High-resolution benthic foraminiferal records of the last glacial termination in the northern North Atlantic

STEFAN NEES

GEOMAR - Research Center for Marine Geosciences, Wischhofstraße 1-3, D-24148 Kiel, Germany

ABSTRACT

Large oceanic changes occurred during the last transition from glacial to interglacial conditions (Termination I), which significantly affected pelagic and benthic environments. This study presents results of a quantitative investigation of benthic foraminifera at four sites distributed along a north-south transect across the northern North Atlantic with a high temporal resolution (± 200 years).

Benthic foraminifera are examined in samples (1-2 cm sampling intervals) from four long sediment cores located in the southern Fram Strait, the Greenland-Iceland-Norwegian Sea (GIN Sea), and the Rockall Plateau. The most prominent species of benthic foraminifera include *Oridorsalis umbonatus, Cibicidoides wuellerstorfi, Cassidulina* spp. group, *Pyrgo rotalaria, Globocassidulina subglobosa* and tubes of agglutinated taxa.

In each core, the climatic amelioration at Termination I is recorded to have occurred in two steps. A first INDAR maximum (**IND**ividuals **A**ccumulation **R**ate = ind/cm^2 ky; GIN Sea: average 3,000-6,000 ind/cm^2 ky, Rockall Plateau: average 150 ind/cm^2 ky) is followed by a period of lower values. A second maximum reveals slightly lower values than the older maximum. Interglacial INDAR values average 700 ind/cm^2 ky for the GIN Sea and 200 ind/cm^2 ky on the Rockall Plateau. This is roughly twice that of typical glacial values.

Meltwater events, identified by stable isotope data and sea-surface temperature reconstructions based on planktic foraminiferal transfer functions, are marked by an increase in endobenthic and opportunistic species. A decrease of reconstructed sea-surface temperatures appears synchronous with the relative INDAR minimum that occurs between the two INDAR maxima. The results indicate a close coupling of sea-surface processes to the benthic realm („pelagic-benthic coupling") with a longitudinally variable strength. The climate signal at the Rockall Plateau revealed by the fossil benthic foraminifera shows a lower amplitude than that of the GIN Sea. The second, younger INDAR maximum is characterized by an increased abundance of epibenthic species at all core locations, suggesting extended lateral bottom currents.

In comparison with various palaeo-climatological data sets, the variability of fossil benthic foraminiferal abundances in the GIN Sea show a distinct coherence with changes of atmospheric temperatures, sea-surface temperatures and the postglacial sea level rise. The variability of the benthic foraminiferal fauna is principally in phase with climate change events.

INTRODUCTION

Glacial terminations

The transitions from glacials to interglacials in the youngest part of the earth's history are major events in the development of the biosphere. With increasing geographical latitude, these „Terminations" forced massive and rapid reorganisations of the entire ecological system both on land and in the oceans. With respect to a geological timescale, climate changes happened in remarkably short periods of time, inducing a highly dynamic environmental impact (Jouzel *et al.*, 1987; Taylor *et al.*,

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1993; Alley *et al.*, 1996). These changes are recorded in environmentally sensitive tracers such as fossil benthic foraminiferal tests. Thus, the investigation of these fossils helps us understand the complex interactions between the atmosphere and the oceans.

Previous studies have shown that glacial-interglacial transitions are not continuous processes, but take place in several steps. The termination of the last glacial has been separated into Termination IA, IB (Duplessy *et al.*, 1981; Broecker *et al.*, 1988), and IC (Mix & Ruddiman, 1985). Terminations IA and IB are documented in most deep-sea $\delta^{18}O$ records (Berger *et al.*, 1987; Sarnthein & Tiedemann, 1990; Jansen & Veum, 1990; Winn *et al.*, 1991). However, the exact timing of these two steps still remains uncertain on a global scale and in high latitudes in particular (Ruddiman & Duplessy, 1985).

The Greenland-Iceland-Norwegian Sea (GIN Sea) is of major importance for the global oceanic circulation system (Figs. 1, 3). Surface water masses of Atlantic and Polar origin meet in this comparably small ocean basin and create one of the most important sources of oceanic deep water (Smethie *et al.*, 1986). The GIN Sea is, thus, an ideal region for studying past changes in the deep ocean (Thiede *et al.*, 1986) and the changes occurring during the last glacial/interglacial transition (Thiede *et al.*, 1985; Henrich, 1992).

Since 1985, the Special Research Project 313 („Sonderforschungsbereich 313" at Kiel University) has been involved in marine research of the northern North Atlantic. In collaboration with the micropalaeontology group at the Department of Geology, Kiel University, a substantial data set has been compiled for reconstructions of past climate changes. In particular the importance of Pleistocene fossil benthic and planktic foraminifera has been demonstrated in a variety of publications (Altenbach *et al.*, 1987; Hald & Vorren, 1987; Mackensen, 1987; Haake & Pflaumann, 1989; Linke, 1989; Nees, 1989; Heeger, 1990; Thies, 1991; Bauch, 1992; Struck, 1992; Altenbach, 1992; Nees & Struck, 1994; Struck, 1995; Bauch, 1996; Struck, *this volume*).

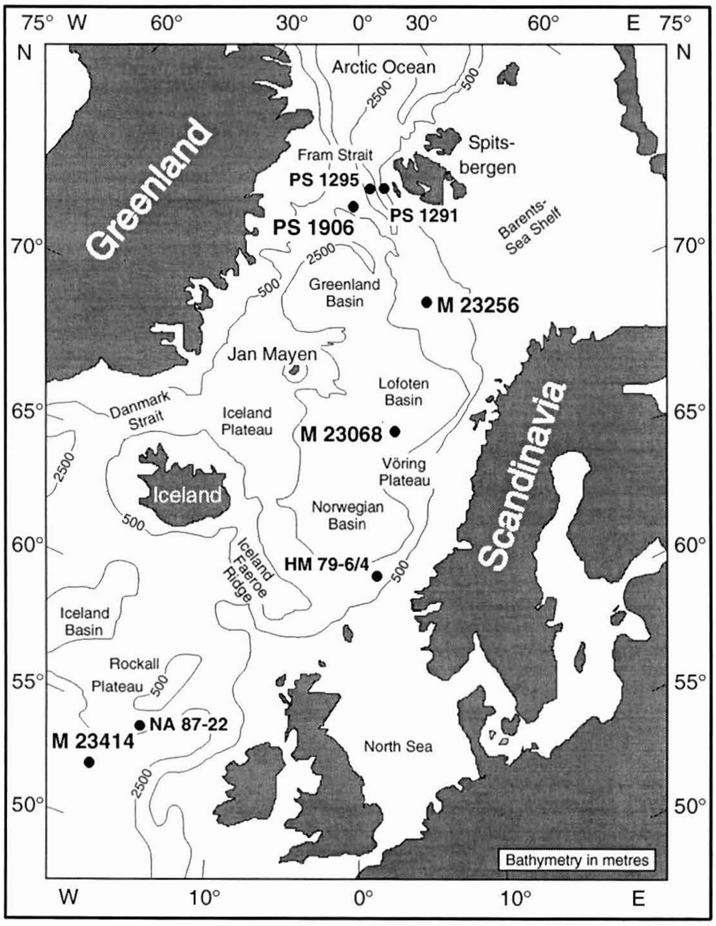

Figure 1. Physiography of the northeastern Atlantic Ocean and the Greenland-Iceland-Norwegian Sea (GIN Sea). This part of the ocean holds a key position in terms of deep-water exchange between the Arctic and the Atlantic Ocean. The core locations are marked with dots.

The precision of the climatic signal in benthic foraminiferal records

Accumulation rates of benthic foraminifera from deep-sea sediment cores reflect the oceanographic variability in the past (Mackensen, 1987). Although specific environmental preferences of benthic foraminifera are largely unknown (Murray, 1995; Jorissen *et al.*, 1995), they appear to be powerful tools for palaeoceanographic reconstructions (Altenbach, 1992; Fig. 2). Only recently the quantification of organic palaeo-flux rates has been realised using benthic foraminifera (Herguera & Berger, 1991; Herguera, 1992). Actuopalaeontological experiments with observations of living benthic foraminifera are also relatively new (Altenbach, 1985; Lutze & Altenbach, 1988; Altenbach *et al.*, 1993).

The use of a climatic signal preserved in fossil remains with a high temporal resolution is also relatively new. Past investigations in the GIN Sea are mainly descriptive and/or stratigraphic in character (Johnson, 1980; Haake & Pflaumann, 1989; Nees, 1989 and 1994). In this region, Struck

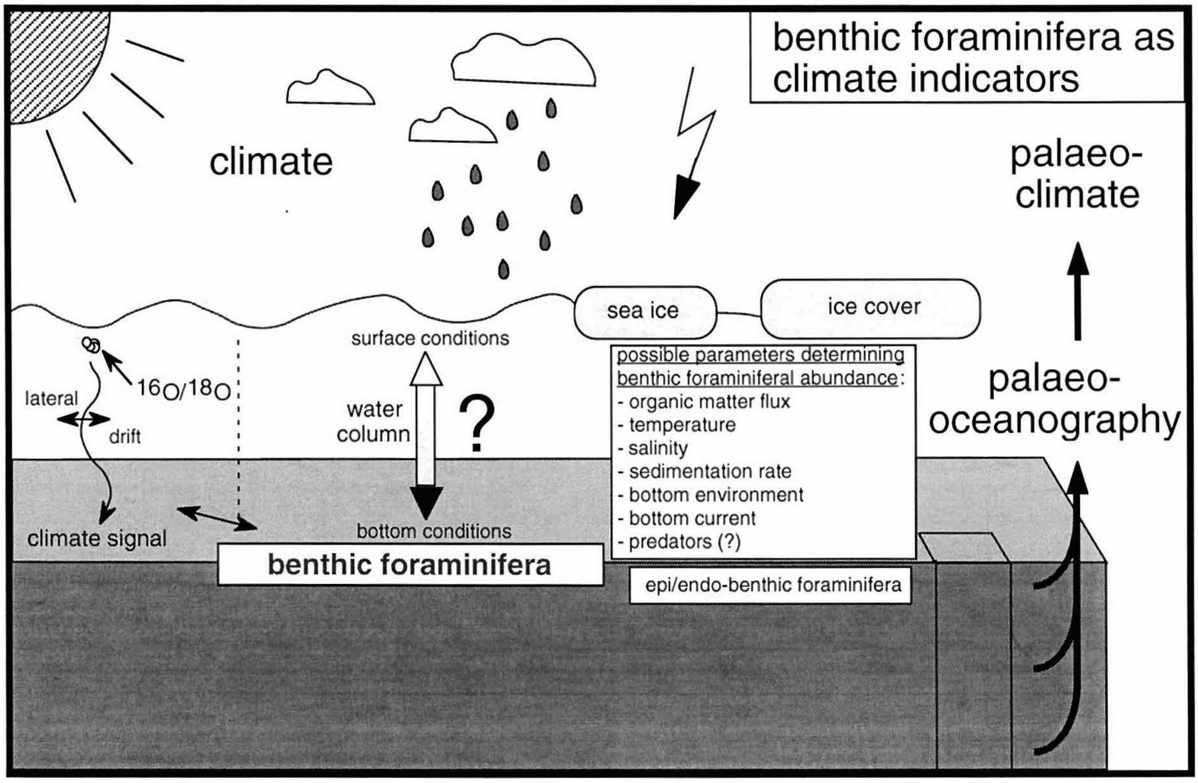

Figure 2. Accummulation rates of benthic foraminiferal assemblages and single species are useful indicators of past environmental changes. This figure illustrates the theoretical path of recording the „environmental signal" (as a secondary climatic signal), its preservation in the ocean sediment and its use as a tool for palaeoclimate reconstructions. With respect to their deep-sea environment, benthic foraminifera rarely receive a climatic-influenced signal as a primary signal, rather as secondary signals such as changes in organic fluxes (food) or changes in physio-chemical parameters of deep- and bottom water masses. Nevertheless, benthic foraminiferal abundances, together with proxies like stable isotope ratios in both planktic and benthic foraminiferal shells, preserve environmental conditions in a manner that allows palaeoclimatic and -oceanographic reconstructions.

(1992) has presented the hitherto most extensive data set of benthic foraminiferal taphocoenoses for the past 600 ky. This allowed him to detect a gradual recolonisation of the Norwegian Sea after the last and the penultimate glacial (Struck, 1995).

A striking feature that is clearly visible in almost all the quantitative benthic foraminiferal distributions is the distinct signal that occurs during dramatic climatic changes, such as glacial terminations (Struck, 1992). The large sampling intervals usually used, however, do not display such important events in greater detail. Stable oxygen isotope investigations have shown that high resolution sampling may reveal significant fluctuations in the climate signal (Weinelt, 1993).

These results give rise to the following questions:

- Does high resolution sampling of deep-sea sediment cores display the variability of benthic foraminiferal assemblages in greater detail, helping to increase the climatic information content of quantitative and qualitative data and subsequently allowing a more precise interpretation of the past variability of changes?
- What is the response of the benthic foraminiferal community to short termed events such as glacial/interglacial terminations?
- Do sea-surface events have an effect on the benthic foraminiferal community? What are the differences of the climatic signal in the benthic foraminifera in the GIN Sea compared to the Rockall Plateau?
- Is a correlation between the climatic signal of fossil benthic foraminifera and other climatic parameters possible?

In order to answer these questions, selected sediment cores from the northern North Atlantic are investigated in this study (Fig. 1). Characteristics of some indicative species, species assemblages, and their temporal variability is discussed. The relatively high temporal resolution of the samples (about 200 years) permits correlation with other climate relevant data sets, and allows new insight into the palaeoclimatic „reconstruction potential" of fossil benthic foraminifera.

Oceanography of the northern North Atlantic

The northern North Atlantic plays a crucial role in the global ocean circulation as link between the Arctic and Atlantic Oceans. The surface circulation is characterized by warm Atlantic water masses intruding from the south along the Norwegian coast and cold Arctic water masses moving south east off the Greenland coast (Fig. 3). As a continuation of the Gulf Stream, the North Atlantic Current carries temperate and highly saline water masses over the Iceland-Faeroe Ridge into the eastern GIN Sea and forms the Atlantic Domain (Swift, 1986). The North Atlantic Current continues as the Norwegian Current to the Arctic Ocean. North of the Scandinavian landmass, a branch of the Norwegian Current diverges into the Barents Sea as the North Cape Current, and eventually produces deep water by cascading into the Arctic Ocean (Jones *et al.*, 1995).

The Transpolar Drift transports low salinity cold water masses from the Arctic Ocean as the East Greenland Current into the Greenland Sea to form the Polar Domain (Fig. 3). These water masses reach the North Atlantic via the Denmark Strait between Iceland and Greenland. The central part of the GIN Sea is characterised by two systems of mixing primary watermasses, and is named the Arctic Domain. The Arctic Front separates the Arctic from the Atlantic Domains, the Polar Front separates the Polar from the Arctic Domains (Fig. 3).

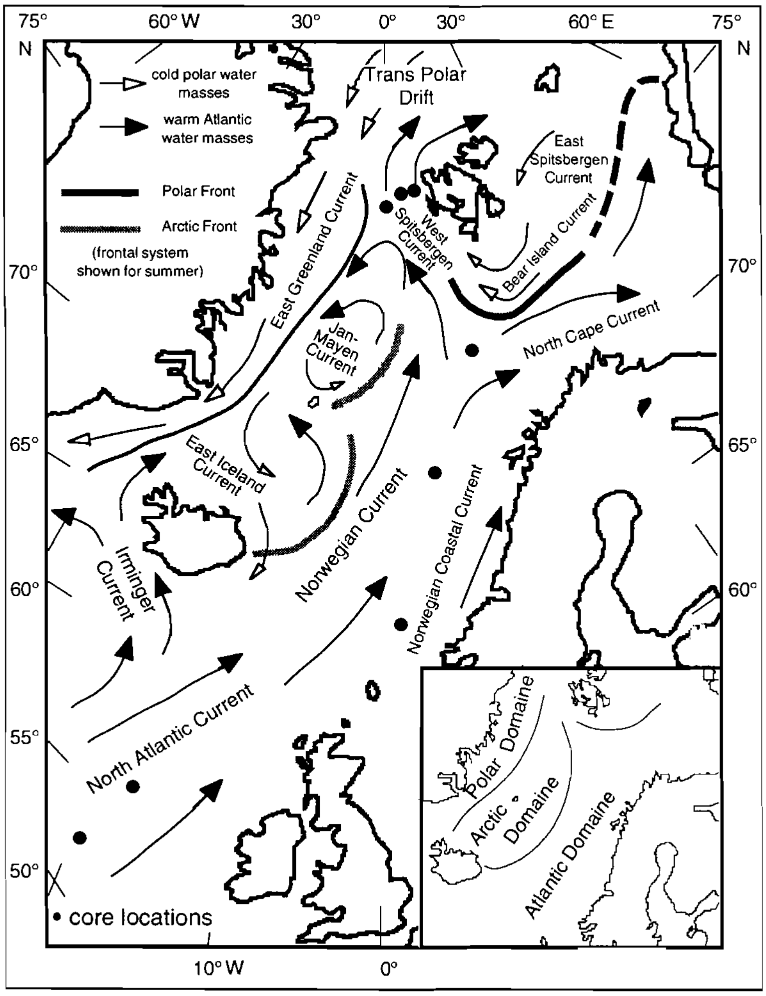

Figure 3. The modern surface circulation pattern of the northern North Atlantic (after Swift, 1986; Koltermann, 1987); core locations are marked with dots (labels see Fig. 1). The oceanographic frontal system in its summer situation (oceanographic domaines after Swift, 1986) is shown in the insert map.

Surface waters in the Arctic Domain (Fig. 3) are cooled in winter by cold, easterly winds. Due to increased density, these waters sink, thus forming deep water. Together with sinking bottom water masses originating from the Barents Sea shelf (Midttun, 1985; Blindheim, 1989), these two major GIN Sea water masses form the Norwegian Sea Deep Water (NSDW) in the Norwegian Basin and the Lofoten Basin area, as well as the Greenland Sea Deep Water (GSDW) in the Greenland Basin area (Fig. 1). The GSDW is further fueled by highly saline cold Arctic Ocean Deep Water (AODW; Aagaard *et al.*, 1991; Rudels & Quadfasel, 1991) through the western parts of the Fram Strait. After convective mixing (Smethie *et al.*, 1986; Clarke *et al.*, 1990), it contributes to the Norwegian Sea Deep Water (NSDW; Swift & Koltermann, 1988). The NSDW is discussed as a possible source of deep water in the Arctic Ocean through the eastern Fram Strait (Jones *et al.*, 1995).

After approximately 30 years of turnover time [Smethie *et al.*, (1986); Heinze *et al.*, (1990) propose a maximum of 13 to 16 years] this oxygen-rich bottom water mass streams together with intermediate water masses as „overflow water" over the ridges that border the GIN Sea in the south (the Iceland-Faeroe Ridge and the

Denmark Strait; Dickson *et al.*, 1990). Together with parts of the Mediterranean Outflow, these waters create the North Atlantic Deep Water (NADW) which ventilates, to a large extent, the world ocean (Broecker, 1987 and 1991).

MATERIAL AND METHODS

Core locations and core data are summarized in Table 1. The sediment cores were sampled either on board the research vessels or from archive material stored at the Department of Geology at Kiel University or the GEOMAR (Research Center for Marine Geosciences, Kiel). In order to cover Termination I, the cores were sampled from the sediment surface downwards until well into the glacial horizons in slices of 1 or 2 cm thickness and intervals of 1 or 2 cm (ca. 100 ml, see Fig. 4, „sample processing"). Long cores and box cores were linked using stable oxygen isotope stratigraphy. In the appendices and graphs, the arithmetic mean of the actual thickness of the sample slice is used.

The processing of sediment samples followed standard procedures (Fig. 4; Struck, 1992). By carefully washing the sediments, damage to arenaceous specimens was largely prevented (Linke, 1986). All sediment samples are therefore considered to be foraminiferally complete for microscopic analysis.

The benthic foraminifera were counted in two subfractions (125-250 µm and 250-2,000 µm). A minimum of 300 tests was counted to ensure statistical reliability. The width of the sample splitter is 2,000 µm, which limits the maximum size fraction.

The raw counts of benthic foraminiferal tests are related to the entire sample (specimens/sample) and further computed with the sample-specific dry weight data of the total sediment (specimens/dry weight). The resulting data set was further processed using physical property data of the sediment to obtain a quantitative benthic foraminiferal accumulation rate *sensu* van Andel *et al.* (1975) and Ehrmann & Thiede (1985). The results are expressed in INDAR (**IND**ividuals **A**ccumulation **R**ate *sensu* Struck 1992) following equation 1

(1)

$$\mathrm{INDAR}\left[\frac{\mathrm{specimens}}{\mathrm{cm}^2\cdot\mathrm{ky}}\right]=\mathrm{counts}\left[\frac{\mathrm{specimens}}{\mathrm{g\ (dry\ sed.)}}\right]\cdot\mathrm{LSR}\left[\frac{\mathrm{cm}}{\mathrm{ky}}\right]\cdot\mathrm{DBD}\left[\frac{\mathrm{g}}{\mathrm{cm}^3}\right]$$

LSR: linear sedimentation rate; DBD: dry bulk density.

(Fig. 5).

Dry bulk density data are provided by the following sources:

Core PS 1906: Kassens (unpublished data);
Core M 23256: Holler & Kassens (1989);
Core M 23068: Kassens (1990);
Core M 23414: Jung (1996).

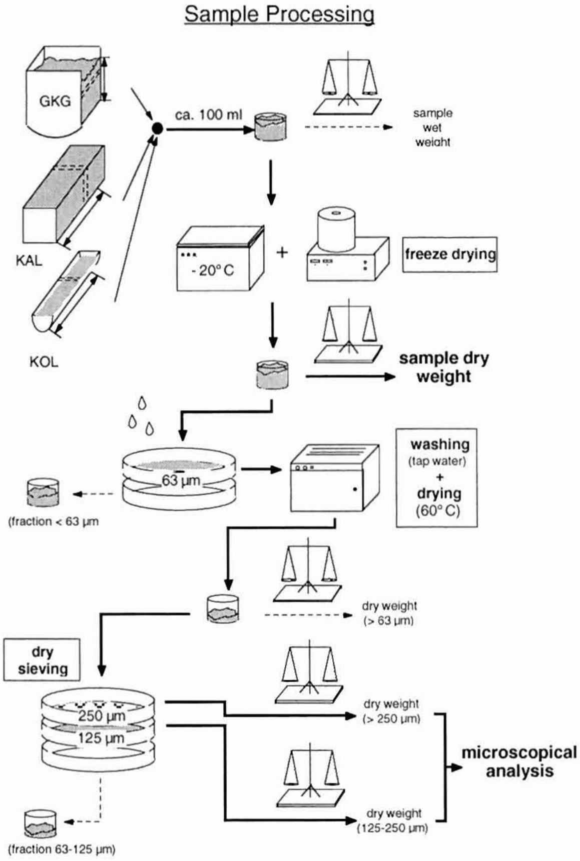

Figure 4. Schematic description of the sample processing technique. The fractionated sediment samples (125 - 250 µm and 250 - 2,000 µm) were analysed using a binocular microscope. Counting results were processed further (see Fig. 5).

Linear sedimentation rates were calculated according to a newly interpreted stratigraphy. In order to compare all data, the percentages and INDAR are plotted versus age in years BP in all graphs of this paper.

STRATIGRAPHY

A large portion of the sediment core stratigraphy was done by other workers (see Appendix 1) using stable oxygen isotope analyses. However, additional stratigraphic work was necessary in all cores to meet the high-resolution objective of this study covering Termination I. At cores PS 1906, M 23256 and M 23068, additional material [*Neogloboquadrina pachyderma* (sin.)] was sampled for oxygen isotope analyses to cover gaps in the existing isotope records. Sample processing and preparation is described in Vogelsang (1990) and Weinelt (1993). The samples were analysed at the Department of

core number	gear	core locations		waterdepth	total recovery	vessel	expedition	year
GIK/AWI		longitude	latitude	(m)	(cm)			
PS 1906 - 1	GKG	2° 9.00' W	76° 50.52' N	2,990	37	RV Polarstern	ARK VII/1	1990
PS 1906 - 2	KAL	2° 9.19' W	76° 50.18' N	2,939	652	"	"	"
M 23256 - 1	KOL	10° 56.60' E	73° 10.30' N	2,061	960*	RV Meteor	M 7/2	1988
M 23068 - 2	GKG	1° 30.15' E	67° 49.99' N	2,228	44	RV Meteor	M 2/2	1986
M 23068 - 3	KAL	1° 30.30' E	67° 50.06' N	2,231	760	"	"	"
M 23414 - 6	GKG	20° 17.40' W	53° 32.20' N	2,201	34	RV Meteor	M 17/2	1991
M 23414 - 9	KAL	20° 17.30' W	53° 32.20' N	2,196	908	"	"	"

GIK = Geological-Palaeontological Institute and Museum, University Kiel; GKG = box corer; KAL = Kasten corer; KOL = piston corer
AWI = Alfred-Wegener-Institute, Bremerhaven

Table 1. Station list and core data (M = RV METEOR; PS = RV POLARSTERN; data from: Thiede & Hempel, 1991; Hirschleber *et al.*, 1988; Gerlach *et al.*, 1986; Suess & Altenbach, 1992; * loss of sediment surface during core recovery).

Pure and Applied Nuclear Physics, Kiel University (Dr. H. Erlenkeuser) using a FINNIGAN MAT 251 mass spectrometer. All the collected data were included into an already existing data set (see Appendix 1 for reference and data sources). The oxygen and carbon isotope data for the last 30 ky from the four cores used in this study are displayed in Fig. 6. Interpretation of the extended stratigraphic data sets and new stratigraphic correlations (pers. comm. Sarnthein, Erlenkeuser and Weinelt, 1993) are listed in Appendix 1.

Age determinations between two isotopic events were calculated (interpolation/extrapolation) and their „^{14}C-ages" were converted to calendar years according to Bard *et al.* (1990). The entire data set, including interpretation, for Core M 23414 was taken from Jung (1996). Stable isotope analyses on material from this core was carried out using specimens of *Globigerina bulloides*. To ensure the best possible stratigraphic reliability the $\delta^{18}O$ data sets of all cores were tested by cross-correlation with the SPECMAP data set (Martinson *et al.*, 1987). This test is based on Milankovitch's theory that climatic cycles correlate with periodic cycles of the earths orbital parameters (Imbrie *et al.*, 1984). The analysis revealed good correlation for the 41 ky cycle in all cores. The 19 ky cycle in Core M 23256 and the 23 ky and 19 ky cycle in Core M 23068 correlated poorly; this is possibly due to interpretational problems for isotopic stages 3.1 to 5.3. (pers. comm. Struck, 1993).

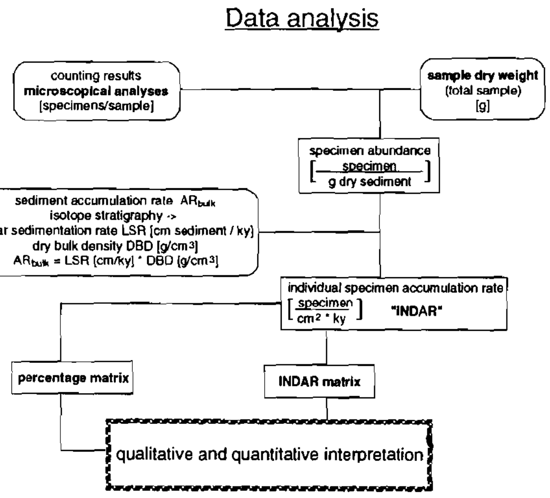

Figure 5: Data processing of the benthic foraminiferal test counts. This procedure, described in detail by Struck (1992), allows a quantitative review of test flux or benthic foraminiferal accumulation rates according to physical sediment and stratigraphic properties.

Based on the stratigraphy presented in Fig. 6 and individual ages calculated for each sample, age/depth graphs were produced and linear sedimentation rates were calculated (Fig. 7).

TAXONOMY

A total of 51 benthic foraminiferal species were taxonomically determined and counted. The most common taxa are listed in Table 2; a complete list of taxa is given in Appendix 2. Additionally, for the practical applications of this study, some species were summarized in four faunal groups on genus level. The taxonomy was controlled by use of micropalaeontological reference slides of the micropalaeontology group of the Department of Geology, Kiel University. Selected species were photographed using a CAMBRIDGE SCAN S2 at the SEM-Unit, The Australian National University, Canberra (Plate 1). The faunal groups include:

The *Cassidulina* sp. group

This group contains the species *C. laevigata* and *C. teretis*. A reliable differentiation of these species is only possible with excellent preservation (Mackensen & Hald, 1988). The description given by Tappan (1951) for *C. teretis* mentions the distinct umbilical plug and specific perforation of the test. These features might not be apparent on fossil specimens. *C. teretis*, described by Belanger & Streeter (1980), is interpreted as *C. laevigata* by Sejrup *et al.* (1981). *C. neoteretis* Seidenkrantz (1995) is believed to be the Recent and Subrecent representative of *C. teretis* and is included in the *Cassidulina* sp. group.

The *Elphidium* sp. group

All taxa belonging to the genus *Elphidium* are lumped together in a single group. They are not further

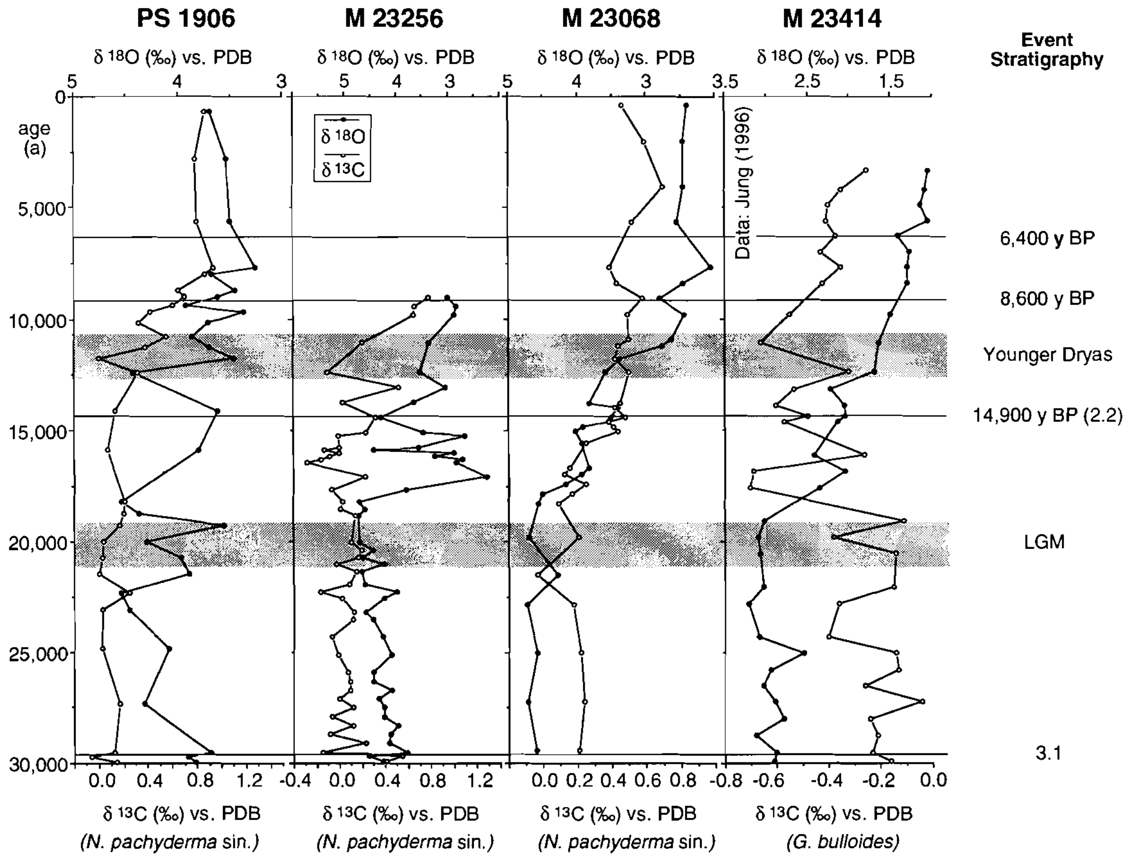

Figure 6. The $\delta^{18}O$ and $\delta^{13}C$ isotopic ratios for the last 30,000 years from cores used in this study. Single stratigraphic events and periods are marked by a stippled pattern or labels. The isotopic ratios were measured on shells of *Neogloboquadrina pachyderma* sin., except core M 23414 where *Globigerina bulloides* was used (includes data from Vogelsang, 1990; Hamich, 1991; Weinelt, 1993; Jung, 1996; see Appendix 1 for data and data sources, LGM = Last Glacial Maximum).

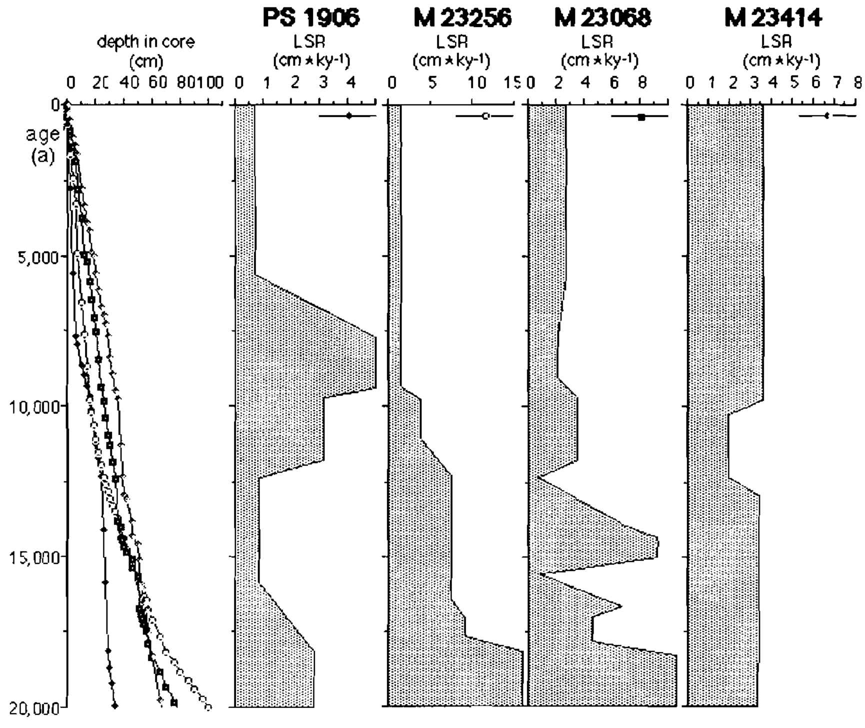

Figure 7. Age/depth control and linear sedimentation rates (LSR) according to the adjusted oxygen isotope stratigraphy. In the glacial section Core M 23256 shows an increased LSR.

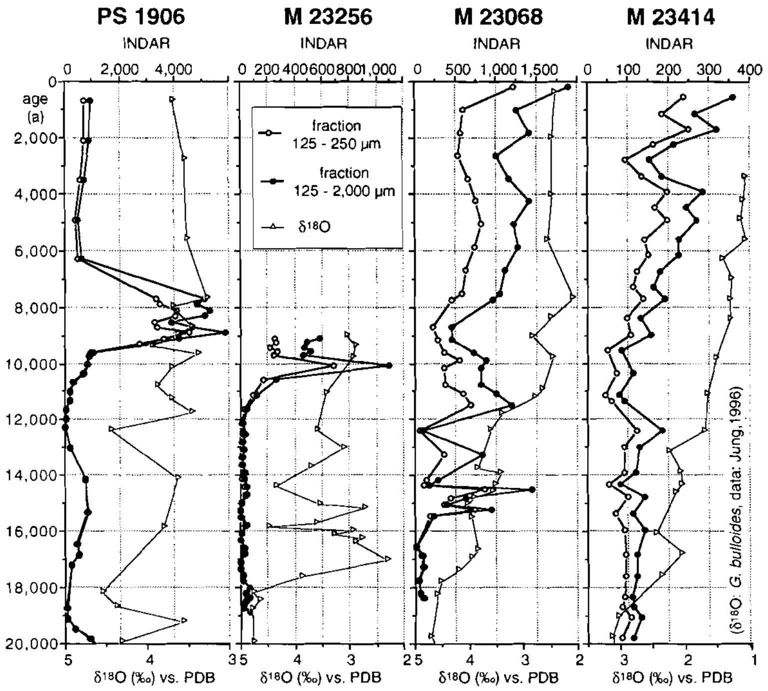

Figure 8. Benthic foraminiferal accumulation rates in the investigated cores of the last 20,000 y (INDAR = individual specimen accumulation rate; specimen * cm^{-2} * ky^{-1}). Filled circles mark the fraction 125 - 2,000 µm, open circles the fraction 125 - 250 µm and triangles the oxygen isotope ratios. The fine fraction dominates the assemblages of all cores. In core M 23414, the relation of the fractions is almost parallel throughout the entire core section.

taxonomically distinguished as they are interpreted as allochthonous faunal elements in deep-sea sediments (eg. Green, 1960; Lagoe, 1979, Murray, 1991).

The *Lagenida* sp. group

The species belonging to the genus *Lagena* appear in great variety but low numbers in the GIN sea (Struck, 1992). In this study, they are not taxonomically distinguished and are grouped together. The tests are usually hyaline and elongated. Spiny extensions and other individual features are often lost on fossil specimens.

The agglutinated tubes group

This group contains entire specimens and fragments of agglutinated tubes that are positively identified as benthic foraminifera. The tests of these species are rarely preserved completely; a taxonomic identification on a species level is mostly impossible. Counts of these fragments are therefore only semiquantitative. According to the extensive work by Thies (1991) using recent material, it is suspected that most of the specimens belong to the genera *Astorhiza* sp., *Rhabdammina* sp., *Saccorhiza* sp. and *Hyperammina* sp.

In general, the preservation of benthic foraminifera in this material is excellent. Corrosional features are rare; they occur only in single samples in glacial sediments and usually affect miliolid tests such as *Pyrgo rotalaria* or round the edges of fragile morphological features such as apertures. Massive carbonate dissolution (see Corliss & Honjo, 1981) is not observed. Textulariid species are usually found to be very well preserved. Possibly favoured by the outline of their tests (bi- and triserial and involute planispiral), these species can withstand the physical stress of sample processing.

RESULTS

Total benthic foraminiferal accumulation rates

In all cores the benthic foraminiferal assemblages are dominated by specimens found in the 125 to 250 µm fraction (Fig. 8). Between 20,000 and 9,600 y BP, the test size in Core PS 1906 shows little variation and is almost entirely dominated by the fraction < 125 µm. After a distinct accumulation minimum at 12,150 y BP (INDAR = 16), a maximum in foraminiferal accumulation occurs at 8,900 y BP with INDAR of 5,863. A younger maximum occurs around 8,000 y BP with INDAR of 5,282, followed by a decrease to INDAR of around 500 in most of the younger samples. In Core M 23256, benthic foraminifera between 18,820 to 11,100 y BP occur almost entirely in the 125-250 µm fraction. The INDAR range between 70 and 0. The INDAR reach a prominent maximum of 1,090 at 10,060 y BP. The total INDAR values for the youngest samples decrease to an average level of around 500 to 600. Due to loss of surface sediment during core recovery, samples younger than approximately 8,500 y BP are not available.

The abundance pattern of benthic foraminifera in Core M 23256 is repeated in Core M 23068. The INDAR in the samples prior to 15,550 y BP vary between 0 and 246. A distinct double maximum occurs around 15,000 y BP, with maximum values of 1,400 INDAR at 14,500 y BP. From approximately 12,000 y BP to Present the samples show little variation in foraminiferal abundance, although the values increase up to 1,800 INDAR. A slight minimum occurs at about 9,000 y BP. Core M 23414 shows very little variation in its INDAR and the proportion between the two counted fractions. The INDAR increase continuously from 113 to 360 INDAR between 20,000 y BP and Present.

Individual species accumulation rates

The abundances of the most important benthic foraminiferal species (Tab. 2) are displayed for each core together with the individual percentage of the entire benthic foraminiferal assemblage (Figs. 8-12). The percentage data often reach very high values, particularly in the glacial samples. This is related to low INDAR and to low species numbers in these samples. In all cores, the individual species abundances vary , but show a pattern which can be related to glacial, interglacial and transitional environments.

Table 2. Alphabetical listing of the most important species of benthic foraminifera found in the investigated sections of the sediment cores.

agglutinated group	*Globocassidulina subglobosa*
Bulimina marginata	*Cassidulina* sp. group
Cassidulina reniforme	*Elphidium* sp. group
Cibicides lobatulus	*Lagenida* sp. group
Cibicidoides wuellerstorfi	*Melonis barleeanum*
Cribrostomoides subglobosum	*Oridorsalis umbonatus*
Epistominella exigua	*Pyrgo rotalaria*
Eponides tumidulus	*Triloculina trihedra*

In Core PS 1906 the INDAR show three ranges with maxima between 20,000 y BP and Recent (Fig. 9). The *Cassidulina* sp. group and *O. umbonatus* have maximum abundances of 220 and 610 INDAR between 19,000 and 20,000 y BP. At 16,800 y BP, *T. trihedra* shows a minor maximum that is accompanied by high percentages of this species. A further maximum range is dominated again by the *Cassidulina* sp. group and *O. umbonatus* with INDAR of 153 and 512, respectively, between 13,000 and 16,000 y BP. From 11,000 y BP onwards, the INDAR of almost any other species start to increase and

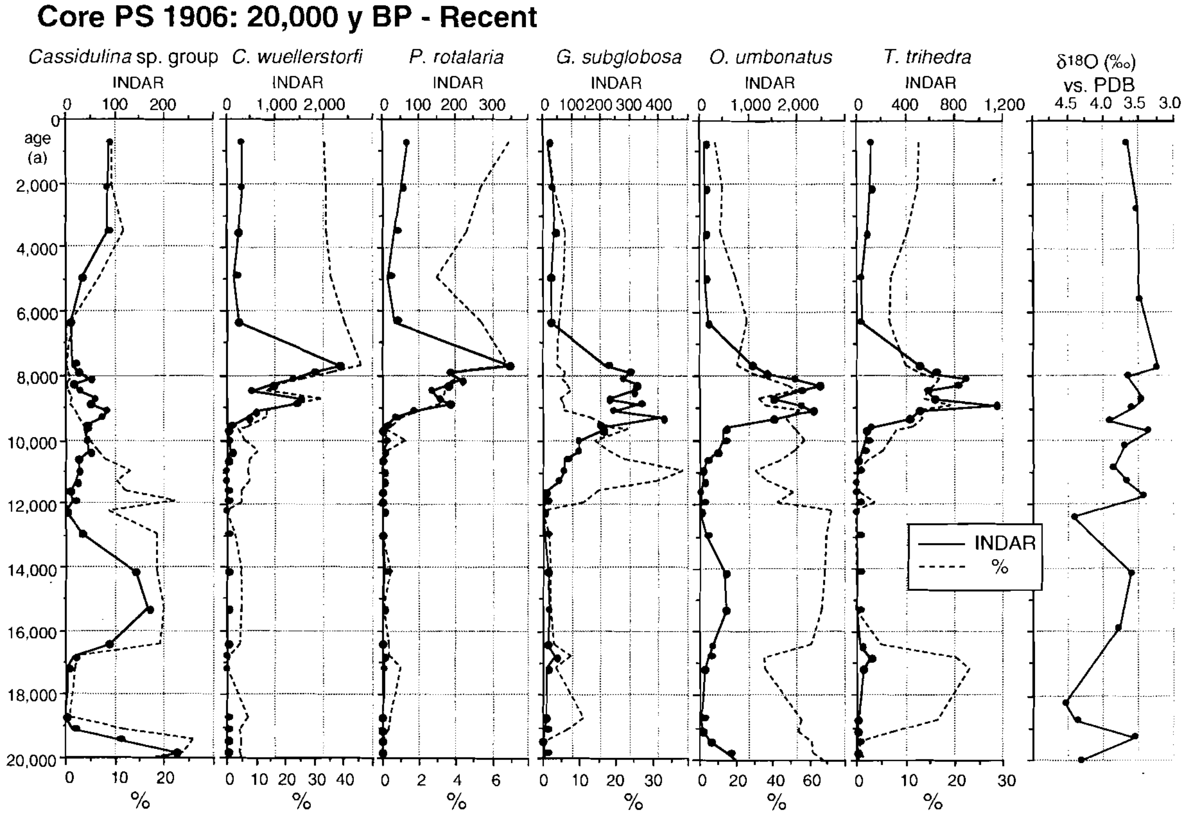

Figure 9. Abundance data of the most common benthic foraminifera in Core PS 1906 from 20,000 y BP to Recent (dashed line = percentages, solid line = INDAR). All species, except the *Cassidulina* sp. group, show a prominent maximum between 9,000 and 8,000 y BP. However, distinct maxima do not appear synchronously. *C. wuellerstorfi* and *P. rotalaria* reach maxima slightly later than the other species.

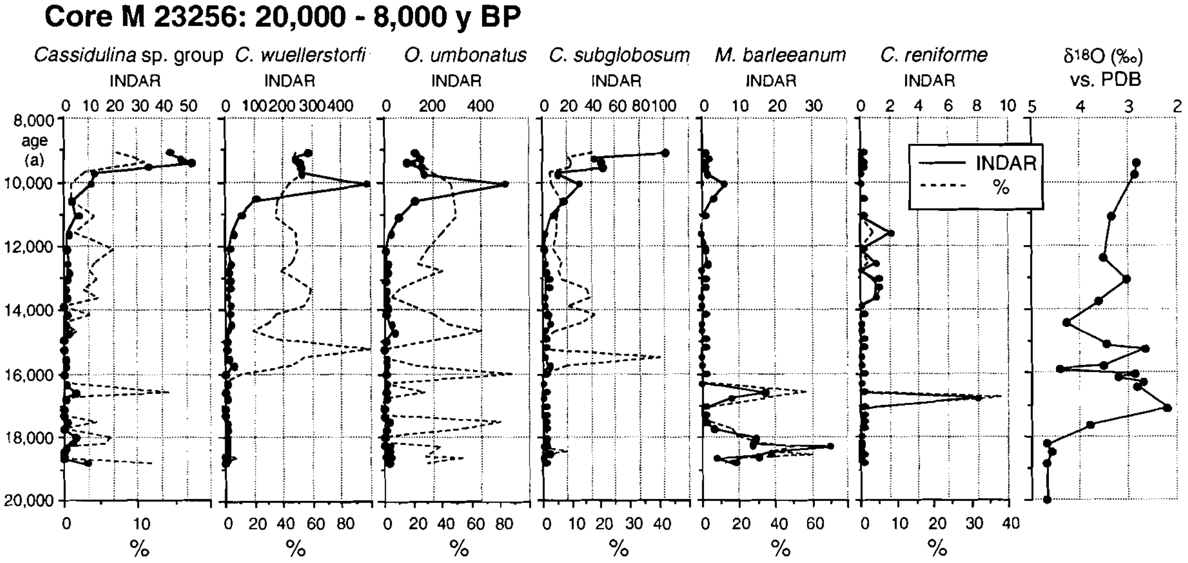

Figure 10. Benthic foraminiferal abundances of the most common species in Core M 23256 (dashed line = percentages, solid line = INDAR). The top sediment layers of this core were lost during core recovery.

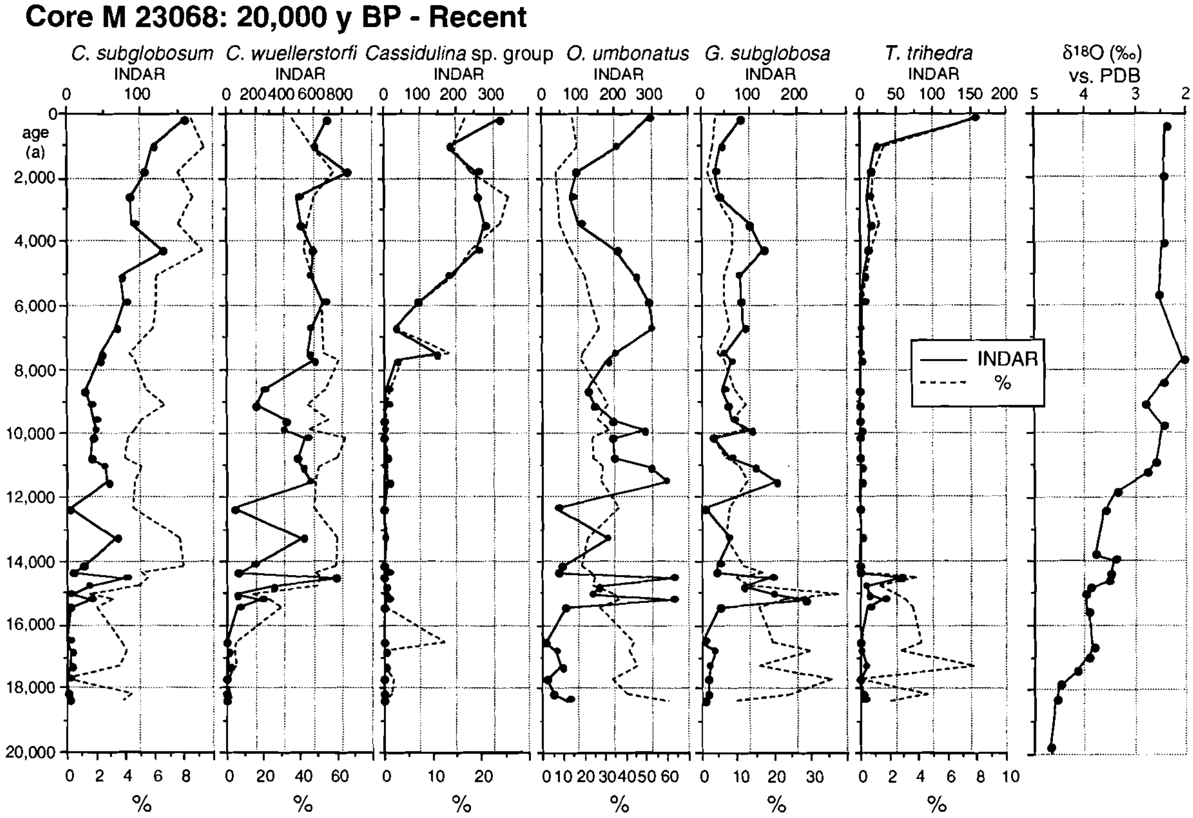

Figure 11. Benthic foraminiferal abundances of the most common species in Core M 23068 (dashed line = percentages, solid line = INDAR).

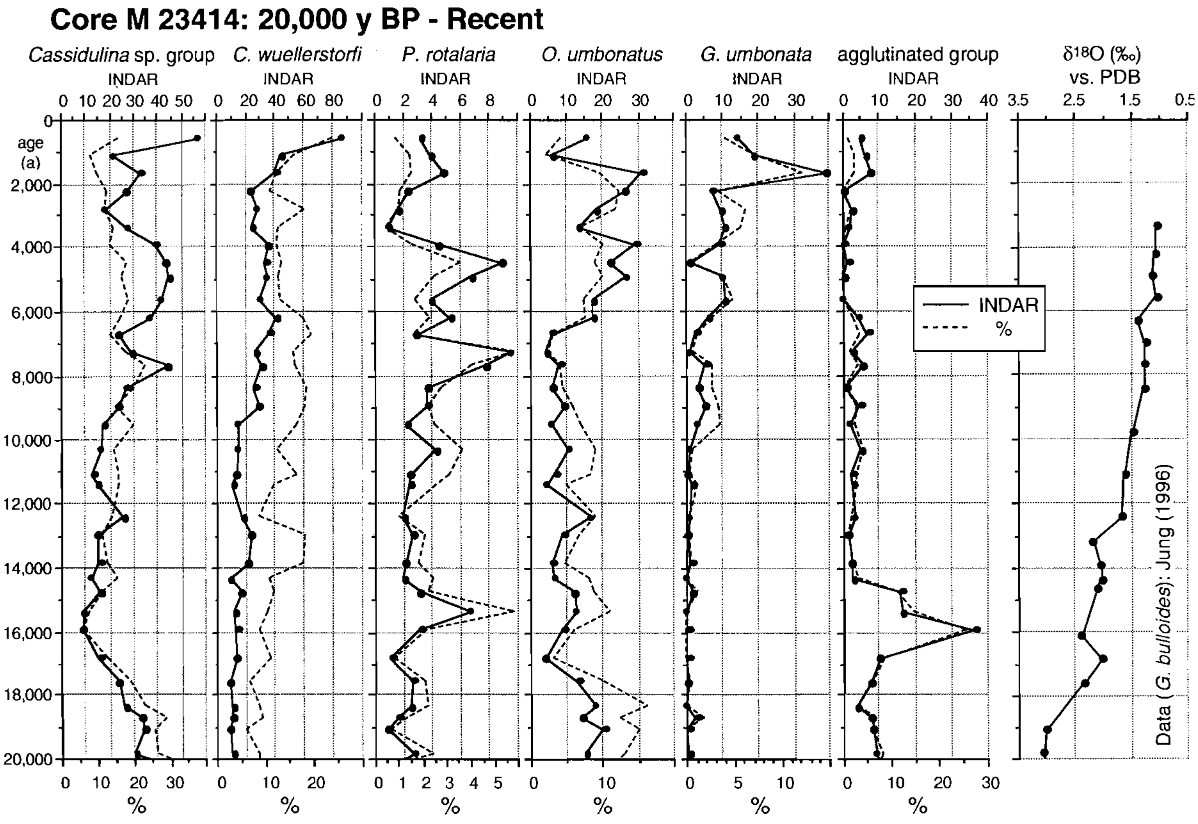

Figure 12. Benthic foraminiferal abundances of the most common species in Core M 23414 (dashed line = percentages, solid line = INDAR).

create a suite of abundance maxima up to ca. 7,000 y BP. *C. wuellerstorfi* and *O. umbonatus* show the highest INDAR with 2,398 and 2,443, respectively. At 7,720 y BP *C. wuellerstorfi* and *P. rotalaria* form a prominent peak. This maximum appears to be the youngest of the suite of high abundance maxima. *T. trihedra*, *G. subglobosa*, *O. umbonatus* and the *Cassidulina* sp. group show a maximum abundance shortly before 8,000 y BP. The younger samples reveal low INDAR and little variation in their benthic foraminiferal abundance.

The benthic foraminiferal abundance in Core M 23256 reveals two maxima (Fig. 10). The older maximum range between 19,000 and 16,000 y BP is dominated by *M. barleeanum* and the *Cassidulina* sp. group. These species reach maximum INDAR of 35 and 8, respectively. *Oridorsalis umbonatus* shows high percentages of the total assemblage but very low abundances during this time. A second interval with maximum values occurs between ca. 11,000 and 9,000 y BP, where most of the species reach highest abundances. A very prominent peak at 10,000 y BP shows *C. wuellerstorfi* and *O. umbonatus* with INDAR of 487 and 498. A younger prominent abundance peak at 9,400 y BP shows the INDAR of the *Cassidulina* sp. group (52) and the agglutinated foraminifer *C. subglobosum* (50). Younger sediments of these cores were lost during core recovery.

The benthic foraminiferal abundance in Core M 23068 shows a less distinct pattern than Cores M 23256 and PS 1906 (Fig. 11). The amplitude of INDAR in all species fluctuates less distinctly and most species, except *T. trihedra* and the *Cassidulina* sp. group, are present in all samples. A maximum abundance range occurs between 15,300 and 14,200 y BP. *C. wuellerstorfi* reaches a maximum INDAR of 772, *O. umbonatus* shows 403, *G. subglobosa* 218 and *C. subglobosum* reaches an INDAR of 83. A second maximum abundance range between 12,300 and 8,600 y BP is formed by the same species. Between 8,000 and 4,000 y BP, *O. umbonatus* and *C. wuellerstorfi* occur in slightly increased INDAR. The *Cassidulina* sp. group also occurs in slightly increased INDAR between 5,000 and 2,000 y BP.

The abundances of all species of benthic foraminifera in Core M 23414 show very little variation (Fig. 12). Along the entire investigated core section the INDAR of *O. umbonatus*, *G. umbonata* and agglutinated tubes only indicate a few ranges with increased values. *O. umbonatus* reveals increased

INDAR between 6,000 and 1,800 y BP with a maxium value of 31. *G. umbonata* shows a distinct INDAR maximum at 1,800 y BP of 39 and the agglutinated tubes occur in increased abundances between 18,000 and 14,000 y BP at a maximum value of 36.

DISCUSSION

The dynamic development of benthic foraminifera during a glacial/interglacial transition

High-resolution records of benthic foraminiferal abundances covering the last glacial termination indicate that the transition from glacial to interglacial conditions occurred in two steps. Bulk benthic foraminiferal accumulation rates in the 125-2,000 µm fraction reveal low values and little variations in glacial samples from all of the cores. Meltwater events or other regional phenomena, such as seasonal sea ice-free sea surfaces or temporary bottom currents, may be responsible for short-term INDAR peaks.

Benthic foraminiferal accumulation rates start to increase during the early termination of the last glacial between 12,500 y BP (Core M 23414 from the Rockall Plateau) and 9,500 y BP (Core PS 1906 from the southern Fram Strait). Within a period of roughly 1,500 years, the INDAR values of the total benthic foraminiferal fauna reach a distinct first maximum („older INDAR maximum"). This event lasts about 500 to 1,000 years. In Core M 23256 it corresponds with the Termination I B (10,400 to 9,900 y BP) described by Broecker *et al.* (1988). The enormous increase of INDAR with a steep gradient indicates an important turning point in the oceanic environment. *Cibicidoides wuellerstorfi* and *O. umbonatus* are the most common species forming this INDAR maximum. A comparable occurrence event is reported by Koç-Karpuz & Jansen (1992) in Core HM 79-6/4, located in the southeastern GIN Sea (Fig. 1). Reconstructed sea-surface temperatures indicate a decrease of 2° C within a period of at least 300 years between 10,100 and 9,600 y BP. The authors coined the term „Younger Dryas II" for this cold spell. Sea-surface temperature reconstructions by Schulz (1995) reveal similar results. The beginning of the sea-surface temperature decrease coincides chronologically with „meltwater event I B" (Fairbanks, 1989).

After this accumulation rate minimum a second peak in benthic foraminiferal accumulation occurs („younger INDAR maximum"), which is most distinct in Core PS 1906 (9,900-7,800 y BP). This event shows, in general, lower INDAR values than the older maximum, but a similar duration of 1,200 ± 500 years. The characteristic species are *C. wuellerstorfi*, *P. rotalaria*, *C. subglobosum*, *O. umbonatus* and *T. trihedra* appear in higher accumulation rates. This second, younger, peak indicates the beginning of the interglacial period and the return of the INDAR to a lower level with little variations. However, values remain two to ten times higher than the average glacial INDAR.

Do benthic foraminifera respond to „meltwater events" and changing sea-surface temperatures?

„Meltwater events" are short-term features, usually of limited extent, that can be traced by $\delta^{18}O$ values of planktic foraminiferal tests (Sarnthein *et al.*, 1992). An identification of true meltwater events is only possible with correlation to sea-surface temperature reconstructions (Weinelt, 1993; Schulz, 1995). These should not show a distinct warming of surface waters, as during the transition from a glacial to an interglacial, but the isotope record should have lighter $\delta^{18}O$ values. Reconstructed sea-surface temperatures by Schulz (1995) allowed the identification of such „meltwater events" in Cores M 23256 and M 23068 prior to the actual glacial termination (Figs. 13 a-d). In the southern Fram Strait (near Core PS 1906), a planktic oxygen isotope record from Core PS 1295 (Jones & Keigwin, 1988) is used to identify a possible meltwater event between 17,000 to 14,000 y BP (Fig. 13 a). A similar event occurs in Core PS 1291 (Fig. 1) located in the eastern Fram Strait (pers. comm. Spielhagen, 1996) and is also recognized in the eastern central Arctic Ocean (Stein *et al.*, 1994).

A minor increase of benthic foraminiferal INDAR values in the cores PS 1906, M 23256 and M 23058 reveals excellent temporal correspondence with identified „meltwater events". Periods of light oxygen isotope values correspond to increased accumulation rates of benthic foraminifera. Thus an environmental change with positive effects on the benthic foraminiferal fauna is suggested. The increased INDAR are formed almost entirely by the fraction 125-250 µm and species of the *Cassidulina* sp. group, *O. umbonatus* and agglutinated tubes, which also form the gradual increase of accumulation rates towards the „older maximum". Sparse but continuous occurrences of *O. umbonatus* in glacial material of GIN Sea cores are already described by Haake & Pflaumann (1989). The occurrence of tests of the *Elphidium* sp. group indicates winnowing and input of shelf sediments (Østby & Nagy, 1982).

The oxygen isotope peaks in Core M 23414 occur synchronously with SST maxima and are therefore interpreted as „warming events" rather than meltwater events (Fig. 13 d). This „warming" is evidence for the influence of warmer Atlantic waters (Ruddiman & McIntyre, 1973; Bard *et al.*, 1987), which do not have such a significant influence on the benthic foraminiferal fauna as is docu-

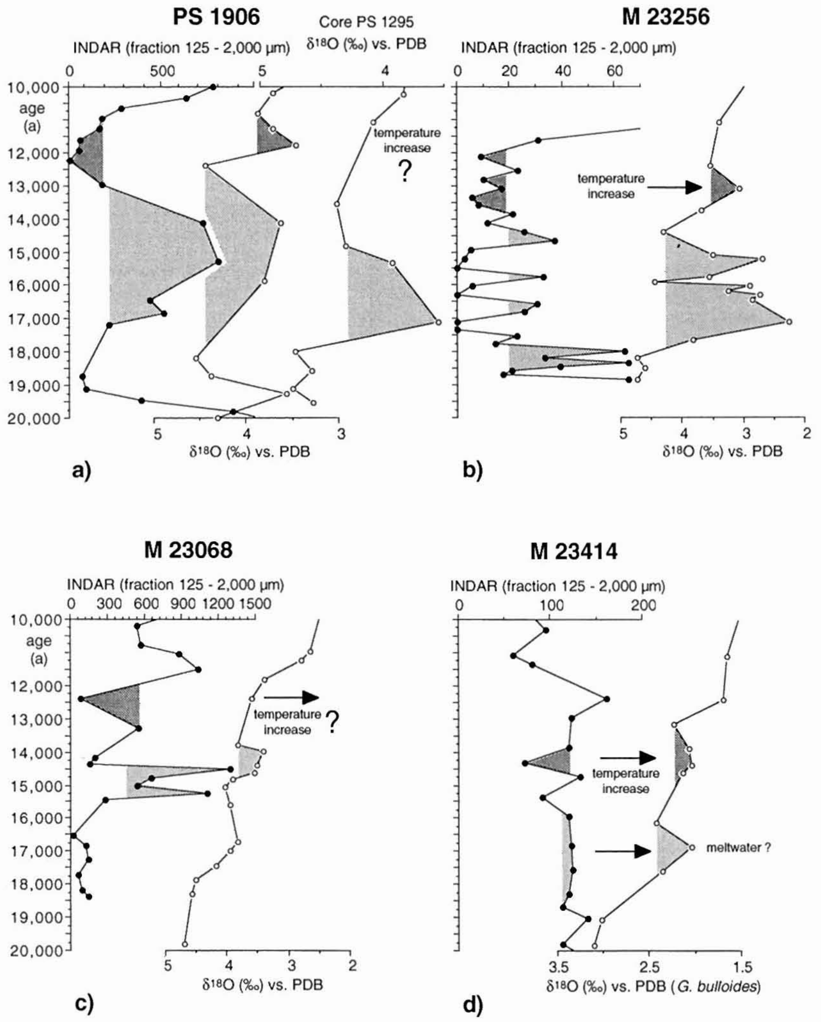

Figure 13 a-d. Accumulation rate maxima of benthic foraminifera occur parallel with shifts of planktic oxygen isotope ratios to lighter values in the period from ca. 17,000 to 14,000 y BP. This temporal coherence indicates a change of environment with positive effects for the abundance of benthic foraminifera (amelioriation of trophic situation?). These shifts are identified as „melt-water events". At all core locations, except Core PS 1906, reconstructed SSTs records do not parallel the oxygen isotope shifts. The oxygen isotope record of Core PS 1295 (Jones & Keigwin, 1988) from the eastern Fram Strait shows the same shape as Core 1906, whereas the younger isotope shift is probably lost due to a large sample spacing. Also, due to a low resolution, the oxygen isotope record in Core M 23068 does not show a younger shift towards lighter values, but an increase of SSTs.

mented at the northern core locations. Core NA 87-22, which is located near M 23414 (Fig. 1), shows parallel increases of salinity (Duplessy *et al.*, 1992) and hence supports this interpretation.

Reconstructed sea-surface temperatures are available for three core locations in this study (Schulz, 1995). These data are correlated with the benthic foraminiferal INDAR and can be related to the lateral influence of the North Atlantic Current and its continuation, the Norwegian Current (Figs. 14 a-c). The SSTs were calculated using the SIMMAX technique (Pflaumann *et al.*, 1996) and show a temporal gradient from south to north through the northern North Atlantic. The first shift to warmer SSTs occured at the Rockall Plateau around 13,400 y BP with 7° C and in the northeastern GIN Sea at 8,600 y BP at 5° C (Schulz, 1995). At the Rockall Plateau location (Core M 23414), the older INDAR maximum occurs synchronously with increased SSTs, whereas in the cores in the eastern GIN Sea (M 23068 and M 23256), INDAR suggest a temperature rise at 10,800 y BP and 10,000 y BP, respectively. Labeyrie *et al.* (1992) postulate that, in this period, the Norwegian Sea was „relatively warm" with salty surface water and cold, ventilated deep water. The later appearance of peaks towards the north is interpreted as indicative of the retreat of glacial ice cover of the GIN Sea (Nees *et al.*, subm.).

Apparently, the abundance of benthic foraminifera is closely related to sea-surface temperature changes. Warmer temperatures are likely to induce an increase of benthic foraminiferal accumulation rates. „Meltwater events" in contrast seem to have a similar effect, but with a considerably lower amplitude. Sediment trap and detailed interdisciplinary studies have already revealed a primary link between the sea surface and the benthic realm, the so-called „benthic-pelagic coupling" (Graf, 1989; Graf *et al.*, 1995). Increased primary production induces, within a period of few days, an increased nutrient flux and sedimentation of phytodetritus. This is detectable in the deep-sea (Graf, 1989; Asper *et al.*, 1992). In particular, some species of filtrating benthic foraminifera are well adapted to respond to pulses of organic matter

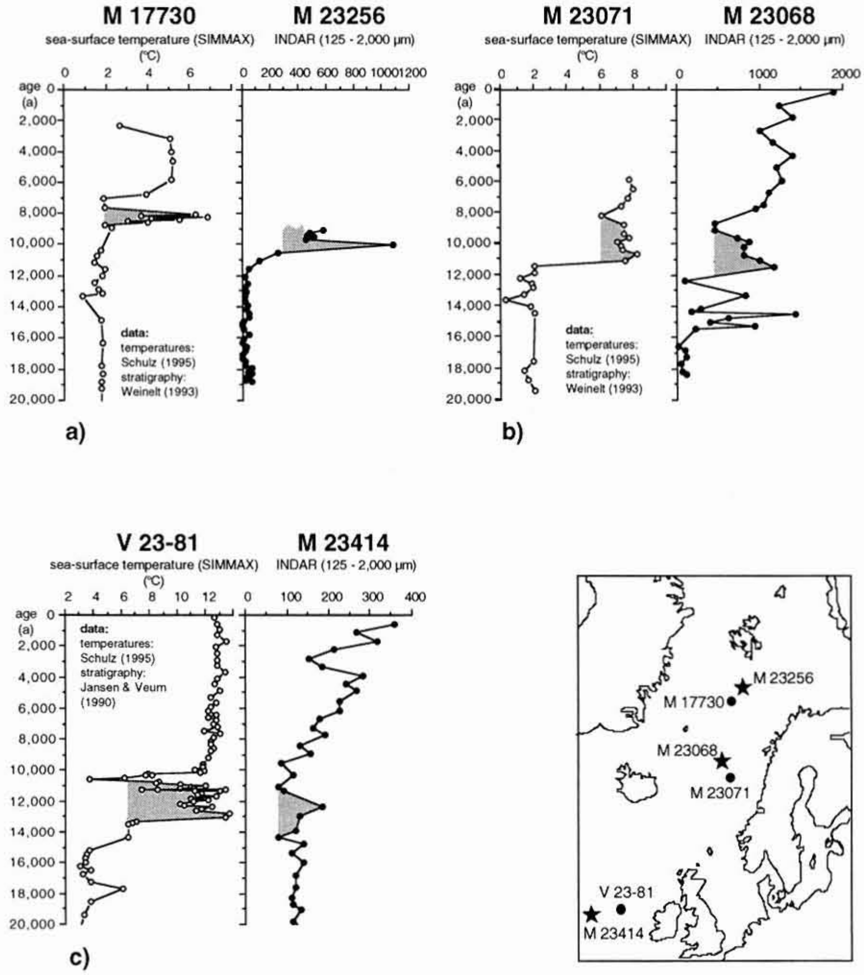

Figure 14 a-c. The benthic foraminiferal accumulation rates can be related to reconstructed sea-surface temperatures. Reconstructed SSTs are available for three core locations in the northern North Atlantic. In all cores, the benthic foraminiferal INDAR show a distinct maximum parallel to a postglacial rise of SSTs. While the INDAR and temperature rise occur synchronously at the Rockall Plateau location (Core M 23414); at the other locations a slight temporal shift occurs. This may be related to inaccuracies in the stratigraphic data of these cores.

input (Gooday, 1988; Gooday & Lambshead, 1989; Smart *et al.*, 1994). The synchronous increase of fossil benthic foraminiferal INDAR with the reconstructed SSTs implies a close link between the sea floor environment and changes of the sea surface.

Palaeoceanographical implications

Accumulation rates of benthic foraminifera clearly reflect oceanic changes in the GIN Sea since the last glacial. Low INDAR with little variation during oxygen isotope Stage 2 indicate a stable benthic environment with little input of organic matter. Kellogg (1980) suggested a year-round sea ice cover for the GIN Sea during the Last Glacial Maximum at 18,000 y BP. Extremely reduced primary production still produced a constant flux of organic matter into the deep-sea (Carey, 1987; Andersen, 1989). In particular, small species appear to respond instantly to minute environmental changes (Fig. 2) and, thus, may indicate variability in the sea ice cover. Short-term input of organic matter synchronous to meltwater events led to increased benthic foraminiferal accumulation rates. These maxima are mainly formed by endobenthic and opportunistic species. There is little sign of lateral advection in the GIN Sea during this period of time. But some occurrences of filtrating species indicate such an event in the eastern GIN Sea. Very low $\delta^{13}C$ values indicate limited exchange between the sea surface and the atmosphere and therefore a closed sea ice cover (Kellogg, 1980; Weinelt, 1993). From 12,400 y BP on Weinelt (1993) suggests the gradual development of an anti-estuarine circulation system with intrusions of warm Atlantic surface waters into the eastern parts of the GIN Sea. This might have created oceanographic conditions which have resulted in increased benthic foraminiferal INDAR. Furthermore the early decomposition of the Barents Sea ice cover by sea level rise (Jones & Keigwin, 1988) might be responsible for the increase of INDAR in the GIN Sea.

Prior to the „older maximum", the INDAR values show a gradual increase. This slow increase lasts up to 1,500 years and can be interpreted as an indicator of increasing flux of organic matter from the sea surface to the sea floor without lateral advection. It is possible that this gradual change results from seasonal advance and retreat of the sea ice cover during the general retreat at the transition from glacial to interglacial. The first influence of warm Atlantic surface water that started to affect the southeastern GIN Sea (Jansen & Bjørklund, 1985) with the establishment of interglacial conditions might have induced the massive benthic foraminiferal INDAR maximum in all of the sediment cores. The increasing abundance of epibenthic species indicate an onset of deep-sea advection.

The following period of low accumulation rates is characterized by an icreased presence of agglutinated species. The INDAR of *C. wuellerstorfi* decreases in all cores prior to the massive increase leading to the second INDAR maximum. During this peak, epibenthic as well as endobenthic species reach high accumulation rates and therefore indicate ideal living conditions. This may be related to an optimized food supply. Under the gradually increasing influence of Atlantic water masses during the transitional phase, more nutrient-rich waters were transported northwards (Nürnberg, 1991). The abundance of epibenthic species indicate additional lateral advection in the deep-sea (Lutze & Thiel, 1989). The „return" of INDAR to a lower level after the younger maximum can not be related to a specific oceanographic event. Based on results of stable oxygen isotope analyses, the postglacial surface circulation in the GIN Sea seems to be stable since 9,000 y BP (Weinelt, 1993). It can be speculated that, in relation to organic matter flux rates, the trophic situation in the deep-sea has been debased due to variations in the zooplankton community during the early Holocene.

Changing climate at Termination I

The INDAR of 11 sediment cores are combined to a „stack" using data of Nees (1989) and Struck (1992) (Fig. 15). This curve represents the benthic foraminiferal accumulation rate in the eastern GIN Sea under the influence of the North Atlantic Current and Norwegian Current. The interpretation of this record, however, is limited to a transect from the Rockall Plateau through the eastern GIN Sea to the southern Fram Strait.

All parameters displayed in Fig. 15 show stable conditions between 20,000 and 16,000 y BP. Solar insolation increased slowly (Imbrie *et al.*, 1992) and reached a maximum at 11,000 y BP, some 2,500 years ahead of the INDAR maximum. Solar insolation is discussed as one of the most important factors influencing the earth's climate and oceanography (COHMAP, 1988; Crowley & Kim, 1992). The stack of benthic foraminiferal accumulation rates shows low values, slowly increasing, in glacial samples to ca. 10,500 y BP. The first step of a „deglacial warming" occured from 16,000 to ca. 11,000 y BP and is documented as a distinct sea-level rise (Fairbanks, 1989), higher SSTs (Schulz, 1995) and an increase in atmospheric temperatures calculated from Greenland (Mayewski *et al.*, 1993) and Antarctic ice cores (Jouzel *et al.*, 1993). Synchronous occurrence of oceanic and atmospheric changes in the North Atlantic region is documented by correlation of sediment core and ice core data (Haflidason *et al.*, 1995). The first step of transition from the last glacial to the present interglacial apparently had only little effect on the benthic foraminiferal accumulation rates. It is possible that climate-related oceanic changes on the sea surface did not increase productivity so that they affected deep-sea habitats by benthic-pelagic coupling.

A period of stagnancy in this warming trend occurs together with the insolation maximum between 13,000 and 11,000 y BP. This period is paralleled by changes in SSTs, sea level and INDAR of benthic foraminifera. A decrease of the sea level rise can be correlated with a decrease of atmospheric temperatures. This cold episode, the Younger Dryas, is well documented in all parameters, except the benthic foraminiferal INDAR. Apparently the deep-sea environment was affected to a lesser extent. Until this period, the benthic foraminiferal fauna was dominated by detritivore, endobenthic and opportunistic species, indicating stable and relatively calm conditions (Struck, 1995). Presumedly all organic matter that served as a major food source was delivered vertically. Studies on the organic components of the sediment in the eastern GIN Sea indicate an accumulation of very mature, terrigenous organic material during this period (Wagner & Henrich, 1994). This material is of low energetic value, but apparently seems to be favoured by endobenthic or opportunistic benthic foraminiferal species. Possibly a coupled process using the terrigenous input as a transporter of organic material from enhanced primary production has increased the organic matter flux rates and subsequent biological activity on the sea floor.

Between 10,000 and 8,000 y BP, SSTs (Schulz, 1995) and atmospheric temperatures (Jouzel *et al.*, 1993) form maxima. Solar insolation has passed its maximum. The melting of ice caps leads to sea level rise and the influence of the Norwegian Current in the eastern GIN Sea increases as well (Bauch, 1992). These changes seem to have an enormous effect on the benthic foraminiferal accumulation rates. INDAR reach a clear maximum around 8,500 y BP, parallel to the atmospheric temperatures reconstructed from the Vostok Ice Core (Jouzel *et al.*, 1993). The climatic conditions during this period created an evironment on the sea floor that apparently favoured the reproduction of benthic foraminifera. Planktic foraminifera and other zoo- and phytoplankton reach high accumulation rates

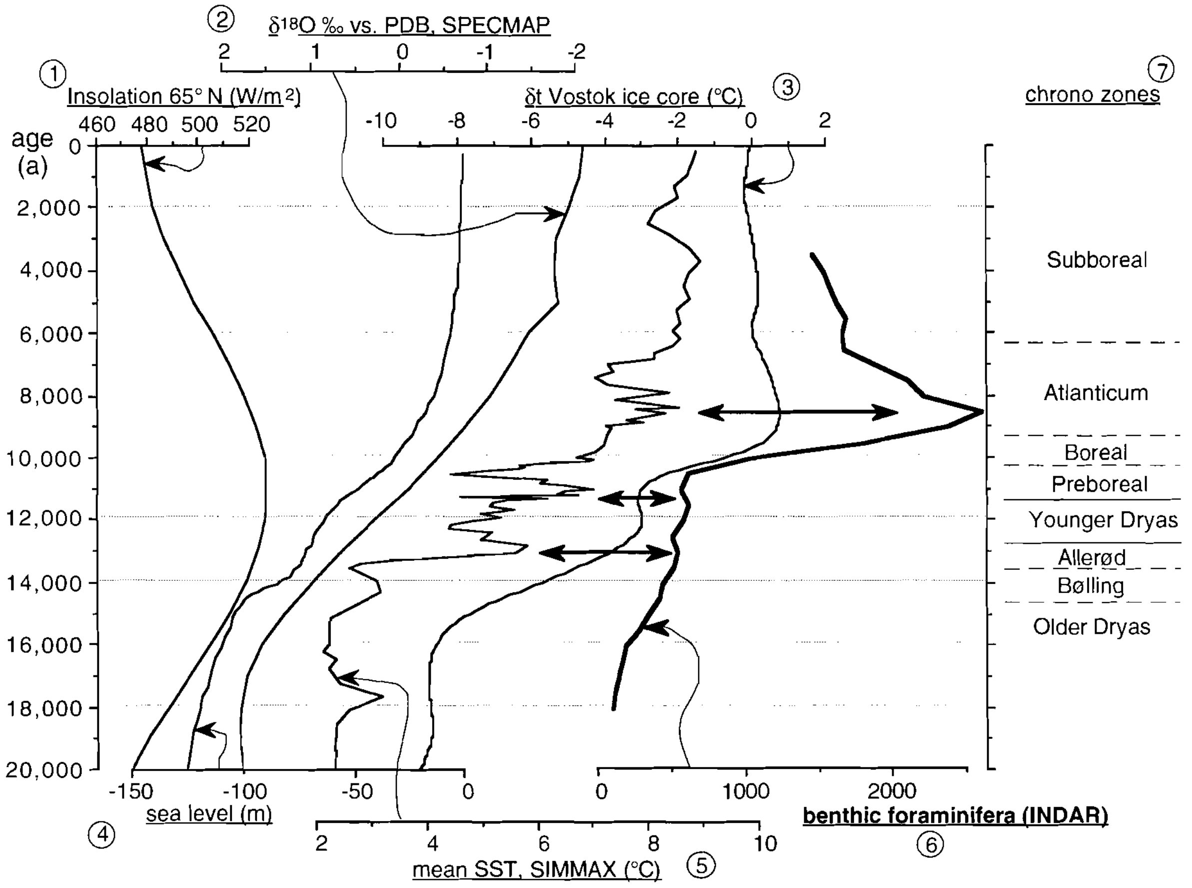

Figure 15. The stack of benthic foraminiferal INDAR of four cores along a transect through the GIN Sea can be correlated to various other regional and global climate records. The resulting maximum around 8,500 y BP occurs in a late phase of the transition from the last glacial to the present interglacial. It correlates well with a global sea level rise, a rise of sea-surface temperatures and a rise of atmospheric temperatures. Older SST warming peaks seem to have had little effect on benthic foraminiferal accumulation rates.

1: Insolation (Imbrie *et al.*, 1992).
2: SPECMAP (Martinson *et al.*, 1987).
3: Vostok Ice Core, temperature difference to the present mean (Jouzel *et al.*, 1993).
4: Sea level changes (Fairbanks, 1989).
5: Sea-surface temperatures (SST); this data set is computed as a stack from three cores located on the Rockall Plateau and the eastern GIN Sea (see Figs. 14 a-c; Schulz, 1995).
6: INDAR of benthic foraminifera, calculated as stack from 11 cores located at the Rockall Plateau and the central and eastern GIN Sea to the southern Fram Strait (data: this study; Nees, 1989; Struck, 1992).
7: Chrono zones (Mangerud *et al.*, 1974; Fairbanks, 1990).

synchronously (Baumann, 1990; Koç-Karpuz & Schrader, 1990; Matthießen, 1991; Bauch, 1992).

The mid-Holocene benthic foraminiferal assemblage is characterised by an increased portion of epibenthic species such as *C. wuellerstorfi*, *O. umbonatus* and *P. rotalaria*. The oceanography of the GIN Sea had changed significantly and shows great similarities with the present situation. Benthic foraminifera indicate greater activity of bottom currents and lateral advection. Despite only small changes in global atmospheric temperatures since 8,000 y BP (Dansgaard, 1987; Jouzel *et al.*, 1993; Johnsen *et al.*, 1992; Kerr, 1993) and insignificant changes in oceanography (Weinelt, 1993) the INDAR of benthic foraminifera decrease after the distinct maximum. An explanation of this maximum could possibly be the quick and optimised consumption of a short-term intensive pulse of organic matter by quickly responding and highly adapted species such as *C. wuellerstorfi*, *M. barleeanum* and *P. rotalaria* (Linke & Lutze, 1993). With the establishment of interglacial conditions, the abundance of benthic foraminifera finally stabilised, exceeding the glacial values of accumulation rates, but remained far below the peak values at Termination I.

CONCLUSIONS

High-resolution investigations of deep-sea benthic foraminifera enable detailed insight of climate-forced palaeoceanographic changes and distinguishes short-term events.

The transition from the last glacial to the present interglacial is documented in benthic foraminiferal accumulation rates as a noncontinuous signal. Glacials are characterized by low benthic foraminiferal accumulation rates. During the transitional phase, the values show two maxima with extremly high values. The present interglacial is characterized by higher accumulation rates than the glacial. However, they remain well below the peak values of the transitional phase.

Benthic foraminiferal accumulation rates reveal an excellent correlation with reconstructed SSTs. Meltwater events are synchronous with increased accumulation rates of endobenthic and opportunistic species of benthic foraminifera. This indicates the direct coupling of sea-surface processes with the deep-sea environment, which is more distinct in the GIN Sea than at the Rockall Plateau.

The correlation of benthic foraminiferal accumulation rates with other climate proxies yields a high temporal coherence with climate changes. The response in the deep sea seems on average to lag atmospheric changes.

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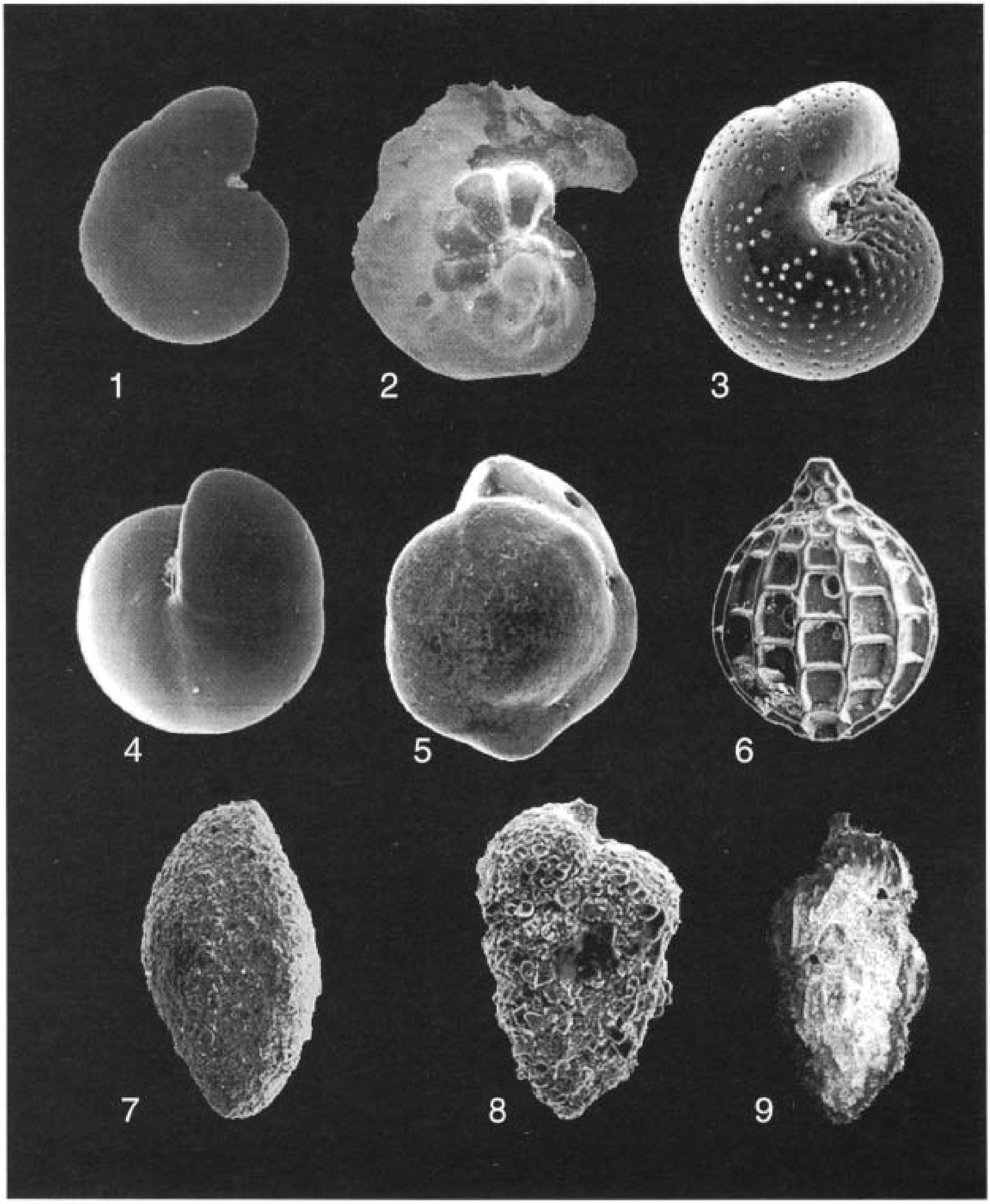

Plate 1. 1. *Gyroidina umbonata* M 23414-5.5, x 114. **2.** *Laticarinina pauperata* M 23414-7.5, x 48. **3.** *Melonis pompilioides* M 23414-1.5, x 132. **4.** *Pullenia bulloides* M 23414-17.5, x 128. **5.** *Oridorsalis umbonatus* PS 1906-4.5, x 161. **6.** *Oolina hexagona* PS 1906-0.5, x 154. **7.** *Sigmoilopsis schlumbergeri* M 23414-1.5, x 86. **8** *Siphotextularia rolshauseni* PS 1906-28.5, x 182. **9.** *Uvigerina peregrina* M 23414-3.5, x 74.

Appendix 2. Taxonomy and synonym list

The taxonomy follows micropalaeontological reference slides hosted at the Department of Micropalaeontology of the Institute of Geology, University of Kiel. The following synonym list records also the taxonomic literature used.

Ammobaculites agglutinans **(d'ORBIGNY)**
*1846 *Spirolina agglutinans* n. - d'ORBIGNY, p. 137, Plate 7 (10-12).
1960 *A. agglutinans* pars- BARKER, p. 66, Plate 32 (19-20 and 24-26).
1980 *A. agglutinans* - HAAKE, p. 7, Plate 1 (11).

Anomalina globulosa **CHAPMAN & PARR**
*1937 *A. globulosa* n. - CHAPMAN & PARR, p. 117, Plate 9 (27).
1971 *A. globulosa* - FEYLING-HANSSEN *et al.*, p. 258, Plate 9 (1-3).

Bolivina pseudoplicata **HERON-ALLEN & EARLAND**
*1930 *B. pseudoplicata* n. - HERON-ALLEN & EARLAND, p. 81, Plate 3 (36-40).
1971 *B. pseudoplicata* - FEYLING-HANSSEN *et al.*, p. 243, Plate 7 (16) and 18 (11).

Bolivinita quadrilatera **(SCHWAGER)**
*1866 *Textilaria quadrilatera* - n. SCHWAGER, p. 253.
1964 *B. quadrilatera* - LOEBLICH & TAPPAN, p. C 548, Plate 434 (1-3).

Buccella frigida **(CUSHMAN)**
*1922 *Pulvinulina frigida* n. - CUSHMANN, p. 12.
1971 *B. frigida* - FEYLING-HANSSEN *et al.*, p. 253, Plate 8 (12-14) and 19 (1).

Bulimina marginata **d'ORBIGNY**
*1826 *B. marginata* n. - d'ORBIGNY, Plate 12 (10-12).
1960 *B. marginata* - BARKER, Plate 51 (3-5).
1980 *B. marginata* - LUTZE, p. 41.

Bulimina striata **d'ORBIGNY**
*1826 *B. striata* n. - d'ORBIGNY, p. 269, nr. 2.
1971 *B. striata* - FEYLING-HANSSEN *et al.*, p. 236, Plate 6 (21).

Cassidulina laevigata **d'ORBIGNY**
*1826 *C. laevigata* n. - d'ORBIGNY, p. 282, Plate 15 (4-5).
1981 *C. laevigata* - SEJRUP *et al.*, p. 290, Plate 1 (5). (s. *Cassidulina* sp. group)

Cassidulina neoteretis **SEIDENKRANTZ**
*1995 *C. neoteretis* n. - SEIDENKRANTZ, p.148, pl. 1, figs. 1-6, pl. 2, figs. 1-14. (s. *Cassidulina* sp. group)

Cassidulina reniforme **NØRVANG**
*1945 *C. reniforme* n. - NØRVANG, p. 41, text fig. 6 e-h.
1980 *C. reniforme* - SEJRUP & GUILBAULT, p. 79-85, fig. 2.

Cassidulina teretis **TAPPAN**
*1951 *C. teretis* n. - TAPPAN, p. 7-8, pl. 1, fig. 30.
1988 *C. teretis* - MACKENSEN & HALD, p. 17, Plate 1 (8-15). (s. *Cassidulina* sp. group)

Cibicides fletscheri **GALLOWAY & WISSLER**
*1927 *C. fletscheri* n. - GALLOWAY & WISSLER, p. 49.
1980 *C. fletscheri* - LUTZE, Plate 12 (11).
1992 *C. teretis* - STRUCK, Plate 1 (7).

Cibicides lobatulus **(WALKER & JACOB)**
*1798 *C. lobatulus* n. - WALKER & JACOB, p. 642, Plate 14 (36).
1884 *Truncatulina lobatulus* - BRADY, p. 660, Plate 92 (10).
1952 *C. lobatulus* - PHLEGER, p. 83, Plate 14 (29).

Cibicidoides wuellerstorfi **(SCHWAGER)**
*1866 *Anomalina wuellerstorfi* n. - SCHWAGER, p. 258, Plate 7 (105, 107).
1978 *P. wuellerstorfi* - LOHMANN, p. 26, Plate 2 (1-4).
1979 *Cibicidoides wuellerstorfi* - LUTZE, p. 426, Plate 1 (5 a-b).

Cribrostomoides subglobosum **(SARS)**
*1868 *Lituola subglobosa* n. - SARS, p.248.
1964 *C. subglobosum* - LOEBLICH & TAPPAN, p. C225, Plate 136 (1, 2).
1981 *Alveolophragmium subglobosum* (SARS) - SEJRUP *et al.*, p. 290, Plate 1 (1).

Cyclogyra planorbis **(SCHULTZE)**
*1854 *Cornuspira planorbis* n. - SCHULTZE, p. 40.
1964 *C. planorbis* - LOEBLICH & TAPPAN, p. C 438, Plate 329 (1, 2).

Dentalina baggi **GALLOWAY & WISSLER**
*1927 *D. baggi* n. - GALLOWAY & WISSLER, p. 49, Plate 8 (14-15).
1953 *D. baggi* - LOEBLICH & TAPPAN, p. 54, Plate 9 (10-15).
1971 *D. baggi* - FEYLING-HANSSEN *et al.*, p. 199, Plate 3 (1).

Dentalina cuvieri **(d'ORBIGNY)**
*1826 *Nodosaria cuvieri* n. - d'ORBIGNY, p. 255.
1964 *D. cuvieri* - LOEBLICH & TAPPAN, p. C516, Plate 403 (3).
1989 *D. cuvieri* - NEES, p. 13, Plate 1 (6).

Dentalina frobisherensis **LOEBLICH & TAPPAN**
*1953 *D. frobisherensis* n. - LOEBLICH & TAPPAN, p. 55-56, Plate 10 (1-9).
1971 *D. frobisherensis* - FEYLING-HANSSEN *et al.*, p. 200, Plate 3 (2).

Dentalina pauperata **d'ORBIGNY**
*1846 *D. pauperata* n. - d'ORBIGNY, p. 46, Plate 1 (57-58).
1953 *D. pauperata* - LOEBLICH & TAPPAN, p. 54, Plate 9 (10-15).
1971 *D. pauperata* - FEYLING-HANSSEN *et al.*, p. 199, Plate 3 (1).

Eggerella bradyi **(CUSHMAN)**
*1911 *Verneulina bradyi* n. - CUSHMAN, p. 54, Plate 87.
1964 *E. bradyi* - LOEBLICH & TAPPAN, p. C275, Plate 186 (1).

Epistominella exigua **(BRADY)**
*1884 *Pulvinulia exigua* n. - BRADY, p. 696, Plate 103 (13-14).
1953 *E. exigua* - PHLEGER *et al.*, p. 43, Plate 9 (35-36).
1960 *E. exigua* - BARKER, Plate 103 (14).

Eponides tumidulus **(BRADY)**
*1884 *Truncatulina tumidula* n. - BRADY, p. 666, Plate 95 (8).
1951 *E. tumidulus* - PHLEGER & PARKER, p. 21, Plate 95 (8).
1992 *E. tumidulus* - TIMM, p. 56, Plate 7 (5 a-b).

Fissurina marginata **SEGUENZA**
*1862 *F. marginata* n. - SEGUENZA, p. 66, Plate 2 (27-28).
1981 *F. marginata* - TODD & LOW, p. 26, Plate 76 (73 a-c).

Fursenkoina fusiformis **(WILLIAMSON)**
*1858 *Bulimina pupoides*, var. *fusiformis* n. - WILLIAMSON, p. 63, Plate 5 (129-130).
1980 *F. fusiformis* - HAAKE, p. 14, Plate 3 (13-14).

Globocassidulina subglobosa **(BRADY)**
*1881 *Cassidulina subglobosa* n. - BRADY, p. 60.
1960 *C. subglobosa* - BARKER, Plate 54 (17).
1992 *G. subglobosa* - SCHIEBEL, p. 47, Plate 2 (14).

Gyroidina umbonata **(SILVESTRI)**
*1898 *Rotalia soldanii* d'ORBIGNY var. *umbonata* n. - SILVESTRI, p. 329, Plate 6 (14).
1958 *G.umbonata* - PARKER, p. 266, Plate 3 (19-20).
1975 *G.umbonata* - SEILER, p. 90, Plate 2 (27-28).

Laticarinina pauperata **(PARKER & JONES)**
*1865 *Pulvinulina repanda* var. *menardii* d'ORBIGNY subvar. *pauperata* n. - PARKER & JONES, p. 395, Plate 16 (50-51).
1953 *L. pauperata* - PHLEGER *et al.*, p. 49, Plate 11 (5-6).
1992 *L. pauperata* - TIMM, p. 58, Plate 7 (13).

Lenticulina gibba **(d'ORBIGNY)**
*1839 *Cristellaria gibba* n. - d'ORBIGNY, p. 40, Plate 7 (20-21).
1960 *L. gibba* - BARKER, p. 144, Plate 69 (8-9).

Marginulina glabra **d'ORBIGNY**
*1826 *M. glabra* n. - d'ORBIGNY, 259, fig. 55.
1923 *M. glabra* - CUSHMAN, p. 127, Plate 36 (5-6).
1992 *M. glabra* - STRUCK, p. 17, Plate 4 (7).

***Melonis barleeanum* (WILLIAMSON)**
*1858 *Nonionina barleeana* n. - WILLIAMSON, p. 32, Plate 3 (68-69).
1981 *N. barleeanum* - SEJRUP *et al.*, p. 293, Plate 1 (12).
1987 *M. barleeanum* - JORISSEN, p. 42, Plate 4 (8).

***Melonis pompilioides* (FICHTEL & MOLL)**
*1798 *Nautilus pompilioides* n. - FICHTEL & MOLL, p. 31.
1979 *M. pompilioides* - LUTZE, p. 428, Plate 2 (1 a-b).

***Nodosaria subsoluta* CUSHMAN**
*1923 *N. subsoluta* n. - CUSHMAN, p. 74, Plate 13 (1).

***Nonionellina labradorica* (DAWSON)**
*1879 *Nonionina labradorica* n. - DAWSON, ELLIS & MESSINA 1940, p. 14167.
1953 *N. labradorica* - LOEBLICH & TAPPAN, p. 86, Plate 17 (1-2).
1981 *N. labradorica* - SEJRUP *et al.*, p. 293, Plate 2 (5-6).

***Nonionella auricula* HERON-ALLEN & EARLAND**
*1930 *N. auricula* n. - HERON-ALLEN & EARLAND, p. 192, Plate 5 (68-70).
1971 *N. auricula* - FEYLING-HANSSEN *et al.*, p. 265, Plate 10 (7-9).

***Oolina hexagona* (WILLIAMSON)**
*1858 *Entosolenia squamosa (MONTAGU)*, var. *hexagona* n. - WILLIAMSON, p. 20, Plate 2 (23).
1953 *O. hexagona* - LOEBLICH & TAPPAN, p. 69, Plate 14 (1-2).
1971 *O. hexagona* - FEYLING-HANSSEN *et al.*, p. 224, Plate 17 (6).

***Oridorsalis umbonatus* (REUSS)**
*1851 *Rotalina umbonata* n. - REUSS, p. 275, Plate 5 (35).
1981 *O. umbonatus* - SEIJRUP *et al.*, p. 293, Plate 2 (2-3).

***Osangularia culter* (PARKER & JONES)**
*1865 *Planorbulina farcta* var. *ungeriana* (d'ORBIGNY) *culter* n. subvar. - PARKER & JONES, p. 421, Plate 19 (1).
1975 *O. culter* - LEROY & HODGKINSON, p. 436, Plate 9 (18).
1982 *O. culter* - LARSEN, p. 72, Plate 25 (1-2).

***Parafissurina groenlandica* STSCHEDRINA**
*1946 *P. groenlandica* n. - STSCHEDRINA, p. 144, 147, Plate 4 (19).
1977 *P. groenlandica* - LAGOE, p. 125, Plate 3 (17).
1980 *P. groenlandica* - TODD & LOW, p. 24, Plate 2 (6 a-b).

***Patellina corrugata* WILLIAMSON**
*1858 *P. corrugata* n. - WILLIAMSON, p. 46, Plate 3 (86-89).
1953 *P. corrugata* - LOEBLICH & TAPPAN, p. 114, Plate 21 (4, 5).
1988 *P. corrugata* - LOEBLICH & TAPPAN, p. 306, Plate 320 (7-14).

***Pullenia bulloides* (d'ORBIGNY)**
*1826 *Noninina sphaeroides* n. - d'ORBIGNY, p. 293, fig. 1, 43.
1971 *P. bulloides* - FEYLING-HANSSEN *et al.*, p. 266, Plate 10 (13-14).
1981 *P. bulloides* - SEJRUP *et al.*, p. 293, Plate 2 (8).

***Pullenia quinqueloba* (REUSS)**
*1851 *Nonionina quinqueloba* n. - REUSS, p. 71, Plate 5 (31 a-b).
1964 *P. quinqueloba* - PHLEGER, p. 383, Plate 3 (23).
1989 *P. quinqueloba* - OKI, p. 149, Plate 7 (a-c).

***Pyrgo rotalaria* LOEBLICH & TAPPAN**
*1953 *P. rotalaria* n. - LOEBLICH & TAPPAN, p. 47-48, Plate 6 (5-6).
1980 *P. rotalaria* - TODD & LOW, p. 24, Plate 2 (20).
1991 *P. rotalaria* - THIES, p. 27, Plate 14 (4 a-c) and 15 (1-21).

***Quinqueloculina pygmaea* REUSS**
*1851 *Q. pygmaea* n. - REUSS, p. 53.
1974 *Q. pygmaea* - LUCZKOWSKA, p. 60, Plate 27 (2).

***Quinqueloculina seminula* (LINNÉ)**
*1758 *Serpula seminulum* n. - LINNÉ, p. 786, Plate 2 (1).
1962 *Q. seminula* - HAAKE, p. 31, Plate 1 (13-14).
1971 *Q. seminulum* - FEYLING-HANSSEN *et al.*, p. 194, Plate 1 (18-20).

***Rupertina stabilis* WALLICH**
*1877 *R. stabilis* n. - WALLICH, p. 502.
1953 *R. stabilis* - PHLEGER et al, p. 50, Plate 11 (19).
1988 *R. stabilis* - LUTZE & ALTENBACH, p. 31-46, fig. 3-5.

***Sigmoilopsis schlumbergeri* (SILVESTRI)**
*1904 *Sigmoilina schlumbergeri* n. - SILVESTRI, p. 267.
1960 *S. schlumbergeri* - BARKER, p. 16, Plate 8 (1-4).

***Siphotextularia rolshauseni* PHLEGER & PARKER**
*1951 *S. rolshauseni* n. - PHLEGER & PARKER, p. 4, Plate 1 (23-24).
1992 *S. rolshauseni* - STRUCK, p. 21, Plate 2 (5-7).
1994 *S. rolshauseni* - NEES & STRUCK, p. 238, Plate 1.

***Stetsonia horvathi* (GREEN)**
*1960 *S. horvathi* n. - GREEN, p. 72, Plate 1 (6).
1989 *S. horvathi* - NEES, p. 12, Plate 3 (4).
1991 *S. arctica* - SCOTT & VILKS, p. 35, Plate 3 (5-14).

***Trifarina angulosa* (WILLIAMSON)**
1971 *T. angulosa* n. - MURRAY, p. 123, Plate 51.
1981 *T. angulosa* - SEJRUP *et al.*, p. 293, Plate 2 (10).
1992 *T. angulosa* - STRUCK, p. 21, Plate 5 (2).

***Triloculina trihedra* LOEBLICH & TAPPAN**
*1953 *T. trihedra* n. - LOEBLICH & TAPPAN, p. 45, Plate 4 (10).
1960 *T. tricarinata* - BARKER, p. 6, Plate 3 (17 a-b).
1964 *T. tricarinata* - FEYLING-HANSSEN, p. 258, Plate 6 (7-8).

***Uvigerina peregrina* CUSHMAN**
*1923 *U. peregrina* n. - CUSHMAN, p. 166, Plate 42 (7-10).
1947 *U. peregrina* - HÖGLUND, p. 279, Plate 23 (9), text Fig. 291-304.
1971 *U. peregrina* - FEYLING-HANSSEN *et al.*, p. 241, Plate 7 (9-11).

Faunal groups (s. main body of text):

Cassidulina sp. group
Elphidium sp. group
Lagenida sp. group
agglutinated tubes group

Appendix 3.1. Count data, fraction 125 - 2,000 µm, Core PS 1906 (specimens/gram dry sediment).

depth (cm)	age (y BP)	dry wt. (g)	A. aggl.	agg. grp.	B. frig.	B. stri.	C. flet.	C. loba.	C. plan.	C. reni.	C. subg.	C. wuel.	Cas. grp.	E. tumi.	Elp. grp.	F. fusi.
0.5	700	47.66	0.00	0.34	5.37	0.00	65.80	59.09	0.00	5.37	13.09	421.32	118.17	21.49	10.74	0.00
1.5	2,100	33.90	11.33	3.78	3.78	0.00	64.90	98.17	0.00	0.00	8.26	413.69	113.51	7.55	15.10	0.00
2.5	3,500	54.59	4.69	0.29	0.00	0.00	50.41	63.31	2.34	0.00	5.86	327.09	114.89	28.14	11.72	0.00
3.5	4,900	44.62	1.43	0.00	0.00	0.00	27.61	20.08	0.00	0.00	5.20	230.21	44.46	31.56	11.47	0.00
4.5	6,300	46.19	0.00	0.00	2.77	0.00	43.30	11.08	0.00	0.00	5.89	330.11	11.08	11.08	5.54	0.00
5.5	7,700	49.77	0.00	0.00	2.57	0.00	41.15	0.00	0.00	0.00	16.07	453.29	2.57	12.86	0.00	0.00
6.5	7,900	52.68	0.00	0.00	0.00	0.00	41.31	0.00	0.00	0.00	4.86	334.09	4.86	14.58	2.43	0.00
7.5	8,100	44.27	1.45	0.00	0.00	0.00	21.69	0.00	0.00	0.00	10.48	264.56	8.67	14.46	0.00	1.45
8.5	8,300	49.69	0.00	0.32	1.29	0.00	12.24	0.00	0.00	0.00	16.10	175.17	2.58	10.30	0.00	0.00
9.5	8,500	52.33	0.00	0.31	3.67	0.00	6.42	0.00	0.00	0.00	8.87	96.31	4.89	15.90	1.22	1.22
10.5	8,700	49.30	0.00	0.00	0.00	0.00	37.65	2.60	0.00	0.00	5.52	276.84	10.39	9.09	1.30	0.00
11.5	8,900	33.61	0.00	0.00	5.71	0.00	22.85	0.00	0.00	0.00	10.00	215.65	7.62	17.14	0.00	0.00
12.5	9,100	38.58	0.00	0.21	0.00	0.00	13.48	0.83	0.00	0.00	6.84	94.35	13.27	9.95	0.00	0.00
13.5	9,300	46.31	0.00	0.17	0.00	0.00	11.92	0.00	0.00	0.00	4.66	73.94	12.44	15.89	0.00	0.00
14.5	9,618	55.40	1.16	0.94	0.00	0.00	3.54	0.00	0.00	0.00	2.96	19.86	9.82	5.78	0.00	0.00
15.5	9,700	50.01	0.64	0.72	0.00	0.00	1.48	0.00	0.00	0.00	0.76	9.28	9.60	5.12	0.64	0.00
16.5	10,018	45.11	1.42	2.04	0.00	0.00	1.60	0.00	0.00	0.00	1.46	15.34	11.35	8.16	0.00	0.00
17.5	10,335	54.83	0.00	0.84	0.00	0.00	2.74	0.00	0.00	0.00	0.47	21.08	12.55	3.79	0.00	0.00
18.5	10,653	41.98	0.00	0.10	0.00	0.00	0.38	0.38	0.00	0.00	0.38	7.05	6.86	3.91	0.38	0.00
19.5	10,971	48.53	0.00	0.16	0.00	0.00	0.49	0.00	0.00	0.00	0.16	4.20	7.09	2.31	0.00	0.00
20.5	11,288	42.11	0.00	0.71	0.00	0.00	1.00	0.00	0.00	0.00	0.14	3.56	4.61	1.71	0.57	0.00
21.5	11,606	39.69	0.00	0.38	0.00	0.00	0.00	0.10	0.00	0.00	0.05	0.78	1.91	0.50	0.20	0.00
22.5	11,924	50.91	0.00	0.55	0.16	0.16	0.20	0.00	0.00	0.00	0.04	0.75	2.91	0.00	0.31	0.00
23.5	12,241	49.19	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.69	0.00	0.65	0.00
24.5	12,980	48.01	0.00	2.71	0.00	0.00	0.02	0.00	0.00	0.02	0.12	4.77	28.31	1.33	0.10	0.00
25.5	14,140	60.40	0.00	0.00	0.00	4.24	0.00	4.37	0.00	0.00	1.19	33.64	122.78	0.00	4.64	0.00
26.5	15,300	59.37	0.00	0.00	0.00	0.00	0.13	0.13	0.00	0.00	0.27	39.35	157.12	0.00	0.54	0.00
27.5	16,460	35.07	0.00	0.23	1.82	0.00	0.11	3.65	0.00	0.00	0.91	20.64	87.60	5.47	0.00	0.00
28.5	16,818	32.34	0.00	0.49	0.49	0.00	0.12	0.00	0.00	0.00	1.98	2.47	4.95	7.42	0.00	0.00
29.5	17,175	25.80	0.00	2.09	0.00	0.00	0.00	0.00	0.00	0.00	1.55	0.16	1.86	5.58	0.00	0.00
30.5	18,737	60.98	0.00	0.10	0.00	0.00	1.67	0.00	0.00	0.00	0.23	2.62	0.26	0.00	0.00	0.00
31.5	19,094	50.05	0.00	0.96	0.00	0.00	1.04	0.00	0.00	3.52	0.04	1.78	4.48	0.00	0.02	0.00
32.5	19,452	64.57	0.00	0.99	0.00	0.00	0.02	0.00	0.00	1.98	0.00	7.73	40.76	0.00	0.05	0.00
33.5	19,810	71.73	0.00	0.22	1.78	0.00	0.22	1.78	0.00	8.92	0.67	17.29	90.90	0.00	0.00	0.00
34.5	20,168	59.96	0.00	0.53	0.13	0.00	0.40	0.00	0.00	2.13	0.67	28.82	60.71	0.00	0.00	0.00
35.5	20,525	56.95	0.00	3.37	2.25	0.00	4.50	4.50	0.00	2.25	1.40	28.80	80.21	6.74	0.14	0.00
36.5	20,883	66.73	0.00	1.32	0.00	0.00	0.00	1.92	0.00	3.84	2.64	14.99	56.71	13.43	0.00	0.00
37.5	21,241	63.56	0.00	1.76	1.01	0.00	1.01	0.00	0.00	0.00	4.78	3.27	21.15	11.08	0.00	0.00
38.5	21,599	48.71	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	1.31	2.30	5.26	3.28	0.00	0.00
39.5	22,100	38.95	0.00	0.41	0.00	0.00	0.82	0.82	0.00	0.00	0.92	0.62	3.29	2.88	0.00	0.00
40.5	22,314	40.09	0.00	0.45	0.00	0.00	1.20	0.05	0.00	0.40	0.50	1.05	0.85	2.39	0.00	0.00
41.5	22,816	50.30	0.00	0.40	0.00	0.00	0.64	0.00	0.00	0.00	1.67	0.08	0.00	4.45	0.00	0.00
42.5	23,318	35.81	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	1.90	0.00	1.79	3.57	0.00	0.00

depth (cm)	I. subg.	L. gibba	Lag. grp.	M. barl.	N. subs.	O. hexa.	O. umbo.	P. corr.	P. rota.	Q. semi.	S. arct.	S. rols.	T. angu.	T. trih.	total
0.5	21.49	0.00	18.13	11.08	0.00	5.37	107.43	0.00	86.61	26.86	70.16	0.00	0.00	162.15	1,248.51
1.5	41.53	0.00	13.45	0.71	0.00	3.78	143.95	0.00	64.90	0.00	33.98	0.00	0.00	151.27	1,212.98
2.5	58.62	0.00	4.98	2.64	0.00	2.34	110.20	0.00	43.96	0.00	9.38	0.00	0.00	98.48	960.18
3.5	35.86	0.00	5.38	7.53	0.00	1.43	126.40	0.00	18.65	0.00	15.78	0.00	0.00	45.90	638.28
4.5	36.03	0.00	6.58	11.43	0.00	0.00	213.73	0.00	45.03	2.77	13.86	0.00	0.00	55.42	824.07
5.5	41.15	0.00	2.57	2.57	0.00	0.00	205.75	0.00	67.51	0.00	7.72	0.00	0.00	100.30	987.58
6.5	55.88	2.43	5.47	2.43	0.00	2.43	263.02	0.00	34.02	0.00	17.01	0.00	0.00	121.49	928.17
7.5	52.04	0.00	3.98	0.00	0.00	0.00	374.79	1.45	40.12	5.78	5.78	0.00	0.00	170.59	1,006.19
8.5	60.54	0.00	3.54	2.58	0.00	0.00	465.61	0.00	33.81	1.61	7.73	0.00	0.00	151.98	955.69
9.5	56.26	0.00	2.45	1.22	0.00	0.00	376.99	0.00	24.46	1.22	3.67	1.22	0.00	103.96	711.48
10.5	40.24	0.00	2.60	7.79	0.00	0.00	277.48	0.00	28.56	0.00	7.79	0.00	0.00	115.86	845.44
11.5	51.41	0.00	7.14	1.90	0.00	0.00	331.33	0.00	29.04	1.90	15.23	0.00	0.00	176.14	919.25
12.5	38.98	0.00	3.53	0.21	0.00	0.00	378.64	0.00	14.10	0.83	7.47	0.00	0.00	83.77	677.45
13.5	69.79	0.00	2.25	1.38	0.00	0.00	258.61	0.00	5.53	0.00	6.91	0.69	0.00	73.59	540.53
14.5	50.83	0.00	0.58	0.00	0.00	0.00	141.16	0.00	1.08	0.00	4.62	0.58	0.00	32.35	276.39
15.5	55.67	0.64	0.12	0.00	0.00	0.00	127.61	0.00	0.48	0.00	6.40	1.28	0.00	19.28	240.39
16.5	31.92	0.00	1.46	0.75	0.00	0.00	129.37	0.00	2.79	0.00	1.42	0.00	0.00	14.90	224.70
17.5	33.56	0.00	0.33	1.17	0.00	0.00	98.27	0.00	0.47	0.29	2.33	0.00	0.00	9.92	188.15
18.5	19.06	0.00	0.38	0.38	0.00	0.00	37.35	0.00	0.00	0.00	6.10	0.00	0.00	1.91	84.99
19.5	20.77	0.00	0.16	0.49	0.00	0.00	16.73	0.00	0.00	0.00	1.65	0.00	0.00	0.16	54.40
20.5	13.68	0.00	0.38	0.00	0.00	0.00	16.29	0.00	0.05	0.00	0.57	0.19	0.00	0.19	43.70
21.5	2.32	0.10	0.15	0.18	0.00	0.00	7.99	0.00	0.00	0.00	0.71	0.00	0.00	0.10	15.47
22.5	1.41	0.00	0.04	0.31	0.00	0.00	5.58	0.00	0.00	0.00	0.00	0.16	0.00	0.47	13.04
23.5	0.00	0.00	0.02	0.02	0.00	0.00	5.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.17
24.5	2.69	0.00	1.69	1.50	0.00	0.00	106.48	0.00	0.00	0.00	2.67	0.02	0.00	0.02	152.51
25.5	12.85	6.49	3.84	6.23	0.00	0.00	447.81	0.00	2.91	0.00	0.00	2.12	0.00	0.00	655.50
26.5	17.25	4.31	6.06	13.74	0.00	0.00	521.74	0.00	0.67	0.00	0.00	4.31	0.00	0.67	784.10
27.5	14.60	1.82	1.94	1.82	0.00	0.00	285.14	0.00	1.48	0.00	0.00	5.47	0.00	21.90	457.14
28.5	13.85	0.00	4.58	5.44	0.00	0.49	64.69	1.48	0.62	0.49	7.42	25.73	0.00	36.61	182.31
29.5	3.72	0.00	0.00	4.65	0.00	0.00	35.27	1.86	0.93	1.24	2.48	12.40	0.00	22.33	97.75
30.5	3.67	0.00	0.31	0.00	0.00	0.00	18.89	0.00	0.13	0.00	0.00	0.00	0.00	5.51	33.40
31.5	2.56	0.00	0.02	0.00	0.00	0.00	20.84	0.00	0.14	0.02	0.00	0.00	0.00	2.88	38.28
32.5	0.99	0.00	0.29	5.23	0.00	0.00	96.76	0.00	0.05	0.00	0.00	0.06	0.00	1.01	156.96
33.5	2.01	0.00	5.02	4.46	0.00	0.00	237.11	0.00	0.11	0.00	0.11	0.22	0.00	3.79	375.07
34.5	2.27	6.54	5.74	7.61	0.00	0.00	374.78	2.13	1.20	0.00	0.00	4.80	0.00	10.81	510.21
35.5	8.99	2.25	4.92	10.96	0.00	0.00	330.40	2.25	0.98	0.00	0.00	9.55	2.25	51.83	564.28
36.5	21.10	0.00	6.71	10.67	0.00	0.12	280.77	0.00	1.20	0.12	0.00	30.93	0.00	59.70	516.95
37.5	28.19	0.00	5.79	6.29	0.00	0.00	144.24	3.02	0.00	0.00	3.02	41.28	0.00	64.44	349.65
38.5	4.68	0.66	0.00	2.14	0.00	0.00	48.37	0.66	0.25	0.00	0.82	18.39	0.00	19.71	108.31
39.5	2.46	0.00	1.23	2.98	0.00	0.41	62.34	1.23	1.23	0.00	2.88	8.32	0.00	12.32	106.60
40.5	3.59	0.00	0.05	2.39	0.00	0.00	43.15	0.80	1.00	0.05	0.80	15.27	0.00	6.39	82.56
41.5	3.18	0.00	0.08	1.27	0.64	0.00	51.61	0.64	1.35	0.00	1.91	30.62	0.00	14.71	114.99
42.5	5.36	0.00	1.90	4.58	0.00	0.00	49.48	1.79	2.23	0.89	3.69	38.65	0.00	19.66	136.50

Appendix 3.2. Count data, fraction 125 - 2,000 µm, Core M 23256 (specimens/gram dry sediment).

depth (cm)	age (y BP)	dry wt. (g)	*A. aggl.*	*agg. grp.*	*B. stri.*	*C. loba.*	*C. reni.*	*C. subg.*	*C. wuel.*	*Cas. grp.*	*D. paup.*	*E. exig.*	*E. tumi.*	*Elp. grp.*	*F. marg.*	*G. subg*
6	9.106	34,60	0,00	0,00	0,00	0,00	0,00	110,98	312,60	45,78	0,46	0,92	0,00	0,00	0,00	8,32
8	9.260	28,32	0,00	0,00	0,00	0,00	0,00	45,20	246,61	49,72	0,00	1,69	0,00	0,00	0,00	8,47
10	9.415	39,78	0,00	0,00	0,00	0,00	0,00	49,07	259,83	52,29	0,40	0,40	0,00	0,00	0,00	5,23
12	9.569	35,32	0,00	0,23	0,00	0,00	0,00	48,92	254,13	32,62	0,00	1,36	0,00	0,00	0,00	6,34
14	9.723	26,92	0,00	0,00	0,00	0,00	0,00	10,40	240,71	12,78	0,89	0,00	0,00	0,00	0,00	10,70
16	10.060	38,53	0,00	0,00	0,00	0,42	0,00	11,21	178,56	4,15	0,00	0,00	0,00	0,00	0,00	14,12
18	10.580	40,32	0,00	0,20	0,00	0,00	0,00	6,05	33,63	0,99	0,10	0,00	0,00	0,00	0,00	3,77
20	11.100	35,69	0,00	0,00	0,00	0,00	0,00	2,19	15,19	1,79	0,00	0,00	0,00	0,00	0,00	1,34
22	11.620	30,36	0,00	0,00	0,00	0,00	0,53	0,86	8,04	0,26	0,00	0,00	0,00	0,00	0,00	0,00
24	12.140	42,92	0,00	0,00	0,00	0,19	0,00	0,19	2,75	0,37	0,00	0,00	0,00	0,00	0,00	0,00
26	12.534	30,31	0,00	0,00	0,00	0,40	0,13	0,40	2,84	0,26	0,00	0,00	0,00	0,00	0,00	0,00
28	12.803	39,80	0,00	0,00	0,00	0,00	0,00	0,15	1,06	0,10	0,00	0,00	0,00	0,00	0,00	0,00
30	13.071	28,53	0,07	0,00	0,00	0,00	0,14	0,32	2,24	0,21	0,00	0,00	0,00	0,00	0,00	0,00
32	13.340	29,95	0,00	0,00	0,00	0,00	0,13	0,37	1,44	0,07	0,00	0,00	0,00	0,00	0,00	0,07
34	13.609	32,25	0,00	0,00	0,00	0,00	0,12	0,43	1,55	0,12	0,00	0,00	0,12	0,00	0,00	0,00
36	13.877	30,73	0,00	0,00	0,03	0,26	0,00	0,46	2,80	0,00	0,00	0,00	0,00	0,00	0,00	0,26
38	14.146	33,99	0,00	0,00	0,00	0,00	0,00	0,62	1,24	0,12	0,00	0,00	0,00	0,00	0,12	0,00
40	14.414	27,93	0,00	0,00	0,00	0,00	0,00	0,82	1,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00
42	14.683	30,44	0,00	0,03	0,00	0,00	0,00	0,30	1,31	0,13	0,00	0,00	0,00	0,00	0,00	0,00
44	14.952	32,57	0,00	0,00	0,00	0,00	0,00	0,00	0,46	0,00	0,00	0,00	0,00	0,25	0,00	0,00
46	15.220	39,71	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00
48	15.489	27,86	0,00	0,00	0,00	0,00	0,00	0,39	0,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00
50	15.757	19,83	0,00	0,00	0,00	0,81	0,00	0,61	3,43	0,00	0,00	0,00	0,00	0,81	0,00	0,00
52	16.026	37,40	0,00	0,00	0,00	0,00	0,00	0,00	0,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00
54	16.294	31,55	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
56	16.563	23,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,69	0,00	0,00	0,00	0,00	0,00	0,00
58	16.783	13,97	0,00	0,00	0,00	0,00	1,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
60	17.100	35,52	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
62	17.320	44,42	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
64	17.540	25,78	0,00	0,16	0,00	0,00	0,00	0,00	0,00	0,16	0,04	0,00	0,00	0,00	0,00	0,16
66	17.760	29,30	0,00	0,00	0,00	0,27	0,00	0,03	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,14
68	17.980	33,36	0,00	0,00	0,00	0,00	0,00	0,06	0,03	0,33	0,00	0,00	0,00	0,00	0,00	0,96
70	18.200	25,35	0,00	0,00	0,00	0,04	0,00	0,04	0,00	0,16	0,00	0,00	0,00	0,00	0,00	0,79
72	18.325	36,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,44
74	18.450	32,12	0,00	0,00	0,00	0,00	0,00	0,25	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0,25
76	18.574	34,25	0,00	0,00	0,00	0,00	0,00	0,00	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00
78	18.699	31,33	0,00	0,00	0,00	0,00	0,00	0,00	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00
80	18.824	18,92	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,63	0,00	0,00	0,00	0,00	0,00	0,85

Appendix 3.2. *continued*

depth (cm)	*L. gibba*	*Lag. grp.*	*M. barl.*	*N. labr.*	*O. umbo.*	*P. bull.*	*P. groe.*	*P. quin.*	*P. rota.*	*S. arct.*	*S. rols.*	*T. trih.*	*U. pere.*	total
6	0,00	1,85	1,39	0,92	141,50	0,00	0,00	0,00	12,25	0,00	0,00	0,00	0,00	636,99
8	0,12	0,85	2,26	0,56	145,20	0,28	0,56	0,00	10,73	0,00	0,00	0,00	0,00	512,26
10	0,24	2,01	0,40	0,00	92,11	0,00	0,40	0,00	10,46	0,00	0,00	0,00	0,00	472,83
12	0,00	2,27	1,36	1,81	144,96	0,00	0,45	0,00	6,34	0,45	0,00	0,45	0,00	501,70
14	0,00	2,08	1,19	0,00	153,64	0,00	0,00	0,00	4,46	0,30	0,00	0,30	0,00	437,44
16	0,00	0,83	2,08	0,00	184,38	0,00	0,00	0,00	3,53	0,00	0,00	0,00	0,00	399,27
18	0,00	0,40	0,60	0,00	44,84	0,00	0,00	0,00	0,79	0,60	0,00	0,40	0,00	92,36
20	0,00	0,06	0,00	0,00	21,07	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	42,08
22	0,00	0,00	0,00	0,00	6,59	0,00	0,00	0,00	0,26	0,00	0,00	0,00	0,00	16,53
24	0,00	0,00	0,19	0,00	1,68	0,00	0,00	0,00	0,19	0,00	0,00	0,00	0,00	5,55
26	0,00	0,00	0,13	0,00	1,45	0,00	0,00	0,00	0,20	0,13	0,00	0,13	0,00	6,07
28	0,00	0,00	0,00	0,00	1,11	0,00	0,10	0,00	0,18	0,00	0,00	0,00	0,00	2,69
30	0,00	0,04	0,00	0,00	1,19	0,00	0,00	0,00	0,25	0,07	0,00	0,07	0,00	4,59
32	0,00	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,00	2,44
34	0,00	0,00	0,00	0,00	0,12	0,00	0,00	0,00	0,19	0,00	0,00	0,00	0,00	2,67
36	0,00	0,00	0,03	0,00	1,04	0,00	0,00	0,00	0,33	0,00	0,00	0,00	0,00	5,21
38	0,00	0,00	0,00	0,00	1,18	0,00	0,00	0,00	0,21	0,00	0,00	0,00	0,00	3,47
40	0,00	0,00	0,00	0,14	2,72	0,00	0,00	0,00	0,32	0,29	0,00	0,00	0,00	6,19
42	0,00	0,00	0,00	0,00	4,57	0,00	0,00	0,20	0,13	0,26	0,00	0,00	0,00	6,93
44	0,00	0,00	0,00	0,00	0,49	0,00	0,00	0,06	0,00	0,00	0,00	0,00	0,00	1,26
46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,40
48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,04	0,00	0,00	0,00	0,00	0,97
50	0,00	0,00	0,00	0,00	1,61	0,00	0,00	0,00	0,20	0,00	0,00	0,00	0,00	7,46
52	0,00	0,00	0,00	0,00	0,86	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,96
54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
56	0,03	0,00	2,77	0,00	1,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,88
58	0,12	0,00	1,15	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,98
60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
64	0,00	0,00	0,16	0,00	2,83	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,49
66	0,01	0,00	0,38	0,00	1,30	0,00	0,00	0,00	0,00	0,14	0,00	0,00	0,00	2,30
68	0,01	0,12	1,02	0,00	0,03	0,00	0,00	0,00	0,00	0,24	1,23	1,20	0,00	5,23
70	0,00	0,16	0,91	0,00	0,16	0,00	0,00	0,00	0,00	0,04	0,32	0,16	0,00	2,76
72	0,00	0,05	2,36	0,00	1,81	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,67
74	0,00	0,06	1,12	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	2,99
76	0,00	0,06	0,99	0,00	0,47	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,06	1,64
78	0,00	0,00	0,32	0,00	0,83	0,00	0,00	0,00	0,00	0,00	0,00	0,26	0,00	1,53
80	0,00	0,05	0,63	0,00	1,53	0,00	0,00	0,00	0,00	0,85	0,42	0,21	0,00	5,18

Appendix 3.3. Count data, fraction 125 - 2,000 µm, Core M 23068 (specimens/gram dry sediment).

depth	age	dry wt.		*A. glob.*		*B. marg.*		*C. wuel.*		*D. baggi*		*D. frob.*		*E. tumi.*		*F. fusi.*	
(cm)	(y BP)	(g)	*A. aggl.*		agg. grp.		*C. subg.*		*Cas.* grp.		*D. cuvi.*		*D. paup.*		*Elp.* grp.		*F. marg.*
0,5	202	14,97	6,41	1,74	8,55	0,00	105,93	453,38	210,79	0,00	0,00	0,00	0,67	8,55	0,00	2,14	0,00
2,5	1.014	14,49	0,00	0,00	0,00	0,00	75,85	380,43	112,84	0,35	0,00	0,00	1,38	7,73	0,00	4,42	0,00
4,5	1.825	12,27	3,26	0,00	1,30	0,00	67,15	520,90	159,73	0,00	0,00	0,00	3,26	5,87	0,00	0,00	0,00
6,5	2.636	18,24	0,00	0,66	0,88	0,00	53,52	300,71	159,68	0,00	0,00	0,44	0,66	2,19	0,00	0,00	0,00
8,5	3.447	16,38	0,00	0,00	0,12	0,00	54,27	313,35	172,27	0,24	0,00	0,00	0,24	1,40	0,00	0,00	0,00
10,5	4.258	14,82	0,00	7,02	0,00	0,00	79,82	363,70	156,01	0,00	0,00	0,54	0,00	1,42	0,00	0,00	0,00
12,5	5.069	19,55	0,00	2,40	0,00	0,00	45,43	354,31	110,51	0,61	0,00	0,00	0,00	1,74	0,00	0,00	0,00
14,5	5.880	18,33	2,02	3,27	0,00	0,00	47,19	410,37	57,61	0,00	0,00	0,00	0,00	0,65	0,00	0,00	0,00
16,5	6.692	20,11	4,77	5,57	0,00	0,00	39,97	356,98	17.50	0,00	0,00	0,20	0,00	0,00	0,00	0,00	0,00
18,5	7,501	15,92	5,02	3,27	0,00	0,00	34,79	432,73	109,41	0,00	0,00	0,38	1,13	1,32	0,00	0,00	3,01
20,5	7.750	17,44	1,84	3,21	0,46	0,00	32,69	444,39	25,70	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22,5	8.684	16,13	0,00	1,36	0,12	0,00	18,35	187,00	3,72	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23,5	9.139	14,84	0,00	2,97	3,24	0,00	22,92	152,75	2,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24,5	9.604	14,29	0,00	1,12	1,12	0,00	17,08	187,01	0,56	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25,5	9.893	16,23	0.49	2,71	4,07	0,00	18,24	181,38	1,48	0,00	0,12	0,00	0,00	0,00	0,00	0,49	0,00
26,5	10.182	11,20	0,00	0,89	0,54	0,00	15,18	235,74	0,71	0,00	0,00	0,00	0,36	0,00	0,00	0,00	0,00
28,5	10.767	17,65	0,00	0,91	0,11	0,00	14,16	214,24	2,95	0,00	0,00	0,00	0,23	0,45	0,00	0,45	0,00
29,5	11.057	19,33	0,00	0,62	0,41	0,00	21,11	212,16	2,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
30,5	11.499	19,53	0,00	3,07	0,31	0,00	21,92	233,51	3,07	0,00	0,00	0,00	0,20	0,00	0,00	0,00	0,00
32,5	12,384	20,50	0,00	0,68	0,39	0,00	8,78	95,32	0,00	0,00	0,00	0,00	0,20	0,00	0,00	0,00	0,00
34,5	13.269	16,35	0,00	1,28	0,00	0,00	14,31	113,33	0,98	0,00	0,00	0,31	0,49	0.00	0,00	0,00	0,00
36,5	14.154	18,90	0,00	0,21	0,00	0,00	4,71	34,76	0,00	0,00	0,00	0.00	0,00	0,00	0,00	0,00	0,00
38,5	14.371	29,12	0,00	0,00	0,00	0,00	1,30	12,46	0,55	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
39,8	14.506	30,00	0,00	0,00	0,00	0,27	10,87	102,67	0,00	0,00	0,00	0,00	0,07	0,00	1,07	0,00	0.13
42,5	14.804	31,47	0,00	0,00	0,06	0,51	3,91	39,85	0,00	0,00	0,00	0,51	0,00	0,00	0,13	0,00	0,06
44,5	15.021	32,36	0.00	0,00	0,09	0,59	0,80	7,14	0,00	0,00	0,00	0,25	0,06	0,00	0,15	0,00	0,12
46,5	15.238	32,64	0,49	0,00	0,18	0,98	3,62	26,59	0,49	0,00	0,00	0,06	0,00	0,00	0,92	0,00	0.12
48,5	15.455	33,62	0,00	0,00	1,73	0,54	0,54	7,97	0,06	0,00	0,12	0,06	0,00	0,00	0,06	0,00	0,06
50,5	16.536	35,38	0,00	0,00	0,51	0,23	0,62	0,93	2,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
52,5	16.836	39,20	0.20	0,00	0,94	0,51	0,59	0,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
54,5	17.269	40,79	0,83	0,00	0,96	0,12	0,91	1,40	0,00	0,00	0,00	0,00	0,02	0,78	0,05	0,00	0,12
56,5	17.703	39,50	0,20	0,00	0,30	0,03	0,00	0,10	0,20	0,00	0,00	0,00	0,00	0,61	0,20	0,00	0,00
58,5	18.181	33,71	0,03	0,00	0,50	0,24	0,68	0,27	0,24	0,00	0,00	0,00	0,00	0,95	0,00	0,00	0,06
60,5	18.370	38,78	0,00	0,00	0,31	0,00	0,41	0,31	0,03	0,00	0,00	0,00	0,00	0,41	0,05	0,00	0,15

Appendix 3.3. *continued*

depth	*G. subg.*		*L. gibba*		*M. barl.*		*N. labr.*		*P. groe.*		*Q. pygm.*		*S. arct.*		*S. schl.*		total
(cm)		*G. umbo.*		*Lag.* grp.		*M. glab.*		*O. umbo.*		*P. rota.*		*Q. semi.*		*S. rols.*		*T. trih.*	
0,5	53,83	0,00	0,00	15,90	0,00	0,00	4,27	190,22	0,00	51,56	2,14	0,00	29,92	0,00	0,00	101,52	1.247,53
2,5	25,54	0,00	0,00	15,46	0,00	0,00	3,31	135,83	0,00	23,74	0,00	0,00	4,42	0,00	0,00	13,18	804,47
4,5	16,95	0,00	0,00	9,78	0,00	0,00	2,61	59,98	0,00	24,77	0,00	0,00	2,61	0,00	0,00	9,13	887,30
6,5	24,46	0,00	0,00	7,68	0,00	0,44	5,70	47,38	0,00	8,99	0,88	0,00	5,70	0,00	0,00	4,83	624,77
8,5	62,51	0,00	0,00	9,16	0,00	0,00	7,39	59,70	0,00	13,74	1,71	0,00	6,04	0,00	0,00	9,40	711,56
10,5	78,61	0,00	0,00	7,42	0,00	0,00	5,87	124,56	0,00	19,84	0,61	0,00	6,64	0,00	0,00	6,61	860,66
12,5	48,81	0,00	0,00	4,50	0,00	0,00	2,61	154,72	0,00	13,10	0,20	0,00	3,27	0,00	0,00	2,66	744,90
14,5	51,66	0,00	0,00	4,20	0,22	0,00	1,69	180,52	0,00	11,13	0,05	0,00	3,27	0,00	0,00	1,53	775,40
16,5	53,30	0,00	0,00	3,23	0,15	0,00	0,65	185,35	0,00	6,96	0,15	0,00	1,59	0,00	0,00	0,80	677.17
18,5	37,56	0,00	0,00	2,07	0,00	0,00	0,00	152,74	0,00	8,10	0,00	0,00	12,06	0,00	0,00	1,00	804,61
20,5	47,83	0,00	0,00	1,09	0,69	0,00	0,46	131,23	0,00	6,77	0,00	0,00	21,11	0,00	0,00	0,00	717,46
22,5	32,24	0,00	0,00	0,74	0,56	0,00	0,00	93,50	0,00	3,10	0,00	0,00	0,99	0,00	0,00	0,00	341,70
23,5	41,12	0,00	0,00	2,43	2,16	0,00	0,00	106,24	0,00	4,85	0,00	0,00	0,00	0,00	0,00	0,00	340,82
24,5	29,12	0,00	0,00	0,00	1,96	0,00	0,00	87,63	0,00	2,38	0,00	0,00	4,48	0,00	0,00	0,00	332,45
25,5	46,21	0,00	0,00	0,00	4,44	0,00	0,00	126,18	0,00	5,05	0,00	0,00	2,96	0,00	0,00	0,00	393,81
26,5	11,07	0,00	0,00	0,89	3,57	0,00	0,00	86,44	0,00	4,29	0,00	0,00	0,00	0,00	0,00	0,00	359,67
28,5	24,92	0,00	0,00	1,13	3,63	0,00	0,00	85,65	0,00	7,14	0,00	0,00	0,45	0,00	0,00	0,00	356,43
29,5	44,71	0,00	0,00	0,41	1,66	0,00	0,00	123,36	0,00	9,94	0,00	0,00	0,00	0,00	0,00	0,00	416,87
30,5	61,66	0,00	0,00	0,82	5,74	0,00	0,00	136,83	0,00	4,30	0,00	0,00	2,46	0,00	0,00	0,00	473,88
32,5	15,02	0,00	0,00	0,00	1,56	0,00	0,00	73,37	0,00	1,17	0,00	0,00	0,00	0,00	0,00	0,00	196,49
34,5	12,72	0,00	0,00	0,00	0,00	0,00	0,00	40,12	0,00	0,49	0,00	0,00	0,00	0,00	0,00	0,00	184,03
36,5	6,77	0,00	0,00	0,00	0,85	0,00	0,00	11,00	0,00	0,26	0,00	0,00	0,00	0,00	0,00	0,00	58,57
38,5	4,40	0,00	0,00	0,00	0,55	0,00	0,00	6,04	0,00	0,07	0,00	0,00	0,00	0,00	0,00	0,00	25,37
39,8	19,47	1,60	0,00	0,00	0,07	0,00	0,00	49,40	0,00	2,13	0,00	0,00	2,67	0,00	0,00	7,73	198,13
42,5	10,68	0,00	0,51	0,00	1,02	0,00	0,00	19,38	0,00	0,10	0,00	0,00	2,03	0,00	0,00	1,02	79,76
44,5	18,79	0,25	0,00	0,25	0,74	0,00	0,00	17,40	0,00	0,12	0,00	0,00	1,48	0,00	0,00	1,24	49,47
46,5	25,98	0,98	0,06	0,49	0,55	0,00	0,00	42,22	0,00	2,02	0,00	0,00	3,43	0,49	0,00	3,49	113,17
48,5	4,28	0,48	0,06	0,00	0,00	0,00	0,06	7,32	0,00	0,89	0,00	0,00	0,95	0,00	0,48	0,95	26,59
50,5	3,17	0,23	0,00	0,03	0,25	0,00	0,00	7,24	0,00	0,06	0,00	0,00	0,23	0,00	0,06	0,68	16,25
52,5	4,29	0,00	0,00	0,00	0,26	0,00	0,05	5,92	0,00	0,23	0,00	0,00	0,00	0,00	0,10	0,41	14,23
54,5	3,95	0,39	0,00	0,02	0,81	0,00	0,00	11,38	0,00	0,61	0,00	0,02	0,00	0,00	0,49	1,96	24,83
56,5	3,44	0,00	0,20	0,00	0,66	0,00	0,03	3,24	0,00	0,15	0,00	0,00	0,00	0,20	0,00	0,00	9,57
58,5	3,80	0,00	0,00	0,00	0,95	0,00	0,00	6,23	0,24	0,21	0,00	0,00	0,00	0,24	0,00	0,71	15,34
60,5	1,06	0,00	0,23	0,00	0,64	0,00	0,00	6,40	0,00	0,08	0,00	0,00	0,00	0,21	0,05	0,21	10,55

Appendix 3.4. Count data, fraction 125 - 2,000 µm, Core M 23414 (specimens/gram dry sediment).

depth (cm)	age (y BP)	dry wt. (g)	A. aggl.	A. glob.	agg. grp.	B. marg.	B. psdp.	B. quad.	B. stri.	C. flet.	C. loba.	C. reni.	C. subg.	C. wuel.	Cas. grp.	D. baggi	D. cuvi.	D. frob.
1.5	560	46.75	0.00	0.00	2.05	1.37	0.00	4.11	0.00	4.11	0.00	0.00	0.68	37.65	24.64	0.00	0.00	0.00
3.5	1.120	24.31	1.32	0.00	2.63	1.65	0.00	5.27	0.00	2.63	0.00	0.00	6.25	18.43	9.21	0.00	0.00	0.00
5.5	1.680	39.49	1.62	0.00	3.24	0.00	3.24	3.24	0.41	8.10	2.03	0.00	2.03	16.61	13.37	0.00	0.00	0.00
7.5	2.240	41.28	0.39	0.00	0.19	0.78	1.55	2.33	0.00	6.78	0.58	0.00	1.55	9.50	11.05	0.00	0.00	0.78
9.5	2.800	37.81	0.21	0.00	1.06	1.69	0.85	0.00	0.00	4.44	0.63	0.85	1.27	11.21	7.41	0.00	0.00	0.00
11.5	3.360	42.99	0.00	0.00	0.74	0.00	0.74	4.47	0.00	5.95	0.74	0.74	0.74	9.30	10.79	0.74	0.00	0.00
13.5	3.920	32.70	0.00	0.24	0.00	0.98	0.00	1.96	0.24	5.87	1.22	0.00	7.83	13.46	14.68	0.73	0.00	0.24
15.5	4.480	41.83	0.00	0.00	0.38	0.77	0.00	0.77	0.57	12.24	0.19	0.00	2.49	12.05	16.07	0.19	0.00	0.19
17.5	4.900	50.86	0.16	0.00	0.16	1.26	1.89	0.00	0.00	5.66	0.31	0.00	3.15	12.90	16.52	0.79	0.00	0.00
19.5	5.600	54.86	0.00	0.00	0.00	0.58	0.00	0.00	0.00	5.83	0.58	0.58	1.75	11.08	15.75	0.00	0.00	0.00
21.5	6.160	37.00	0.00	0.00	1.73	0.86	0.86	0.00	0.00	8.00	0.22	0.00	0.22	15.35	13.84	0.00	0.00	0.00
23.5	6.720	59.01	0.00	0.00	2.44	0.54	0.00	0.00	0.00	2.44	1.90	0.00	1.63	13.01	8.95	0.00	0.00	0.00
25.5	7.280	51.56	0.00	0.00	0.93	0.62	0.00	1.24	0.00	3.26	0.78	0.00	1.55	9.15	10.24	0.00	0.47	0.00
27.5	7.700	55.62	0.00	0.00	2.16	0.58	0.58	0.00	0.00	1.87	0.29	0.58	1.01	11.36	16.25	0.00	0.00	0.14
29.5	8.400	29.07	0.00	0.00	0.25	0.61	0.00	0.50	0.18	2.45	0.06	0.00	0.41	9.69	10.45	0.06	0.06	0.28
31.5	8.960	26.52	0.00	0.00	1.71	0.06	0.45	0.30	0.11	2.52	0.58	0.39	1.14	11.18	9.23	0.34	0.00	0.11
33.5	9.520	30.59	0.00	0.00	1.54	0.79	0.00	0.00	0.07	1.07	0.58	1.25	1.46	9.73	11.91	0.32	0.11	0.00
35.5	10.320	57.68	0.00	0.00	3.27	1.36	0.00	0.36	0.00	0.84	0.21	4.36	2.20	9.85	11.58	0.00	0.00	0.12
37	11.100	42.13	0.00	0.00	1.52	0.95	0.00	0.00	0.19	0.95	0.95	3.04	1.71	8.92	8.54	0.38	0.00	0.00
39	11.360	45.10	0.00	0.00	1.77	0.89	0.00	0.71	0.00	0.71	0.71	3.19	1.95	7.10	9.93	0.00	0.00	0.35
41	12.400	32.09	0.00	0.00	1.25	0.25	0.00	0.00	0.00	0.50	0.25	2.49	1.25	6.23	9.72	0.00	0.00	0.00
43	12.990	36.97	0.00	0.00	0.54	0.87	0.00	0.00	0.00	2.16	0.00	1.30	0.00	8.66	5.41	0.43	0.00	0.00
45	13.875	43.69	0.00	0.00	0.73	0.18	0.00	1.10	0.00	0.55	0.27	1.10	0.00	6.32	4.49	0.00	0.00	0.00
47	14.318	36.41	0.00	0.00	0.88	0.22	0.00	0.00	0.00	0.44	0.00	0.44	0.44	2.86	4.17	0.22	0.00	0.00
49	14.760	41.01	0.00	0.00	5.27	0.20	0.00	0.00	0.00	0.78	0.78	0.78	0.39	5.56	5.36	0.49	0.00	0.00
51	15.350	43.14	0.00	0.00	5.56	0.74	0.00	0.00	0.00	0.00	0.37	0.74	0.93	3.89	2.97	0.37	0.00	0.00
53	15.940	40.59	0.00	0.00	11.63	0.39	0.00	0.00	0.00	1.18	0.79	0.39	1.18	3.94	2.76	0.39	0.00	0.00
55	16.825	44.68	0.00	0.00	3.76	0.72	0.36	0.00	0.00	0.72	0.00	1.43	0.90	4.83	5.55	1.43	0.00	0.00
57	17.563	34.83	0.00	0.00	2.76	0.23	0.00	0.00	0.00	0.00	1.03	0.46	1.49	2.99	8.50	0.92	0.00	0.00
59	18.300	38.09	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.53	0.32	0.00	0.74	3.78	9.77	0.42	0.00	0.00
61	18.674	38.89	0.00	0.00	3.09	0.00	0.00	0.00	0.00	0.00	1.44	0.00	0.62	4.32	13.37	0.41	0.00	0.00
63	19.047	33.25	0.00	0.00	3.37	0.00	0.00	0.00	0.00	1.44	0.60	0.00	1.20	3.25	13.83	0.00	0.00	0.00
65	19.793	42.05	0.00	0.00	3.52	0.00	0.00	0.00	0.00	0.38	0.48	0.00	0.86	3.71	11.51	0.38	0.00	0.00
67	20.241	35.84	0.00	0.00	3.91	0.00	0.00	0.00	0.00	0.45	0.56	0.00	0.89	4.69	17.75	0.00	0.00	0.00
69	20.689	33.02	0.00	0.00	3.39	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.48	4.72	18.90	0.00	0.00	0.00

Appendix 3.4. *continued*

depth (cm)	D. paup.	E. brad.	E. exig.	E. tumi.	Elp. grp.	F. fusi.	F. marg.	G. subg.	G. umbo.	L. gibba	L. paup.	Lag. grp.	M. barl.	M. glab.	M. pomp.	N. auri.	N. labr.
1,5	0,00	6,16	2,05	1,37	0,00	0,00	6,84	1,37	6,16	2,74	0,00	4,11	3,42	0,68	4,11	1,37	1,37
3,5	0,00	1,32	1,32	0,00	0,00	0,00	7,90	1,32	7,90	0,00	0,00	3,62	2,63	0,00	2,63	0,00	0,00
5,5	0,41	3,65	1,62	0,00	0,00	0,00	0,00	3,24	16,21	0,00	0,00	3,24	10,53	0,00	2,43	3,24	0,00
7,5	0,00	0,97	1,55	0,00	0,00	0,00	5,43	1,55	2,91	0,00	1,16	1,16	3,68	0,00	2,71	0,78	0,00
9,5	0,00	1,27	0,00	0,21	0,00	1,69	0,85	0,85	3,81	0,00	0,85	2,75	1,48	0,00	1,06	0,00	0,00
11,5	0,00	1,86	2,98	1,49	0,00	0,00	1,49	2,23	4,09	0,00	0,00	2,23	1,49	0,00	0,00	0,00	0,74
13,5	0,00	2,69	5,87	0,00	0,00	0,98	2,94	3,18	3,43	0,00	0,24	7,09	7,58	0,00	0,49	0,00	0,98
15,5	0,00	4,21	5,36	0,00	0,00	0,00	0,77	0,19	0,38	0,77	0,19	0,96	2,49	0,77	1,53	2,30	0,00
17,5	0,00	3,78	9,44	0,00	0,00	0,00	1,89	0,63	3,78	0,63	0,16	3,15	3,78	0,00	1,89	1,26	0,63
19,5	0,00	4,08	6,42	0,00	0,00	0,58	2,33	0,58	4,08	0,58	0,00	2,04	4,96	0,00	1,46	0,58	0,00
21,5	0,00	7,14	6,92	0,00	0,00	0,86	3,46	0,86	2,16	0,00	0,00	1,73	2,16	0,43	1,08	0,86	0,00
23,5	0,00	0,81	4,34	0,00	0,00	0,54	2,17	1,63	0,81	0,00	0,00	2,71	2,71	0,00	2,98	1,08	2,17
25,5	0,00	4,50	3,72	0,00	0,00	0,62	1,86	0,62	0,31	0,00	0,16	1,24	4,50	0,00	0,16	1,24	0,00
27,5	0,00	2,88	4,60	0,58	0,00	0,58	2,88	0,00	1,87	0,00	0,00	1,01	4,17	0,00	0,00	1,15	0,00
29,5	0,00	2,49	3,64	0,61	0,00	0,50	0,44	0,78	1,33	0,44	0,22	1,24	2,56	0,00	1,44	0,00	0,06
31,5	0,00	4,08	4,87	0,00	0,00	0,39	1,79	0,50	2,09	0,39	0,00	2,16	2,65	0,00	0,39	0,70	0,06
33,5	0,00	2,44	3,36	0,26	0,00	0,26	0,47	1,20	2,13	0,00	0,06	4,27	3,59	0,00	0,77	0,00	0,00
35,5	0,00	3,02	6,27	1,19	0,36	1,19	1,32	1,74	0,48	0,00	0,24	2,81	3,00	0,00	0,86	0,00	0,00
37	0,00	1,33	3,80	0,00	0,00	2,28	0,76	0,19	0,19	0,38	0,00	0,95	4,18	0,00	1,14	0,00	0,00
39	0,00	2,13	5,32	0,00	0,00	0,18	1,42	0,89	0,71	0,00	0,00	4,26	3,37	0,00	0,53	0,71	0,18
41	0,00	3,24	7,98	0,00	0,00	1,00	1,00	1,25	0,25	0,50	0,00	4,74	6,73	0,00	0,25	1,00	0,00
43	0,00	0,65	5,63	0,87	0,00	0,54	1,30	0,43	0,11	0,87	0,00	1,51	3,90	0,00	0,11	0,43	0,00
45	0,00	1,10	2,93	0,00	0,00	0,00	2,56	1,10	0,18	0,00	0,00	2,47	2,66	0,00	0,18	0,37	0,00
47	0,00	0,66	0,44	0,44	0,00	0,00	2,20	0,00	0,00	0,00	0,00	1,32	3,52	0,00	0,44	0,00	0,00
49	0,10	1,27	5,66	1,17	0,00	0,00	1,56	0,78	0,59	0,00	0,00	0,78	4,00	0,00	0,39	0,39	0,00
51	0,37	1,11	3,15	1,11	0,00	0,37	0,74	0,00	0,00	0,00	0,00	0,37	3,89	0,00	0,00	0,74	0,00
53	0,00	0,39	4,93	0,39	0,00	0,39	0,39	2,76	0,00	0,39	0,00	0,00	1,77	0,00	0,59	0,00	0,00
55	0,00	0,54	5,19	0,36	0,00	0,00	1,43	1,07	0,00	0,90	0,00	0,72	2,15	0,00	0,00	0,00	0,00
57	0,00	0,00	3,10	1,03	0,00	0,00	1,38	0,46	0,11	0,92	0,00	0,57	3,45	0,00	0,46	0,46	0,00
59	0,00	0,74	0,74	0,42	0,00	0,00	2,52	0,42	0,00	0,42	0,00	1,79	1,37	0,00	0,11	0,00	0,00
61	0,00	0,62	1,85	1,23	0,41	0,41	1,23	0,41	0,82	0,62	0,00	1,23	0,62	0,00	0,21	0,00	0,00
63	0,00	0,24	0,36	0,48	0,00	0,48	0,00	1,68	0,00	0,48	0,00	1,92	2,17	0,00	0,24	0,48	0,00
65	0,00	0,38	0,38	0,76	0,00	0,38	1,52	2,28	0,10	0,38	0,00	0,57	1,81	0,00	0,95	0,00	0,38
67	0,00	0,11	0,45	0,45	0,00	1,34	1,79	1,45	0,00	0,00	0,00	1,90	0,78	0,00	0,45	0,00	0,00
69	0,00	0,36	0,48	0,97	0,00	0,48	0,97	0,97	0,00	0,00	0,00	0,97	0,00	0,00	0,24	0,00	0,00

Appendix 3.4. *continued*

depth (cm)	N. subs.	O. cult.	O. hexa.	O. umbo.	P. bull.	P. groe.	P. quin.	P. rota.	Q. pygm.	Q. semi.	R. stab.	S. rols.	S. schl.	T. trih.	U. pere.	total
1,5	0.00	6,84	0,00	6,84	0,68	0,00	7,53	1,37	0,68	0,68	0,00	0.00	8,21	6,84	0,00	156.06
3,5	0,99	5,27	1,32	2,63	3,95	0,00	6,91	1,65	0,00	0,33	0.00	1,32	5,92	2,63	3.95	112,88
5,5	0.00	1,62	4,86	12,97	1,62	0,00	4,05	2,03	0,00	0.41	0.00	0,00	3,65	0,41	2.03	132,08
7,5	0,00	6,20	0,00	10,85	3,29	0,00	0,39	0,97	0,00	0,00	0,19	0,00	3,68	0,78	3,10	86,82
9,5	0.00	1,69	0,00	7,41	1,48	0,00	0,85	0,63	0,00	0,21	0,00	0,85	1,69	0,00	2.12	61,36
11,5	0,00	0,74	1,49	5,21	1,49	0,00	5,58	0,37	0,00	0,00	0,00	0,00	4,09	0,00	0,00	72,58
13,5	0.00	0,98	0,00	11,01	1,22	1,96	1,22	1,71	0,00	0.73	0,00	0,00	4,16	0,98	0,98	107,89
15,5	0,00	0,77	0,00	8,22	2,68	1,53	2,49	3,25	0.00	0,77	0,00	0,00	2,87	0,77	0,19	89,31
17.5	0,00	1,89	0,00	10,07	4,09	0,00	2,20	2,52	0,00	0,79	0,00	0,63	2,36	0,63	0,63	99.57
19,5	0,00	1,17	0,00	6,42	1,75	0,00	1,46	1,46	0,00	1,46	0,00	0,58	6,12	0,00	0,29	84,58
21,5	0,00	1,73	0,00	6,49	0,00	0,00	2,16	1,95	0,00	0,00	0,00	0,00	2,59	0,86	0,00	84,54
23,5	0,00	1,63	0,00	2,17	1,08	0,00	0,81	1,08	0,00	0,54	0,00	0,54	4,34	1,08	0,00	66,16
25,5	0,00	0,62	0,00	1,40	1,24	0,00	1,24	3,41	0,00	0,78	0,00	0,62	1,40	0,00	0,00	57,87
27,5	0,00	0,58	0,58	2,88	1,73	0,14	1,29	2,88	0,00	0,00	0,00	0,58	3,88	1,15	0,00	70,19
29,5	0,00	0,77	0,22	2,38	0,88	0,00	1,72	1,45	0,00	0,00	0,00	0,00	2,51	0,66	0,63	51.95
31,5	0,00	1,79	0.30	3,60	1,36	0,30	1,71	1,38	0,00	0,09	0,04	0,39	1,80	0,04	0,11	61,12
33,5	0,00	0,89	0,00	4,08	0,63	0,00	1,07	1,48	0,00	0,17	0,00	0,26	2,11	0,89	0,11	59.31
35,5	0,00	2,58	0,00	7,27	1,50	0,00	1,14	2,87	0,00	0,42	0,12	0,00	4,79	0,95	0,24	78.54
37	0.00	0,38	0,00	4,56	0,95	0,00	2,28	1,71	0,00	0,38	0,00	0,38	0,95	0,38	0,00	54.31
39	0,00	2,13	0,00	3,19	1,24	0,00	1,60	1,60	0,00	0,71	0,00	0,00	3,90	0,35	0,00	61.73
41	0,00	0,00	0,00	6,48	1,75	0,75	3,49	0,75	0,50	0,00	0,00	0,50	4,99	1,50	0.50	71,05
43	0,00	1,30	0,00	3,14	0,65	0,00	1,41	0,97	0,43	0,00	0,00	0,43	2,81	0,00	0,00	46,85
45	0,00	0,37	0,00	1,65	1,10	0.09	0,73	0,64	0,00	0,00	0,00	0,73	1,46	0,00	0,00	35,07
47	0,00	0,44	0,00	2,20	2,20	0,22	1,54	0,66	0,00	0,22	0,00	0.00	0,66	0,00	0,00	26.81
49	0,00	0,78	0,39	4,10	1.95	0,00	0,39	1.07	0.00	0,39	0,00	0,39	1.37	0.00	0,00	47,11
51	0,00	0,37	0,00	4,27	1,11	0,00	0,37	2,23	0,00	0,00	0,00	0,00	2,04	0,00	0,00	37,83
53	0,00	0,00	0.39	2,76	2,76	0,00	0,79	0,99	0,00	0,39	0,00	0,39	1,38	0,79	0.00	45,33
55	0,00	0,00	0,00	1,43	5,19	0,00	1,43	0,36	0,00	0,36	0,00	0,36	2,33	0,72	0,00	44.23
57	0,00	0,46	0,46	4,48	4,71	0,00	0,46	0,92	0,00	0,11	0,00	0,00	1,95	0,00	0,00	43,87
59	0,00	1,26	0,00	6,83	1,89	0,00	2,10	0,95	0,00	0,63	0,00	0,00	2,73	0,00	0,00	41,90
61	0,00	0,00	0,00	5,76	3,91	0,41	0,00	0,62	0,00	1,03	0,00	0,00	1,44	0,00	0,00	46,08
63	0,00	1,68	0,00	8,18	2,05	0,60	3,37	0,36	0,00	2,05	0,00	0,00	2,29	0,48	0,12	53,41
65	0,00	0,76	0,00	5,71	0,38	0,00	1,90	1,05	0,00	0,67	0,00	0,76	1,05	0,00	0,00	43,00
67	0,00	0,45	0,00	6,14	2,90	0,00	1,79	0,45	0,00	1,00	0,00	0,45	2,57	0,00	0,00	52,68
69	0,00	0,48	0,12	7,63	2,91	0,00	1,70	1,09	0,00	0,73	0,00	0,00	0,61	0,48	0,12	49,06