frequency of storm floods, but relatively undisturbed by bioturbation. Since 1885 the fishing fleet of Germany has been doing beam-trawl fishing along the coast of Germany. This can have contributed to sediment redistribution in the area. In addition there has been a systematic deepening of the Elbe and Weser River shipping channels since the end of the 19th century, bringing more sediment into the water column. The sediments might have reached the Helgoland mud area to some extent. It has also been discussed whether the sediments filling the depression might come from the island of Helgoland itself. Between 800 and 1649 AD the island has lost around 90 % of its land mass (Figure 3) (Hebbeln et al. 2003).

2.3 Recent benthic foraminifera of the North Sea

Around 400 different species of benthic foraminifera have been found in the North Sea and around 250 of these have been found to have a significant abundance. The northern and southern parts of the North Sea are known to have differentiating species abundance and faunal composition (Jarke 1961). Gabel (1971) made a full description of the foraminiferal fauna in the North Sea. It was found that the benthic foraminifera have their main colonisation area in the northern parts. This distribution pattern was believed to be caused by several factors, but the intensity of the water movement near the sea bottom was mainly considered. In the southern part of the North Sea the intensity of water movement is very high causing the lower foraminiferal abundance.

2.4 Pollution history

The North Sea is largely enclosed by highly industrialized land masses. Little is recorded or known of the exact amounts or influence of the pollutants brought to the North Sea and the German Bight. It is assumed that emission of heavy metals into the water and air around the North Sea started to increase in the 19th century. The construction of sewage systems led to raw sewage and sewage sludge discharge to the ocean and emission of man-made organic chemicals commenced before the 1940s. A big fishing fleet in the North Sea introduces intensive fishing activity and the southern parts of the North Sea carries some of the world's

busiest shipping lanes. Large oil and gas resources have been exploited since the 1970's (Salomons et al. 1988).

In the 1970s it was realized that the emission of heavy metals and pesticides (i.e. DDT, toxaphene, dieldrin and HCB) affected the environment. The pollution discharge into the North Sea was then regulated and the amount of many known contaminants was reduced. In addition new substances are transported to the North Sea and their effect on the environment is usually unknown (Sündermann et al. 2002).

There are over 500 oil and gas production sites in the North Sea and the network of pipelines laid out on the sea bottom cover a length of 10 000 km (Figure 1b). About 13 % of the oil input into the North Sea is coming from oil tanker spills. The rest comes from municipal wastewater, normal ship traffic, oil platform accidents and natural oil leaks. Oil spill floating on the ocean surface, killing sea birds and reaching our beaches is a well known environmental problem, but some oil also sinks down and covers the ocean bottom. Although there is a big amount of oil coming into the system, the ocean bottom is not covered by oil because up to 50 % of an oil spill can evaporate at the sea surface, and the oil does not reach all areas of the North Sea. No effective clean up strategies exist today and therefore it is set a goal to prevent more oil spills in the future (Sündermann et al. 2002).

Even more negative impacts are expected in the North Sea system due to transportation and energy production. Huge wind parks are planned for the German Bight and a giant airport might be built off the coast of the Netherlands (Sündermann et al. 2002).
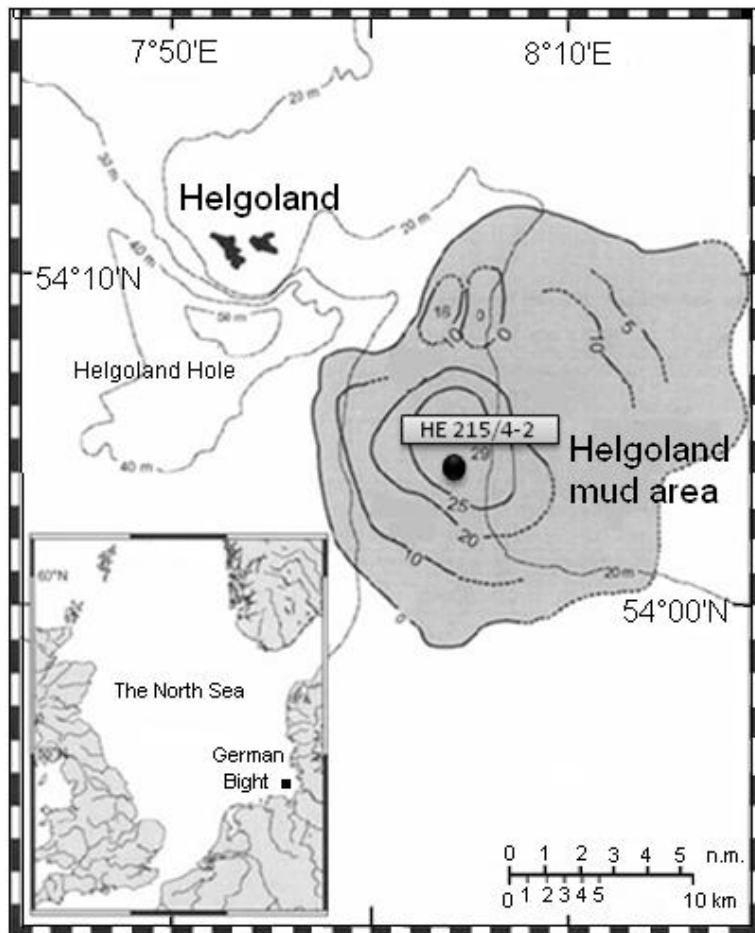
Figure 2: Location maps. The Helgoland Mud Area found in the German Bight showing the depth of sediments found in the depocenter and the depth of the ocean floor in the area. The extraction point of the core is marked (Hebbeln et al. 2003).

Figure 3: Historical map showing the Island of Helgoland around 800AD (largest extension). The light shaded area shows the size of the island around 1300 and the darker shading the size in 1649. The size of Helgoland Island has not changed much since 1649 (Hebbeln et al. 2003)

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3 Materials and Methods

3.1 Sampling procedures

Core HE 215/4-2 was recovered on the 9th of August 2004 in the German Bight, east off Helgoland, 54,072 °N and 8,074 °E, at 23 meter depth. The core was recovered with a gravity corer and is 486 cm long in total. A team from the Alfred Wegener Institute for Polar and Marine Research recovered the core onboard FS Heincke on cruise HE 215.

Sedimentological studies have already been carried out in connection with the sampling of the core in 2004. Selected depths of the core were radiocarbon dated and the mean grain size was calculated (Hass, unpublished work). According to the radiocarbon dating the sediment core represent a time scale of the last 1000 years. In geochemical analysis the total organic carbon (TOC) and $\delta^{15}N$ [‰] was measured (Serna, unpublished work). The sediments consist of homogeneously brown mud with some dark brown layers in between. The oldest sediments are quite fine grained and an upwards coarsening to sandy mud was observed. The core has been kept in a cold room since it was recovered in 2004.

3.2 Foraminiferal analysis

In December 2008 and January 2009 the core was sampled in 1 cm thick slices every tenth centimetres, with some irregular exceptions because of other samplings done on the core. The samples where freeze dried for 48 hours in a Christ Alpha 1-4 LD Plus with a temperature of -20°C and a vacuum of 1 mbar, then weighted and subsequently wet sieved to obtain the particles larger than 63 μm. The samples were oven dried at 40°C, split in fractions > 125 μm and 63 – 125 μm and weighted once more.

The > 125 μm fractions were used for the foraminiferal analysis as this is a standard used in most studies with better opportunities for comparisons. The 125 - 63 μm was scanned trough and the specimens were also found to difficult to classify and could have given errors to the

results. If possible, 300 specimens were counted in every sample. When samples contained more than 300 specimens they were split to contain a fitting amount. The specimens were identified and picked using a stereomicroscope. Gypsum crystals were found in many of the samples, but the foraminifera showed no signs of dissolution. It was therefore assumed that the forming of the gypsum crystals can not be related to dissolution of foraminiferal test calcite.

The number of foraminifera per gram sediment (absolute abundance) was calculated from the dry weight of the sediments measured before sieving. Diversity H(S) was calculated using the Shannon – Wiener index (Buzas & Gibson 1969) given as

$$H(S) = -\sum_{i=1}^{S} (P_i)(\ln P_i)$$

where S is the number of species observed in the sample and P_i is the proportion of each species. A Q-mode principal component analysis was carried out to determine dominant faunal assemblages and their temporal changes in the core using SYSTAT 12 (2007). All benthic foraminifera were included in the analysis, assuming that the few species with a percent < 1 would have a neglectable effect on the results. The benthic foraminifera accumulation rates (BFAR) were not calculated because sedimentological data were missing for the calculations.

Photos of abundant species were taken with a Scanning Electron Microscope, LEO 1455 VP from Zeiss. The stub was covered with gold and the VP modus was used to obtain the highest possible quality of the photos. Adobe Photoshop CS2 was then used to process the pictures.

Approximately twelve *Elphidium incertum* tests from every sample in the upper part of the core and approximately twelve *E. excavatum* tests from every sample in the bottom of the core (overlapping with five samples for interspecific calibration) were picked out and sent to the Alfred Wegner Institute in Bremerhaven for stable oxygen isotope measurements.

Because of limited time and a long waiting list for measurements, the data was not ready before the delivery of this thesis.

4 Results

4.1 Faunal composition

A total of 20 benthic foraminiferal species, 1 agglutinated and 19 calcareous, were found in the core. Only 11 of these species had an abundance equal to or higher than 3 %. Some planktic foraminifera were also found, but they will not be considered in this study. One of the most abundant species (figure 4) was *Nonion* cf. *depressulum* (Walker & Jacob 1798) (Pl. 2, Fig. 1-2) with high abundance throughout the core, with exception of the uppermost 100 cm. *Ammonia beccarii* (Linné 1758) (Pl. 1, Fig. 1-2), *A. tepida* (Cushman 1926) (Pl. 1, Fig. 3-4) with high abundance around 200 cm core depth and again at ~450 cm core depth. *Elphidium excavatum* (Terquem 1876) (Pl. 1, Fig. 5-6), *E. incertum* (Williamson 1858) (Pl. 1, Fig. 7-8) and *E. magellanicum* s.l. (Heron-Allen & Earland) 1932 (Pl. 1, Fig. 9-11) had high abundance in the upper ~150 cm of the core and *E. excavatum* again at ~350 cm core depth. *E. williamsoni* (Haynes 1973) (Pl. 1, Fig. 12-13) has its maximum in the middle of the core decreasing to both directions.

Although not dominating the fauna in general, several species were found with down- core increasing abundances. These include *Quinqueloculina* spp. (Pl. 2, Fig. 8-9), *Bolivina* sp.1 (Pl. 2, Fig. 4), *Stainforthia concava* (Höglund 1947) (Pl. 2, Fig. 5) and different species from the family Rosalinidae (*Rosalina* spp., *Gavelinopsis* cf. *translucens* (Phleger & Parker 1951)) (Pl. 2, Fig. 10-13). The Rosalinidae were lumped together due to bad preservation and difficulties of classification in most of the specimens found. Specimens of *Patellina corrugata* were also counted as Rosalinidae due to the same reasons. References for all classifications made are shown in the species list in Appendix A and the counts from the samples are listed in Appendix B.

It needs to be noted that one species, which was found throughout the core with varying abundances, proved itself difficult to classify: First classified as a *Siphotextularia* the species was counted and included in the data analysis. It was later found that the aperture was differentiating from that of a *Siphotextularia* (Pl. 2, Fig. 3) as it is big and situated as an

opening at the base of the last chamber. The species similarities to biserial planktic forms were pointed out. Cretaceous rocks containing the biserial planktic form *Heterohelix* can be found around the German Bight and on the island of Helgoland. Although the specimens were well preserved it was concluded to classify them as *Heterohelix* (Schiebel pos. communication).

The absolute abundance shows big temporal variations in the core (figure 5a). From around 300 cm core depth to the bottom of the core, the abundance is quite low with values less than 2000 foraminifera per gram sediment. Three peaks at 70-90 cm (~1800 AD), 160-170 cm (~1670 AD) and 250-270 cm (~1450 AD) core depth can be seen where the highest peak reaches 30 000 foraminifera per gram sediment. The upper 170 cm of the core (from ~1770 AD) show a decrease in abundance down to ~1000 foraminifera per gram sediment. The diversity H(S) (figure 5b) is also showing a decreasing trend in the uppermost 100 cm of the core from an average of 1,9 to 1,6. The sample at the bottom of the core is differentiating itself from the rest of the core with a much lower value of 1,2.

4.2 Principal component analysis

A principal component analysis is performed to extract assemblages of associated species. The three first principal components (factors) account for 89,7% of the total variance (figure 6 and table 1). The first factor explains 33,69% of the total variance. The assemblage is dominated by *Nonion* cf. *depressulum* and found at 100-150 cm, 160-180 cm, 210-340 cm and 360-470 cm depth in the core. Associated species include *Elphidium incertum* and *E. magellanicum* s.l. The second factor explains 33,39% of the total variance. The assemblage, is dominated by *Elphidium excavatum* and found at 0-150 cm, 260 cm and 330-380 cm depth. The associated species of this group are *E. magellanicum* s.l. and *Elphidium incertum*. The third factor explains 22,63% of the total variance. Dominated by *Ammonia tepida*, this assemblage is found at 60 cm, 150 cm, 160-220 cm, 240-270 cm, 290-300cm, 350-360 and 450-482 cm core depth. Here the associated species are *Ammonia beccarii*, *Eggerelloides scabrus* and *Elphidium excavatum*.
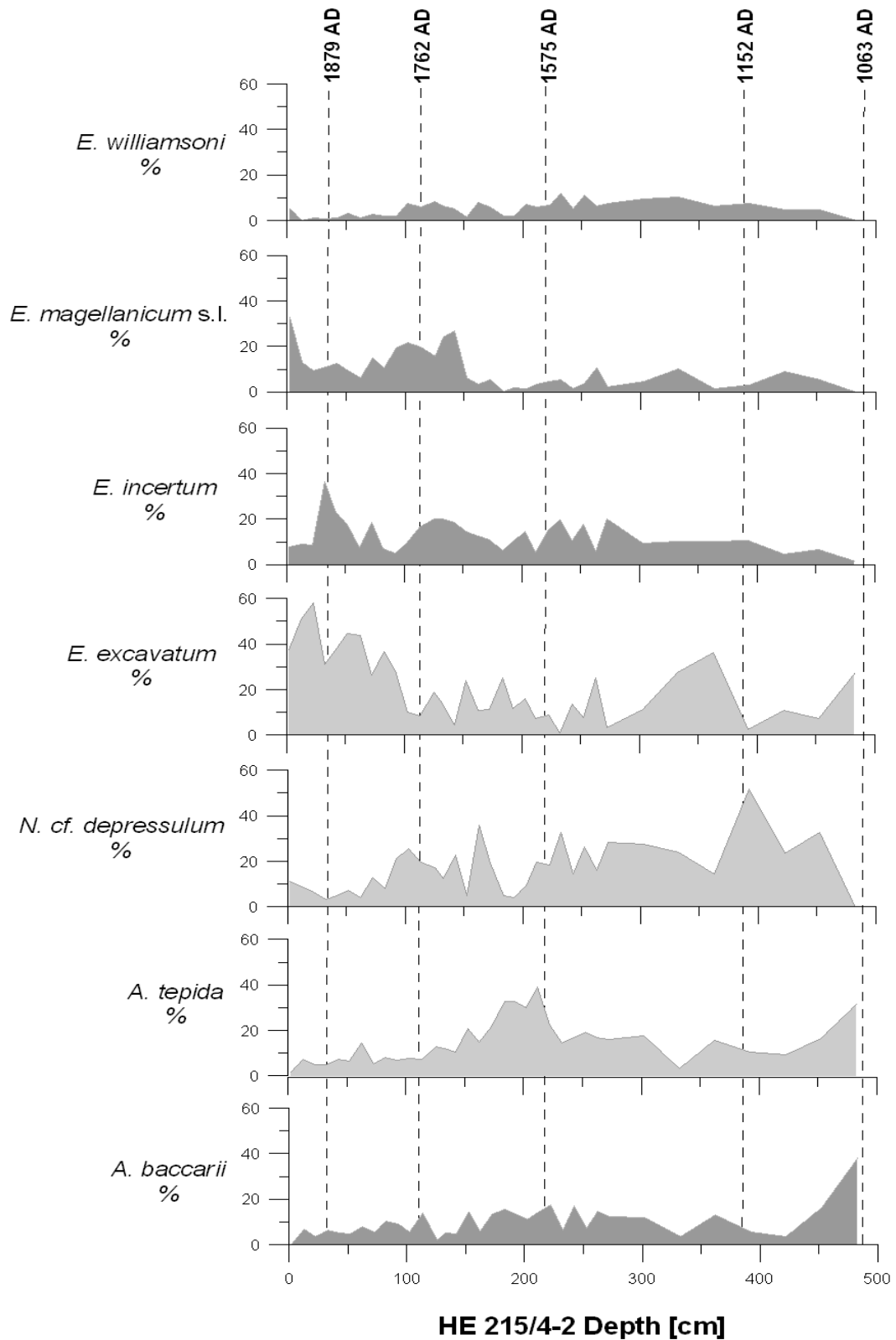
Figure 4: Temporal changes in the most abundant species found in the core (shown in percent). The light grey coloured species are the three most abundant ones. The dotted lines provide the age model (years AD).
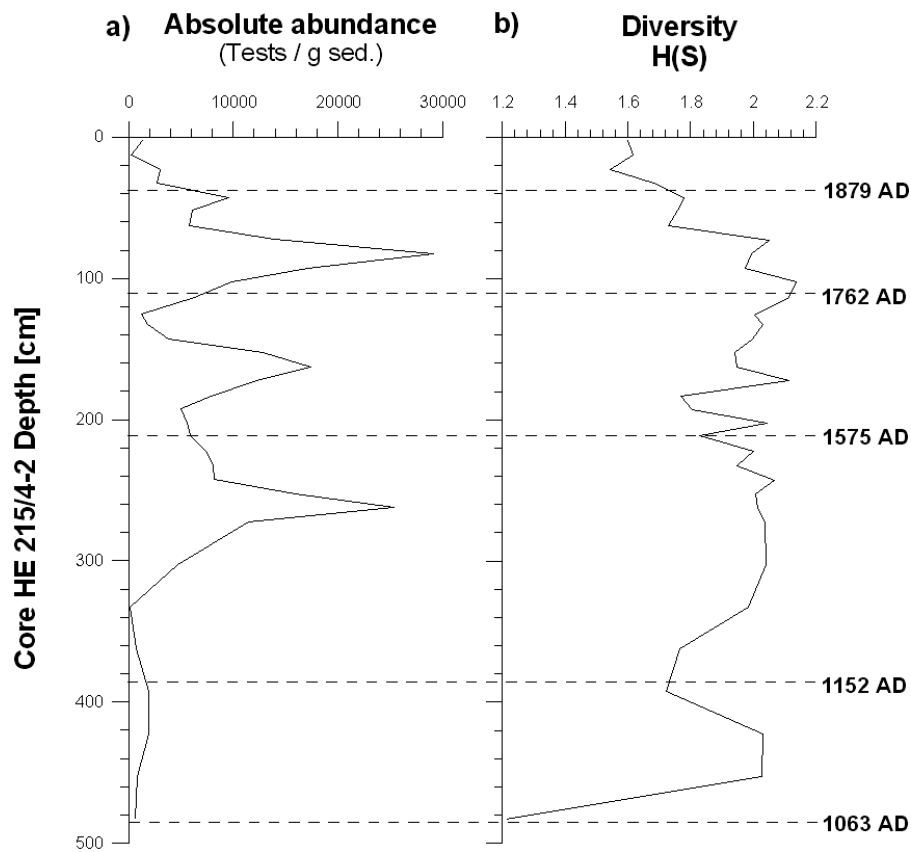
Figure 5: Temporal changes in a) absolute abundance of foraminifera and b) diversity H(S). The right hand side provides the age model (years AD).

Table 1: Principal component analysis with percent of total variance explained for each mode. Dominating and associated species are listed with their scores in brackets.

| Modes	Variance explained	Dominating species	Associated species
Assemblage 1	33.69 %	*Nonion* cf. *depressulum* (3,95)	*Elphidium incertum* (1,42) *Elphidium magellanicum* s.l.(1,16)
Assemblage 2	33.39 %	*Elphidium excavatum* (4,23)	*Elphidium magellanicum* s.l.(1,65) *Elphidium incertum* (0,97)
Assemblage 3	22.63 %	*Ammonia tepida* (3,55)	*Ammonia beccarii* (2,05) *Eggerelloides scabrus* (1,11) *Elphidium excavatum* (1,04)
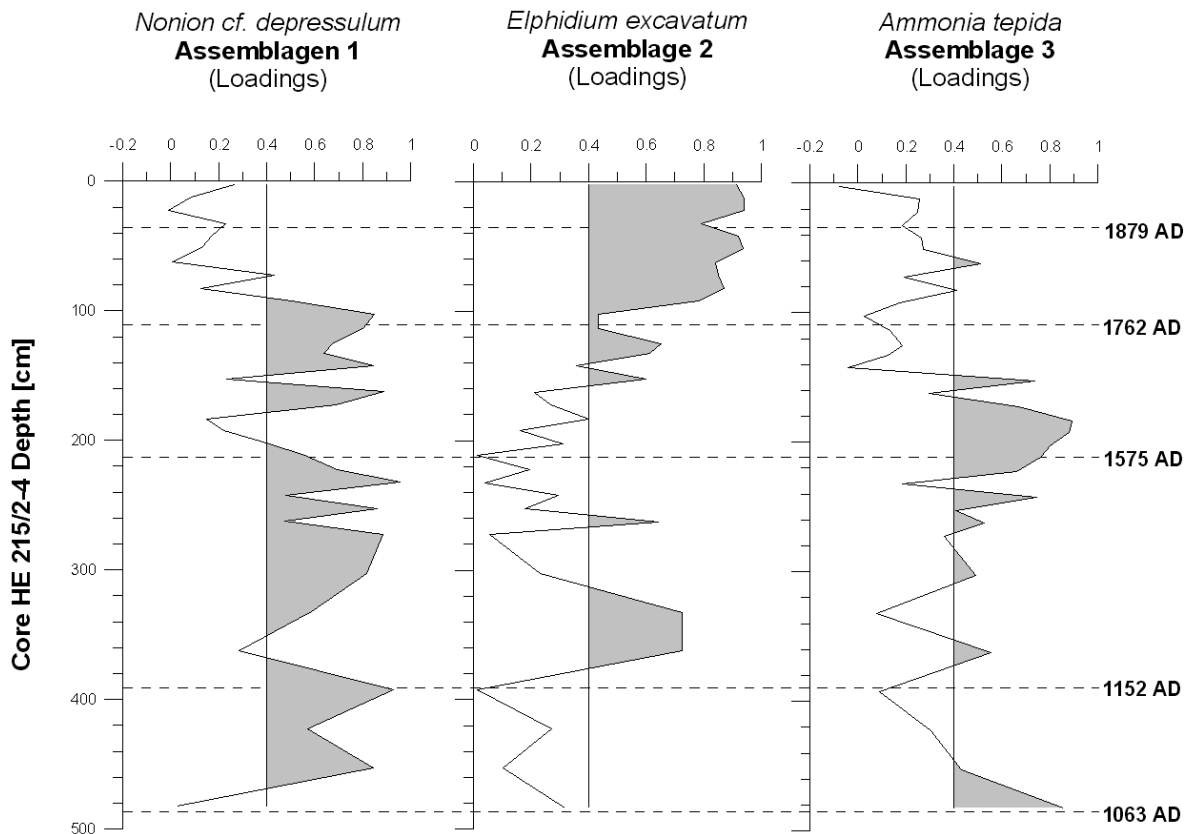
Figure 6: Temporal changes of the factor loadings. Assemblage 1 is dominated by *Nonion* **cf.** *depressulum,* **Assemblage 2 is dominated by** *Elphidium excavatum***, and Assemblage 3 is dominated by** *Ammonia tepida.* **Factor loadings >0,4 indicate significant influence of the assemblage. The right hand side provides the age model (years AD).**

4.3 Abnormal Test Morphology

10 of the 20 species recognised in the samples were found to have specimens with abnormal test morphologies. The percentage of abnormal tests in the samples (figure 7a) shows that there is an increasing amount of abnormal tests in the uppermost 100 cm. In the lower parts of the core the deformation percentages are quite low and stable with an average of 3-4 % abnormal tests. In the beginning of the 1800s at 70-80 cm core depth an increasing trend is recognised until there is a peak of 20 % abnormal tests at the top of the core. Looking closer at the abnormalities in the different species it is mainly the *Elphidium excavatum* and *E. magellanicum* s.l. that have increasing trends in the uppermost part of the core (see figure 7b and 7c).
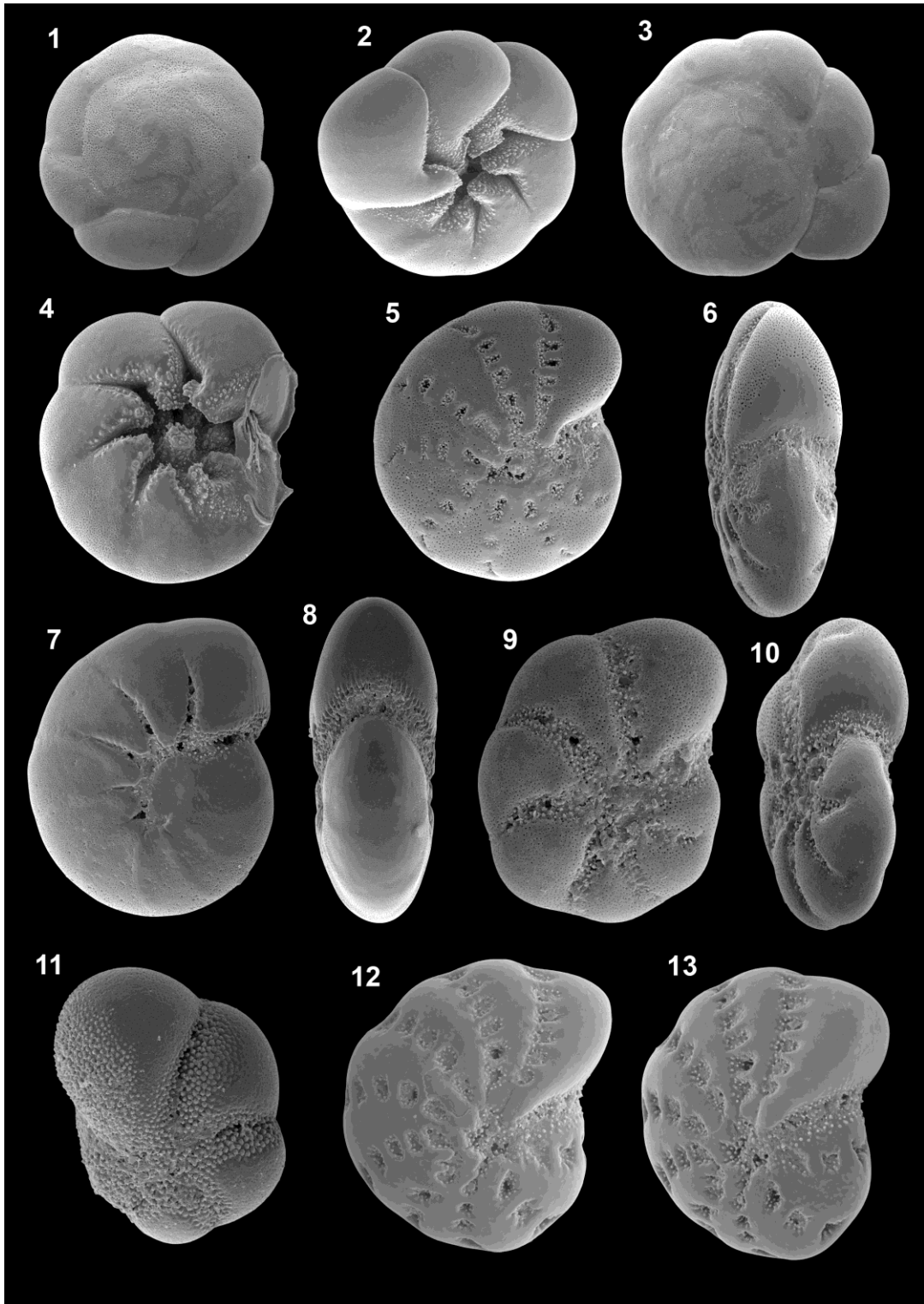
Plate 1: 1-2 *Ammonia beccarii* (Linné 1758) 1. Spiral view (× 388) 2. Umbilical view (× 505). **3-4** *Ammonia tepida* (Cushman 1926) 3. Spiral view (× 516) 4. Umbilical view (× 538). **5-6** *Elphidium excavatum* Terquem 1876 5. (× 407) 6. (× 620) **7-8.** *Elphidium incertum* (Williamson 1858) 7. (× 403) 8. (× 578). **9-11** *Elphidium magellanicum* s.l. (Heron-Allen & Earland 1932) 9. (× 734) 10. (× 1.07 K) 11. (× 829). **12-13** *Elphidium williamsoni* (Haynes 1973) 12. (× 735) 13. (× 856).
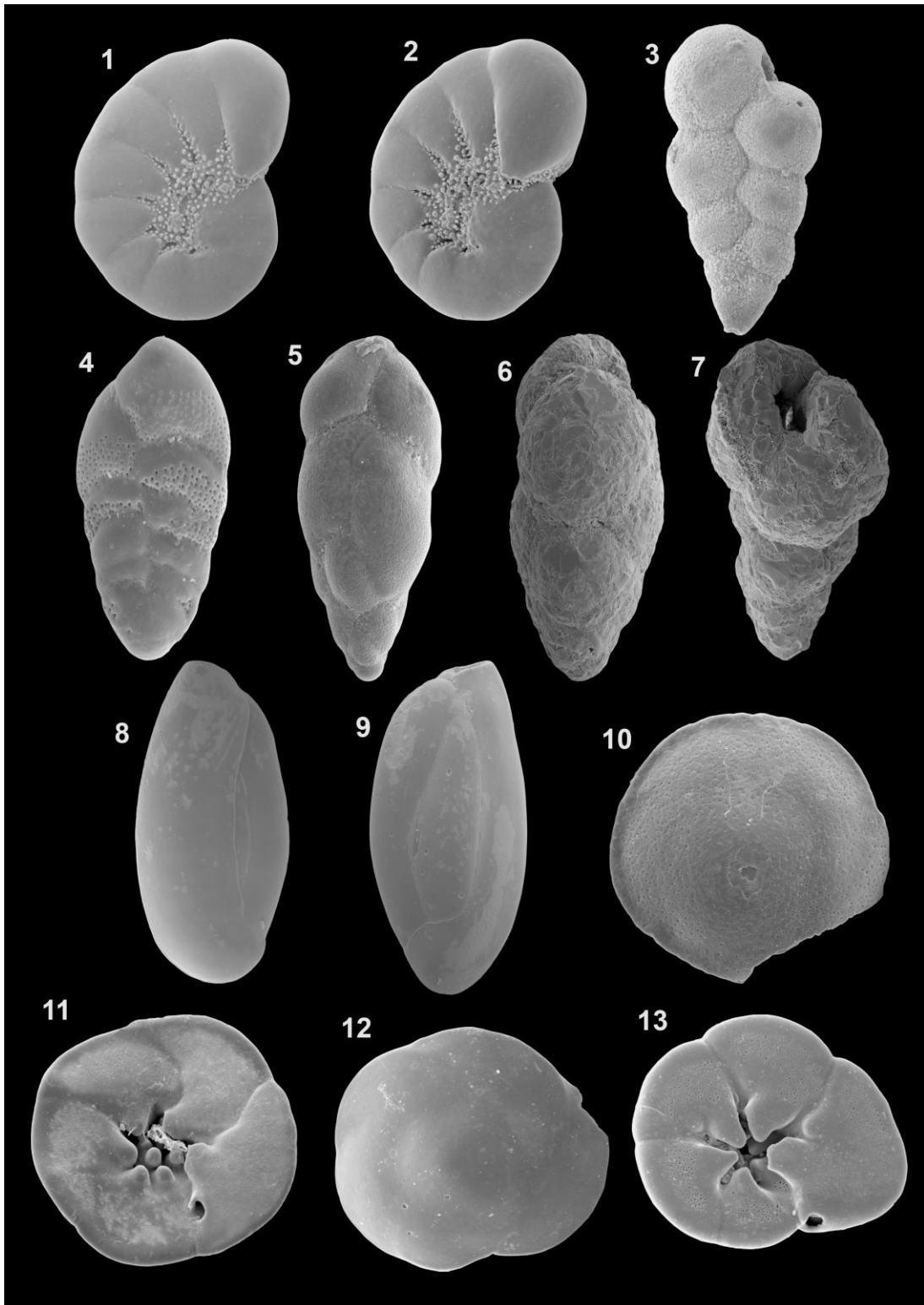
Plate 2: 1-2 *Nonion* cf. *depressulum* Walker & Jacob 1798 1. (× 681) 2. (× 825). **3** *Heterohelix* ? sp.1 (× 1.07 K). **4** *Bolivina* sp.1 (× 1.47 K). **5** *Stainforthia concava* (Höglund 1947) (× 790). **6-7** *Eggerelloides scabrus* (Williamson 1858) 6. (× 449) 7. (× 493). **8-9** *Quinqueloculina* spp. 8. (× 276) 9. (× 284). **10-13** Rosalinidae spp. 10-11 *Gavelinopsis* cf. *translucens* (Phleger & Parker 1951) 10. Spiral view (× 804) 11. Umbilical view (× 1.08 K) 12-13 *Rosalina* spp. ? 12. Spiral view (× 901) 13. Umbilical view (× 1.08 K)

Six of the eight morphological abnormality modes listed by Geslin et al. (2000) were recognized in the samples. The different modes and the species representing them are the following:

1. Over- developed chamber(s) (Pl. 3, Fig 1-2 and Pl. 4, Fig 1-4) found on both *Ammonia* species, all four *Elphidium* species and *Nonion* cf. *depressulum*.

2. Reduced chamber(s) size (Pl. 3, Fig 3-5) found on all four *Elphidium* species, *Nonion* cf. *depressulum* and *Ammonia tepida*.

3. Abnormal additional chamber(s) (Pl. 3, Fig 6-7 and Pl. 4, Fig 4) found on both *Ammonia* species*, Elphidium excavatum* and *E. magellanicum* s.l.

4. Abnormally protruding chamber(s) found on the *Ammonia* species.

5. Distorted chamber arrangements (Pl. 3, Fig 8-12) found on *Ammonia* spp.*, Elphidium Excavatum* and *E. magellanicum* s.l.

6. Complex form (Pl. 4, Fig 5) found on *Elphidium excavatum*.
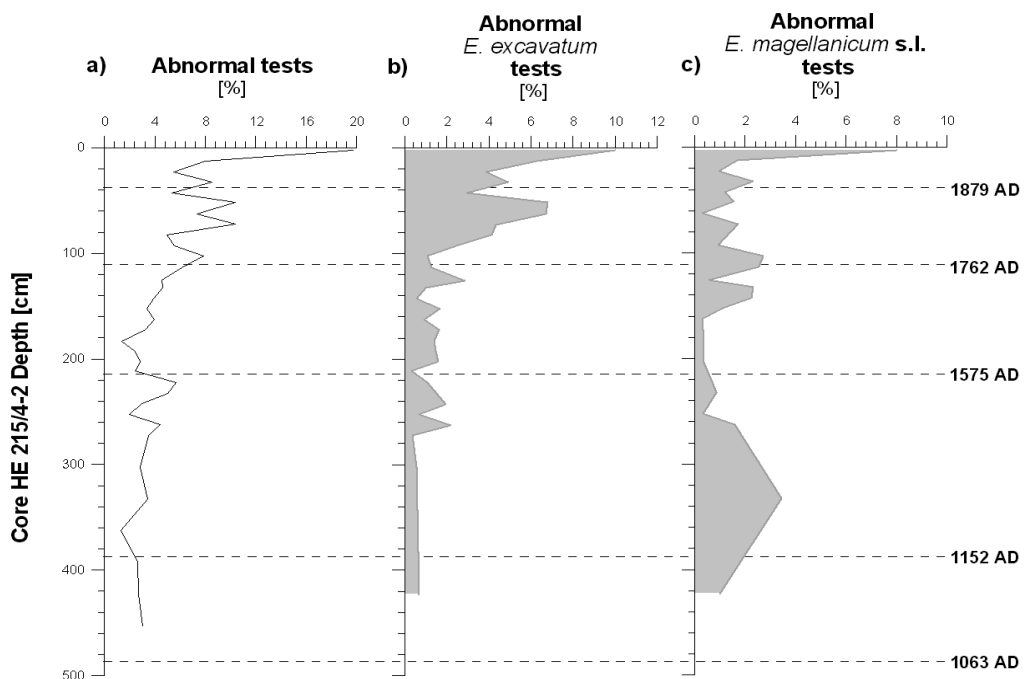
Figure 7: Temporal changes in a) percentage of total abnormal tests in the samples, b) percentage of abnormal tests in *E. excavatum* and c) percentage of abnormal tests in *E. magellanicum* s.l. The right hand side provides the age model (years AD).

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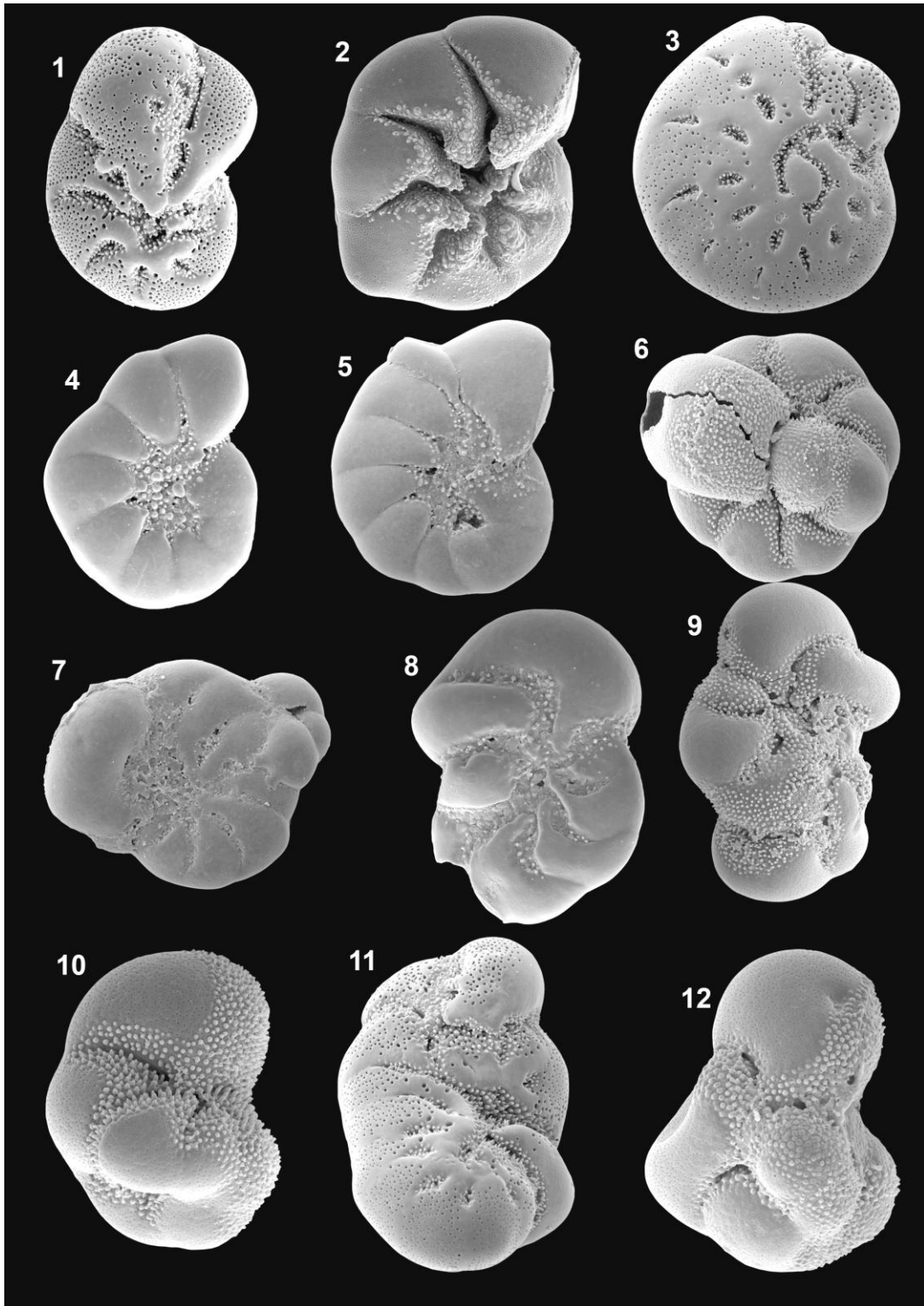
Plate 3: 1-2 Over-developed chambers 1. *Elphidium excavatum* (× 705) 2. *Ammonia tepida* (× 478). **3-5** Specimens with reduced chamber sizes 3. *Elphidium excavatum* (× 502) 4. *Nonion* cf. *depressulum* (× 804) 5. *Nonion* cf. *depressulum* (× 707). **6-7** Abnormal additional chambers on 6. *Ammonia* sp (× 662) and 7. *Elphidium 3* (× 707). **8-12** Distorted chamber arrangements on 8. *Elphidium magellanicum* s.l. (× 1.02 K) 9. *E. magellanicum* s.l. (× 754) 10. *E. magellanicum* s.l. (× 1.19 K) 11. *E. excavatum* (× 774) 12. *E. magellanicum* s.l. (× 1.06 K)
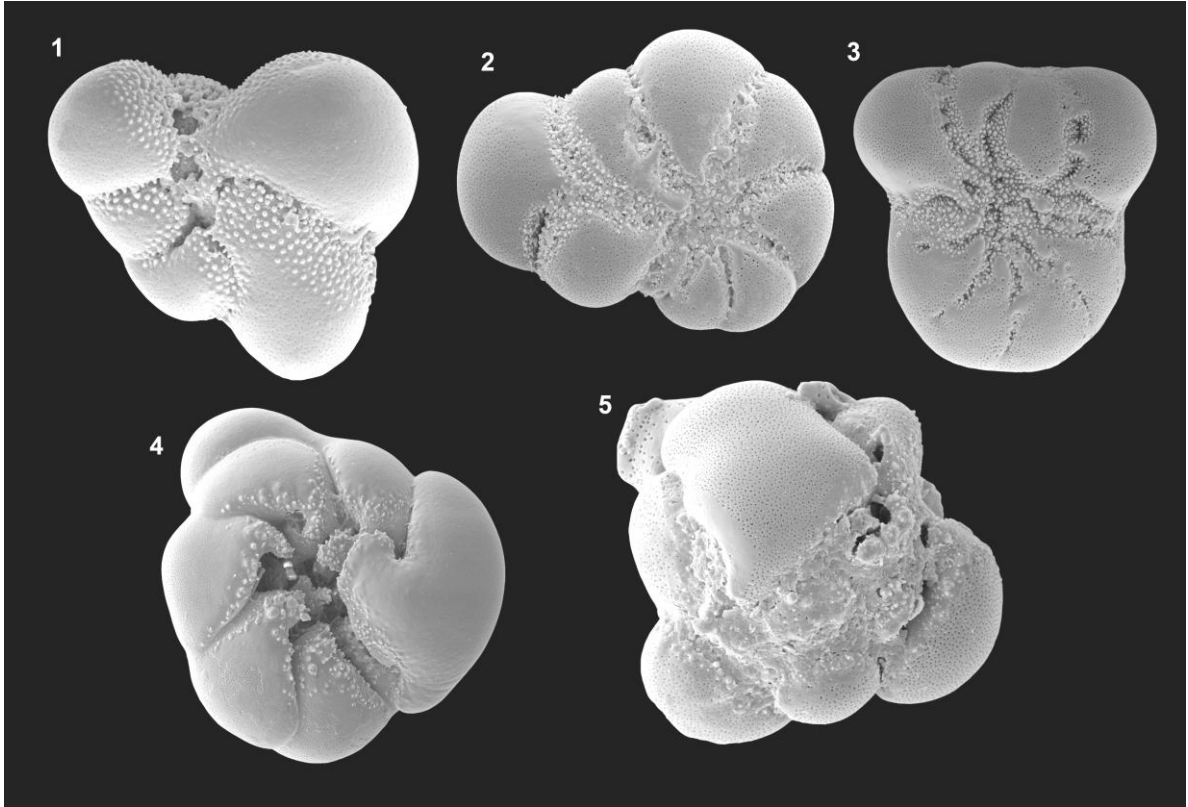
Plate 4: 1-3 Over-developed chambers on 1. *Elphidium magellanicum* s.l. ($\times$ 961) 2. *E. excavatum* ($\times$ 760) and 3. *E. excavatum* ($\times$ 475) **4** Abnormal additional chamber and over-developed chamber on *Ammonia beccarii* ($\times$ 476) **5** Complex form of *Elphidium excavatum* ($\times$ 850)

5 Discussion

5.1 Natural changes in the North Sea

5.1.1 The pre- anthropogenic fauna

The *Nonion cf. depressulum* assemblage from the principal component analysis (figure 6) is believed to be the natural assemblage in the core for the following reasons. It is most abundant until ~1800 AD only with smaller fluctuations where the *Ammonia tepida* assemblage dominates. This pattern has only one exception between ~1200 and 1300 AD, where the *Elphidium excavatum* assemblage dominates. It was found that all faunal changes, where the *Nonion cf. depressulum* assemblage decreases in abundance, were accompanied by a drop in diversity (figure 8, R=0,88). The *Elphidium excavatum* assemblage and the *Ammonia tepida* assemblage can therefore be interpreted as opportunistic species occurring under special conditions. The occurrence of these opportunistic species can possibly be explained by natural environmental changes. This will be discussed in chapter 5.1.2 and 5.1.3.

Figure 8: Temporal changes in the diversity and factor loadings of the *Nonion cf. depressulum* **assemblage.**

5.1.2 The Medieval Warm Period and the Little Ice Age

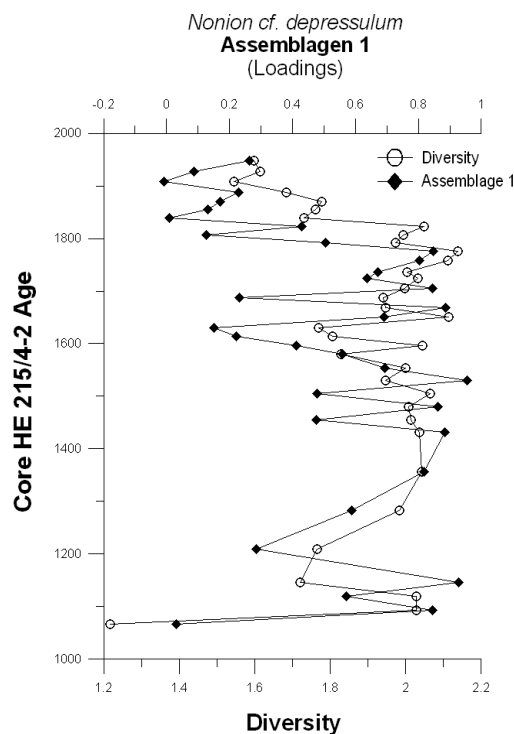Two short- term climate anomalies are known from the last 1000 years of the Holocene. The Medieval Warm Period (MWP), beginning around 800 AD and ending in the beginning of the 1300 AD (Grove 1988) and the Little Ice Age (LIA) from about 1350 until 1900 AD (Gil et al. 2006). The LIA with lower temperatures than average (approximately 1°C globally) was marked by advancing glaciers far beyond their limits both before and after the period (Bowen 1991). The MWP was marked by warmer conditions. Looking at the assemblages from the principal component analysis (figure 9), it is clear that the species of the *Ammonia tepida* assemblage, with a big peak between 1600 and 1700 AD, show a higher abundance in the Little Ice Age period.

The two *Ammonia* species from the *Ammonia tepida* assemblage are well known as salinity variation tolerant species (Armstrong & Brasier 2005). Scheurle et al. (2004) reconstructed the discharge from the Elbe River and the sea- surface salinity in the German Bight for the last 800 years. They studied the $\delta^{18}O$ record giving sea- surface salinity. Salinity patterns near river outlets are controlled by river discharge. Since the precipitation within the catchment area controls the amount of river discharge, the salinity can also be used as proxy for long- term precipitation records (Scheurle et al. 2004). Looking at the records of sea- surface salinity and river discharge it was clear that the general trend in precipitation and salinity correlates well with the abundance of the *Ammonia tepida* assemblage (figure 10). The period with most precipitation and lowest salinity can be found between ~1400 AD and ~1650 AD in the middle of the LIA. As expected, if the *Ammonia tepida* assemblage was an opportunistic species adapted to a period of severe salinity variations, there was another drop in diversity around 1600 AD (figure 8). The *Ammonia tepida* assemblage is differentiating from the precipitation and salinity trend in the 20th century. It is believed that there are also other factors influencing the fauna from there on, as will be discussed in chapter 5.2. It can also be noted that the appearance of the opportunistic *Elphidium excavatum* assemblage between 1200 and 1300 AD coincides with a very dry period and thus higher salinity contents.

5.1.3 The North Atlantic Oscillation

The most important force, driving variations in the North Sea, is the NAO. The NAO index is a measure of the air pressure differences between the Azores High and the Iceland Low. The anomaly between Lisbon, Portugal and Stykisholmur, Iceland is the most widely used NAO index and extends back to 1864 AD (Trenberth et al. 2007). Changes in the air pressure give variations in temperature and precipitation. When the NAO index has unusually high values (positive), strong westerly winds with mild, rainy and even stormy winters occur in the North Sea and Western Europe. When the NAO index has unusually low values (negative) it is reflected by extremely cold and dry winters (figure 11). Giving short term variation as well as changing mean values over several years, it is difficult to separate the natural NAO and the man- made influence on the climate (Sündermann et al. 2002). Changing the amount of precipitation, the NAO can affect the German Bight with more freshwater discharge and following salinity changes just as inferred for the LIA and MWP. During the LIA, it can be possible that ice formed during the winter in the German Bight. This is especially true if the NAO had negative values during the LIA. It appears obvious that enhanced ice cover had a strong impact on the coastal environments contributing to the observed faunal changes.

5.1.4 Clay content

Elphidium williamsoni shows a significant correlation with the percent of clay content in the core (figure 12, R=0,40). This is indicating that *E. williamsoni* might be substrate-controlled. As the material is coarsening upwards in the core, *E. williamsoni* is decreasing. A change in grain size coincides with a change in food availability and food quality. The change in sedimentation can be caused by the direction or strength of the Elbe River or the deposition of more/less material during the erosion of the Helgoland Island (Hass pos. communication). In the first case the flow direction can be positioned over the sediment depocenter or more energy could be present to transport coarser materials. In the latter scenario much more fine material could be available for deposition in the erosion period. In addition there has been a systematic deepening of the Elbe and Weser River shipping channels since the end of the 19th century, bringing more sediment into the water column

(Sündermann et al. 2002). Although this material could to some extent have reached the area, the decrease in clay content started earlier and the anthropogenic changes appear of minor influence to the substrate.

5.2 Anthropogenic changes in the North Sea

Most studies carried out in an area with a polluted environment have shown that there is a lowering in the diversity of foraminifera species. Thus, diversity can then be used as a measure of environmental stress from pollution or other factors influencing the communities in the area (Frontalina & Coccioni 2007). It was noted that the total abundance in the core was decreasing dramatically since the beginning of the 1800s. Changes like this one have happened two more times in the last 1000 years, as can clearly be seen in figure 5a. The
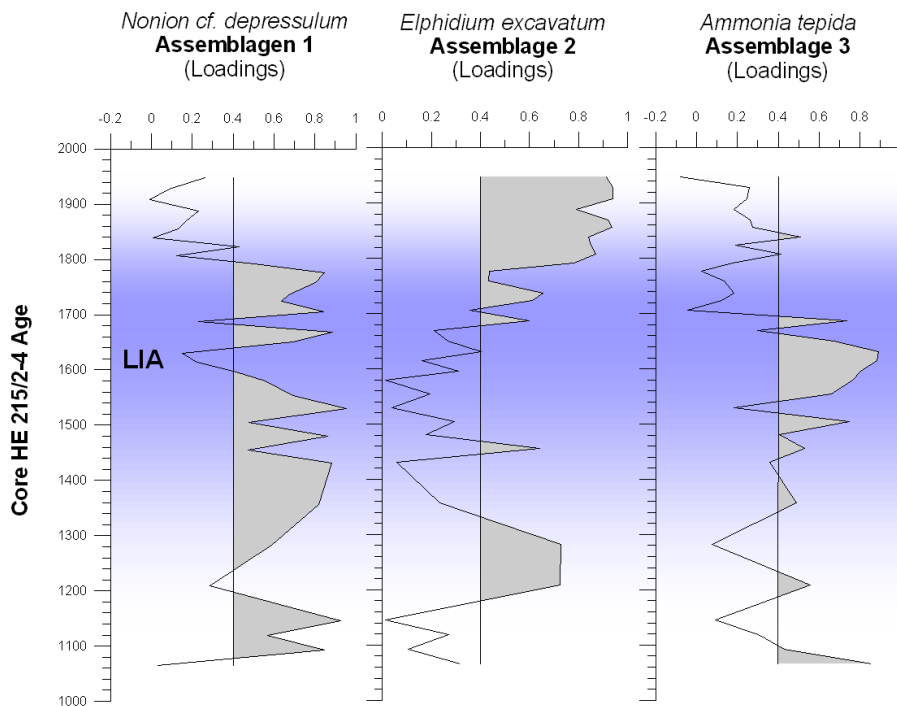
Figure 9: Temporal changes of the factor loadings. The coloured area outlines the Little Ice Age (LIA), where the *Ammonia tepida* assemblage has the biggest loadings in the middle of the cold period, the *Nonion cf. depressulum* assemblage in the beginning and end and the *Elphidium excavatum* assemblage before and after the cold period.
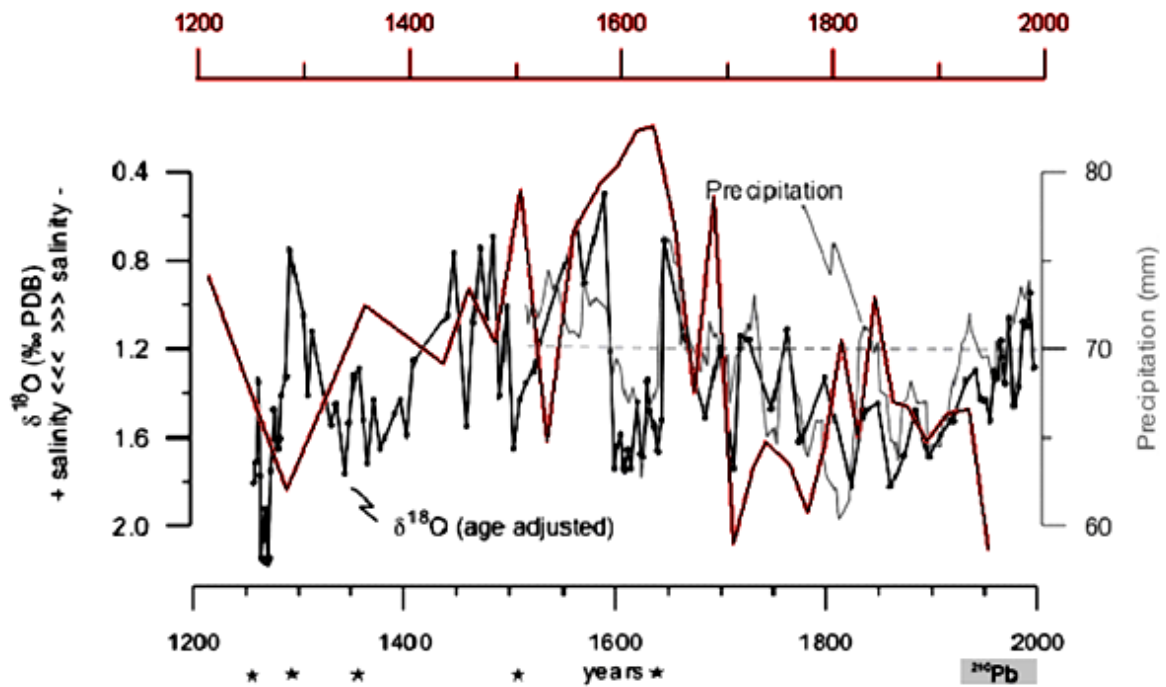
Figure 10: δ¹⁸O data from the Helgoland mud area (black line), an annual precipitation dataset reconstructed for central Europe (gray line) (Scheurle et al. 2004) and the loadings of the *Ammonia tepida* **assemblage (red line). There can be some mistakes in the plot caused by offset in years for the two different age models.**
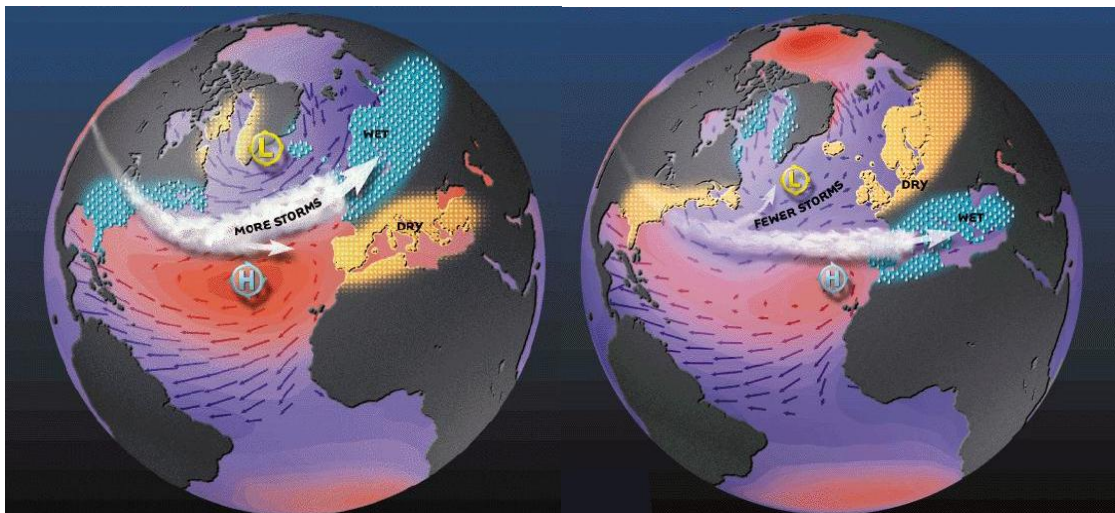
Figure 11: Schematic diagram showing some of the climatic consequences of positive (left) and negative (right) phases of the NAO (PAOC 2000). When the NAO has positive values strong westerly winds with mild, rainy and even stormy winters occur in the North Sea and Western Europe. When the NAO has negative values it is reflected by extremely cold winters where ice can form in the southern North Sea.

changes could be caused by periods with sedimentation rates exceptionally low compared to the rest of the core, giving a high accumulation rate. In the last 200 years however, the decrease in total abundance is also followed by a decrease in species diversity (figure 13). The decrease in diversity suggests a significant anthropogenic influence, e.g. pollution in the area, giving a more stressed environmental situation. If the decrease in total foraminiferal abundance was actually caused by pollution is difficult to determine, since fluctuations of the same magnitude have happened before.

The results suggest that the *Elphidium excavatum* assemblage, with *Elphidium excavatum*, *E. incertum* and *E. magellanicum* s.l., is an anthropogenic forced assemblage, taking over at the beginning of the 19th century. The assemblage clearly consists of opportunistic species because of the big diversity decrease. Knowing that the North Sea has been under extreme human influence since the 19th century, as explained in chapter 2, a big assemblage change around this time was expected. Knowing exactly what made the foraminiferal fauna respond in this way is not easy to distinguish. As mentioned before, the amount of many different pollutants commenced at the same time. Some possible settings will be discussed in chapter 5.2.1 and 5.2.2.

5.2.1 The history of eutrophication in the German Bight

Eutrophication is linked to an increase in chemical nutrients like phosphor or nitrogen (Campbell & Reece 2008), accompanied by an increase in phytoplankton biomass and often hypoxia. In an early stage, eutrophication has a positive effect on the environment because the food supply is increased. In a later stage, however, the rapid increase in organic matter fluxes and decomposition leads to oxygen depletion. Oxygen- depleted ecosystems are commonly characterized by extreme high density and low diversity. Faunal communities that are linked to eutrophication are commonly found in enclosed coastal environments near cities around the world (Tsujimoto et al. 2008).
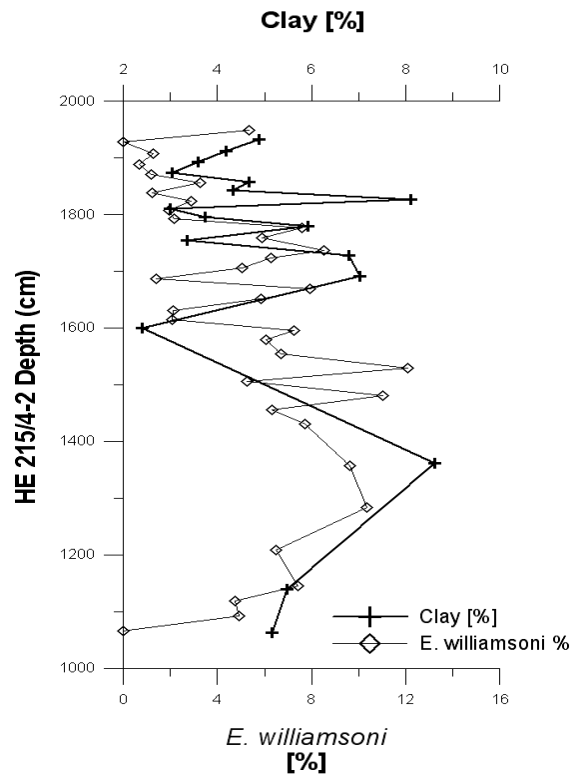
Figure 12: Temporal changes of the clay content and *E. williamsoni* abundance given in percent (Hass, unpublished work).
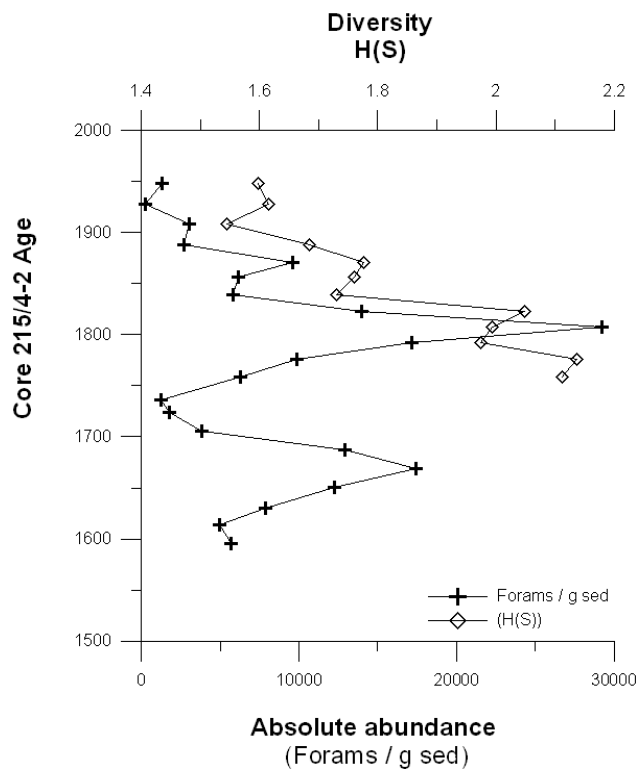

Figure 13: High resolution temporal changes of the last 400 years in absolute abundance and diversity.

The TOC content and the $\delta^{15}N$ are used as indicators for eutrophication. While TOC gives the amount of organic matter deposited, the $\delta^{15}N$ can indicate the source of the organic matter. Thus, higher $\delta^{15}N$ values indicate a higher terrestrial input (Hu et al. 2008). Comparison of these biogeochemical parameters with the foraminiferal distribution pattern in the core revealed that the increase in *E. excavatum* was following the increasing trends of both biogeochemical eutrophication indicators (figure 14). The increase starts around 1750 AD for the $\delta^{15}N$ and around 1800 AD for the TOC.

Eutrophication usually leads to extremely high population densities of a few opportunistic species able to tolerate the low oxygen conditions (Tsujimoto et al. 2008). In other studies *Elphidium excavatum* has shown particular tolerance to various types of contamination in temperate regions. This might be caused by the species high mobility, giving it the ability to flourish in areas which often are exposed to physical and/or chemical stress (Alve 1995). Although it was expected to find that *Ammonia beccarii*, *A. tepida* and *Eggerelloides scabrus* are dominating the upper part of the core as well, the opposite is reflected in the data. It was expected because *Ammonia* species in general are known to survive in almost any environment. *A. beccarii* is also noted as a good indicator for eutrophication (Tsujimoto et al. 2008). *E. scabrus* is known to have a high mobility and to be tolerant to most types of pollution (Alve 1991; Alve 1995).

5.2.3 Abnormal test morphologies

Abnormal test morphologies can be caused by both natural and anthropogenic environmental stress. Causes of abnormality from anthropogenic origin include pollution of heavy metals, hydrocarbons, organic matter and chemical pollutants. Natural origins can be caused by hyper- or hypo- salinity, low oxygen levels, input of natural trace elements or changes in the pH-value or nutrients. Abnormalities can also be caused by mechanical stress like hydrodynamics, but the tests are then often "characterised by the presence of scars, irregular contours of crushed or repaired chambers, or by the construction of new chambers in a coiling plane different from the original ones" (Geslin et al. 2000). It is, however, difficult to separate the anthropogenic from the natural sources of stress and find a single cause for the abnormalities observed (Coccioni 2000).

Information on the sensitivity of foraminifera to pollution is not as well known as for other parameters like oxygen and organic matter (Scott et al. 2001). Even though earlier publications mostly relate abnormalities to natural environmental stress, it has been suggested since the 1980s that abnormalities could be used as bio indicators of pollution (Alve 1995; Alve 1991; Sen Gupta 2003). To be able to use the abnormal foraminiferal tests however, it is necessary to make a reliable distinction between the natural and anthropogenic impacts in the study area (Geslin et al. 2000). Foraminifera inhabiting intensively contaminated environments tend to have an above background percentage of abnormal tests and the deformations can then be found in more species than normal. The test abnormality parameters have shown best results when used together with independent environmental data for the post- and pre- contamination intervals (Scott et al. 2001). In this study parameters for eutrophication was available for comparison, but regrettably no measurements of hydrocarbon, heavy metal or chemical pollution have jet been obtained. Such data would allow a more elaborate evaluation of potential contamination impacts on the fauna.

The core shows various faunal changes through time as described above, but the increase in abnormality abundance restricted to the top of the core and is mostly occurring in two of the species (*Elphidium excavatum* and *E. magellanicum* s.l.). The onset of the increase is dated to the beginning of the 1800 AD and can be a possible response to the beginning of anthropogenic trace metal input into the region around 1820 AD (Hebbeln et al. 2003). It is also possible that the abnormalities can be caused by the increasing nutrient levels. The increasing abnormality trends fit the eutrophication indicators TOC and C / N both with total abnormal tests and with the abnormal tests of *E. excavatum* (figure 15). Even though there are some higher TOC and C / N values further down core in the pre- contamination sediments, the abnormalities have not been increasing or decreasing with it.
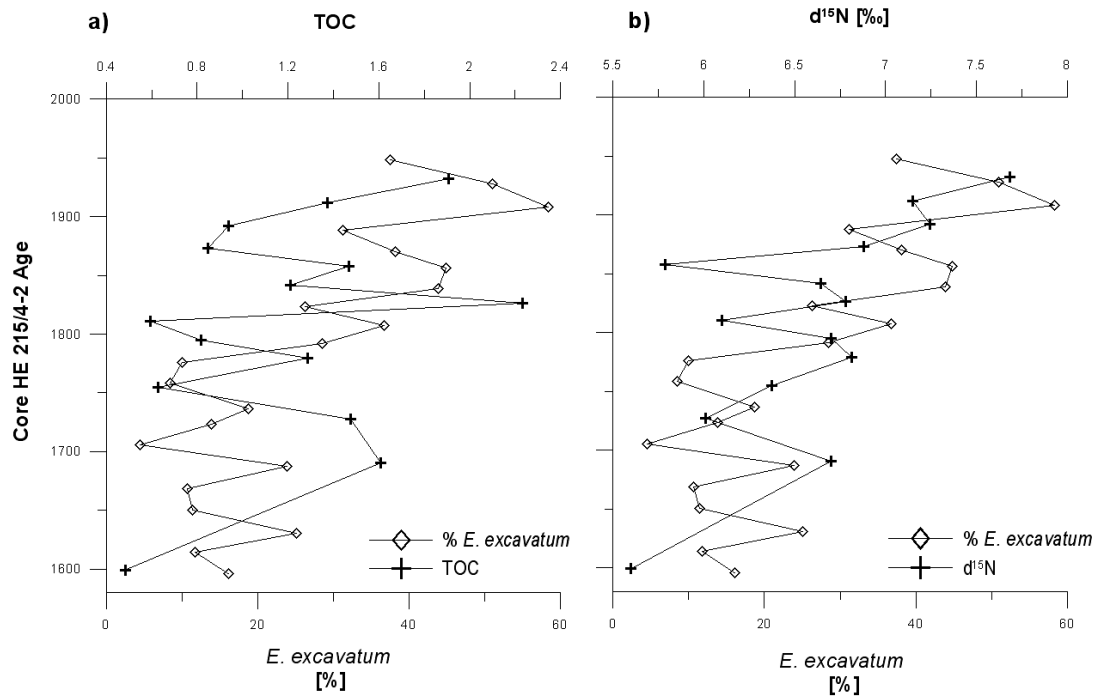
Figure 14: Temporal changes in _E. excavatum_ (shown in % of total foraminiferal abundance) compared with a) TOC and b) d^{15}N (Serna, unpublished data).
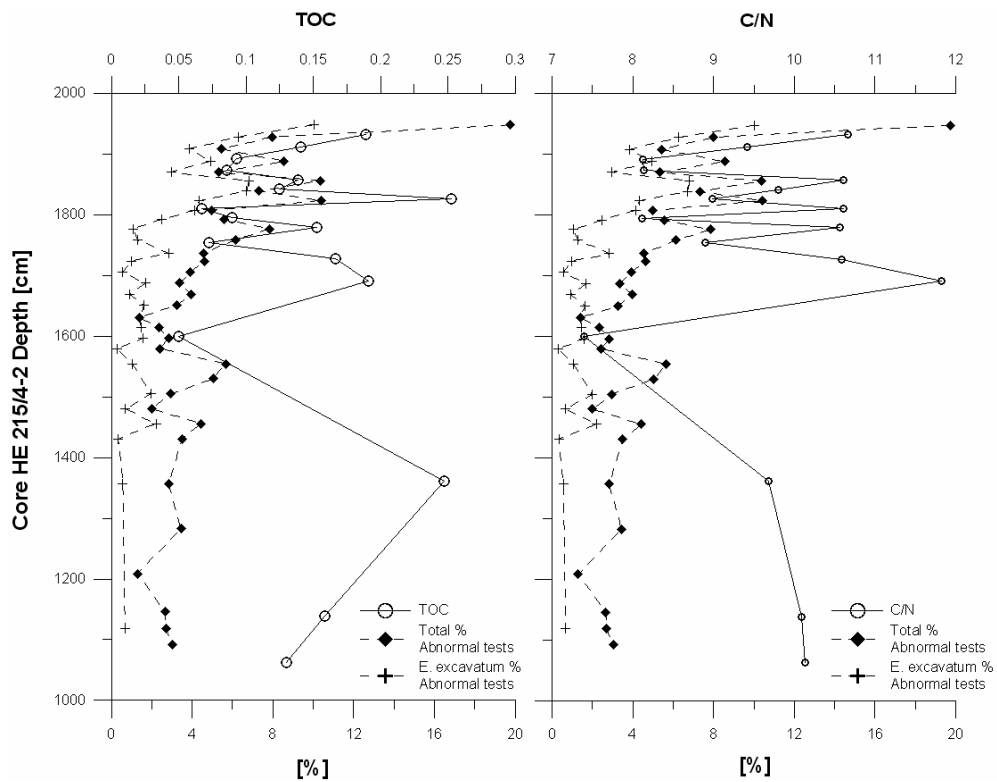
Figure 15: Temporal changes in abnormal tests (shown in percent) compared with TOC and C/N (Serna, unpublished data).

6 Conclusion

Using the high resolution sediment record from the Helgoland Mud Area in the German Bight, North Sea, pre- anthropogenic and anthropogenic forced faunal assemblages were studied. Even in a natural state, there is strong external forcing on the environment in the North Sea. In addition the North Sea is surrounded by heavily industrialised countries. Pollution input is known to have commenced around the beginning of the 19th century. As foraminifera are quite responsive to environmental change they have a great potential as index group for monitoring pollution from diverse sources. Using a record reaching ~1000 years back in time the natural state of the North Sea foraminiferal fauna could be studied and compared to the pollution affected fauna. Two different stages were found:

- **Natural variability:** From ~1000 AD until 1800 AD the fauna can in general be described with an assemblage of *Nonion* cf. *depressulum*, *Elphidium incertum* and *E. magellanicum* s.l. that is characterised by high species diversity and linked to average salinity of coastal water. The natural assemblage was found to be intercepted during shorter time intervals as response to short- term climatic trends.

- **Recent eutrophication stage:** In the beginning of the 19th century increasing amounts abundance of opportunistic taxa such as *Elphidium excavatum*, *E. incertum* and *E. magellanicum* s.l. were found to correlate with eutrophication indicators. In addition the fauna contained a much higher percentage of abnormal test morphologies in the 19th and 20th century.

The results demonstrate that benthic foraminifera can be used successfully as proxies for both natural and anthropogenic environmental changes in the German Bight.

Acknowledgements

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Appendix A: Species list

The classification system from Loeblich & Tappan (1987) was used. The species list is given with the classification and the synonyms used for the classification listed with references underneath.

Class **Foraminifera**

Suborder **Textulariina**

    Family Eggerellidae - Cushman 1937

        Eggerelloides scabrus **(Williamson 1858)** Pl. 2, Fig. 6-7

        Eggerella scabra, De Nooijer 2007: Pl. 2, Fig. B

        Eggerelloides scabrus (Williamson), Cimerman & Langer 1991: Pl. 8, Fig. 7

        Eggerella scabra (Williamson), Gabel 1971: Pl. 5, Fig. 8-10

Suborder **Miliolina**

    Family Miliolidae

        Quinqueloculina **spp.** Pl. 2, Fig. 8-9

Suborder **Rotaliina**

    Family Patellinidae – Rhumbler 1906

        Patellina corrugata **(Williamson 1858)**

        Patellina corrugata (Williamson), Cimerman & Langer 1991: Pl. 14, Fig. 7-12

        Patellina corrugata (Williamson), Gabel 1971: Pl. 15, Fig. 29-31

    Family Lagenidae – Reuss 1862

        Lagena **spp.**

Family Polymorphinidae – D'Orbigny 1839

Globulina **spp.**

Family Ellipsolagenidae – Silvestri 1923

Oolina **spp.**

Family Bolivinidae – Glaessner 1937

Bolivina **sp.1** Pl. 2, Fig. 4

Family Cassidulinidae - D'Orbigny 1839

Cassidulinoides **sp.1**

Family Buliminidae – Jones 1875

Bulimina aculeata **D'Orbigny 1826**

Bulimina aculeata D'Orbigny**,** Sgarella & Moncharmout Zei 1993: Pl. 15, Fig. 1

Bulimina aculeata D'Orbigny**,** Cimerman & Langer 1991: Pl. 63, Fig. 10-11

Bulimina aculeata D'Orbigny**,** Gabel 1971: Pl. 14, Fig. 10-11

Stainforthia concava **(Höglund 1947)**

Stainforthia concava (Höglund), Wollenburg 1992: Pl. 16, Fig. 1

Stainforthia concava (Höglund), Gabel 1971: Pl. 14, Fig. 23

Family Uvigerinidae – Haeckel 1894

Trifarina angulosa **(Williamson 1858)**

Angulogerina angulosa (Williamson), Cimerman & Langer 1991: Pl. 66, Fig. 3-4

Trifarina angulosa (Williamson), Gabel 1971: Pl. 15, Fig. 15-16

Family Rosalinidae – Reiss 1963

Gavelinopsis cf. *translucens* (Phleger & Parker 1951), Pl. 2, Fig 10-11

Gavelinopsis translucens (Phleger & Parker), Sen Gupta 2003: Fig. 12,6 K & N

Gavelinopsis translucens (Phleger & Parker), Schiebel 1992: Pl. 4, Fig. 5

Rosalina spp. Pl. 2, Fig. 12-13

Family Rotaliidae – Ehrenberg 1839

Ammonia beccarii (Linné 1758), Pl. 1, Fig. 1-2

Ammonia parkinsoniana (D'Orbigny), Sgarella & Moncharmout Zei 1993: Pl. 20, Fig. 3-4

Ammonia beccarii (Linné), Gabel 1971: Pl. 17, Fig. 1-3

Ammonia tepida (Cushman 1926), Pl. 1, Fig. 3-4

Ammonia tepida (Cushman), Frontalina & Coccioni 2007: Pl. 1, Fig. 6

Ammonia beccarii var. *tepida* (Linneo), Sgarella & Moncharmout Zei 1993: Pl. 20, Fig. 5-6

Family Elphidiidae – Galloway 1933

Elphidium excavatum (Terquem 1876), Pl. 1, Fig. 5-6

Elphidium excavatum (Terquem), De Nooijer 2007: Pl. 1, Fig. H

Criboelphidium excavatum (Terquem), Riveiros & Patterson 2007: Fig. 14, 1a and b

Cribononion excavatum (Terquem), Gabel 1971: Pl. 13, Fig. 10-11, 13-14, 17-18

Elphidium incertum (**Williamson 1858**) Pl. 1, Fig. 7-8

Criboelphidium incertum (Williamson)*,* Gabel 1971: Pl. 13, Fig. 13-14

Criboelphidium incertum subsp. (Lutze)*,* Gabel 1971: Pl. 13, Fig. 19-20

Elphidium magellanicum (**Heron-Allen & Earland 1932**), Pl. 1, Fig. 9-11

Elphidium magellanicum (Heron-Allen & Earland), Riveiros & Patterson 2007: Fig. 15, 4a, b and c

Elphidium williamsoni **Haynes 1973**, Pl. 1, Fig. 12-13

Criboelphidium williamsoni (Haynes), Frenzel et al. 2005: Fig. 2, 8

Nonion* cf. *depressulum (**Walker & Jacob 1798**) Pl. 2, Fig. 10-11

Nonion depressulum (Walker & Jacob), De Nooijer 2007: Pl. 1, Fig. K

Haynesina depressula (Walker & Jacok), Cimerman & Langer 1991: Pl. 83, Fig. 1-4

Appendix B: Foraminiferal abundance

Depth-interval (cm)	2-3	12-13	22-23	32-33	42-43	51-52
Ammonia beccarii	1	28	11	19	17	30
Ammonia tepida	5	30	16	15	25	43
Ammonia spp.	1		2	3		
Bolivina sp.1						
Bulimina aculeata						
Cassidulinoides sp.1						
Eggerelloides scabrus		2	11	11	20	27
Elphidium excavatum	112	211	182	95	129	290
Elphidium incertum	23	38	27	111	77	115
Elphidium magellanicum s.l.	98	54	29	33	42	60
Elphidium williamsoni	16		4	2	4	21
Elphidium spp.		2	1	2	2	6
Globulina spp.						1
Heterohelix ? sp.1	3	2			1	1
Lagena spp.						1
Nonion cf. *depressulum*	33	37	20	10	17	47
Oolina spp.						
Quinqueloculina spp.	1	4				2
Rosalinidae spp.	4	1	2			
Stainforthia concava						
Trifarina angulosa						
Recent planktic foraminifera	1	2	1			
Undetermined foram. tests	1	3	6	3	4	3
Total	**299**	**414**	**312**	**304**	**338**	**647**

Depth-interval (cm)	62-63	72-73	82-83	92-93	102-103	113-114
Ammonia beccarii	26	19	38	30	20	55
Ammonia tepida	47	18	29	22	28	29
Ammonia spp.		4		3	1	
Bolivina sp.1			1		3	3
Bulimina aculeata						
Cassidulinoides sp.1						
Eggerelloides scabrus	44	33	48	10	27	13
Elphidium excavatum	144	91	133	92	37	33
Elphidium incertum	25	65	25	17	35	65
Elphidium magellanicum s.l.	20	52	38	62	80	77
Elphidium williamsoni	4	10	7	7	28	23
Elphidium spp.			2	1	3	
Globulina spp.						
Heterohelix ? sp.1		2	2		1	
Lagena spp.	1		1			
Nonion cf. *depressulum*	13	44	29	68	94	76
Oolina spp.						
Quinqueloculina spp.			1	2		2
Rosalinidae spp.		2	3	2	8	3
Stainforthia concava			1	4	1	2
Trifarina angulosa						
Recent planktic foraminifera		2	2		2	
Undetermined foram. tests	4	4	2	3	2	9
Total	**328**	**346**	**362**	**323**	**370**	**390**

Depth-interval (cm)	125-126	132-133	142-143	152-153	162-163	172-173
Ammonia beccarii	7	16	17	51	19	42
Ammonia tepida	45	37	37	74	49	66
Ammonia spp.		1		3		
Bolivina sp.1	2	2	2	1		
Bulimina aculeata						
Cassidulinoides sp.1						
Eggerelloides scabrus	4	9	6	45	18	25
Elphidium excavatum	66	42	16	85	35	35
Elphidium incertum	71	61	67	52	42	34
Elphidium magellanicum s.l.	56	73	96	22	12	17
Elphidium williamsoni	30	19	18	5	26	18
Elphidium spp.	3	2	4		2	2
Globulina spp.						
Heterohelix ? sp.1					1	
Lagena spp.		1				
Nonion cf. *depressulum*	60	38	81	17	118	59
Oolina spp.			1			
Quinqueloculina spp.		1	1		1	3
Rosalinidae spp.		1	2		2	4
Stainforthia concava			3			
Trifarina angulosa						1
Recent planktic foraminifera	3			1	1	1
Undetermined foram. tests	5		7		2	
Total	**352**	**303**	**358**	**356**	**328**	**307**

Depth-interval (cm)	183-184	192-193	202-203	211-212	222-223	232-233
Ammonia beccarii	66	46	35	47	50	29
Ammonia tepida	141	111	95	129	63	66
Ammonia spp.		1	5	2		
Bolivina sp.1				1		7
Bulimina aculeata						
Cassidulinoides sp.1						
Eggerelloides scabrus	48	77	16	7	11	1
Elphidium excavatum	108	40	51	24	25	4
Elphidium incertum	27	35	47	18	44	91
Elphidium magellanicum s.l.	2	6	5	12	13	25
Elphidium williamsoni	9	7	23	20	19	55
Elphidium spp.	4				4	3
Globulina spp.						
Heterohelix ? sp.1			1	1		1
Lagena spp.				1		1
Nonion cf. *depressulum*	21	14	30	65	52	150
Oolina spp.			1			
Quinqueloculina spp.	2		2			10
Rosalinidae spp.	1	1	1		2	8
Stainforthia concava						3
Trifarina angulosa						
Recent planktic foraminifera	1	2	2	1		2
Undetermined foram. tests			3	3		
Total	**430**	**340**	**317**	**331**	**283**	**456**

Depth-interval (cm)	242-243	252-253	262-263	272-273	302-303	332-333
Ammonia beccarii	52	21	46	35	42	1
Ammonia tepida	52	58	53	46	63	1
Ammonia spp.						
Bolivina sp.1	1		2	3	1	1
Bulimina aculeata						
Cassidulinoides sp.1				1		
Eggerelloides scabrus	55	8	4	2	18	
Elphidium excavatum	41	23	80	9	40	8
Elphidium incertum	32	54	19	58	34	3
Elphidium magellanicum s.l.	5	12	34	6	16	3
Elphidium williamsoni	16	33	20	22	34	3
Elphidium spp.	1			1	1	
Globulina spp.				1		
Heterohelix ? sp.1	1		1	1		
Lagena spp.					1	
Nonion cf. *depressulum*	44	79	51	81	97	7
Oolina spp.	1					
Quinqueloculina spp.	1	2	2	3		1
Rosalinidae spp.	2	5	4	13	1	1
Stainforthia concava		4		3	2	
Trifarina angulosa						
Recent planktic foraminifera	1	1		1	3	
Undetermined foram. tests			1			
Total	**305**	**300**	**317**	**286**	**353**	**29**

Depth-interval (cm)	362-363	392-393	422-423	452-453	482-483
Ammonia beccarii	10	21	11	43	24
Ammonia tepida	12	40	27	44	20
Ammonia spp.					
Bolivina sp.1		4	4	3	
Bulimina aculeata			1		
Cassidulinoides sp.1					
Eggerelloides scabrus	2	9	85	11	1
Elphidium excavatum	28	10	32	19	17
Elphidium incertum	8	40	14	18	1
Elphidium magellanicum s.l.	1	12	27	14	
Elphidium williamsoni	5	28	14	13	
Elphidium spp.		1		2	
Globulina spp.					
Heterohelix ? sp.1		2	1		
Lagena spp.			1		
Nonion cf. *depressulum*	11	195	70	86	
Oolina spp.					
Quinqueloculina spp.		8	1	6	
Rosalinidae spp.		6	5	4	
Stainforthia concava		1	2	1	
Trifarina angulosa					
Recent planktic foraminifera					
Undetermined foram. tests					
Total	**77**	**377**	**295**	**264**	**63**