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MODERN DISTRIBUTION OF BENTHIC FORAMINIFERA FROM DISKO BUGT, WEST GREENLAND

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ABSTRACT

Benthic foraminifera were investigated from 20 grab samples collected from a large marine embayment, Disko Bugt, along the west Greenland margin. Agglutinated and calcareous foraminifera were found throughout Disko Bugt, with agglutinated species dominating 19 out of the 20 samples. The most common species are *Adercotryma glomerata, Spiroplectammina biformis, Textularia earlandi, Cribrostomoides crassimargo* and *Reophax fusiformis*. Six faunal assemblage zones were identified from cluster analysis and detrended correspondence analysis. The relationship between the foraminifera and environmental variables was investigated using canonical correspondence analysis. From this analysis, bottom water salinity and water depth were identified as the most important environmental variables explaining the foraminiferal assemblages. This result suggests water mass characteristics in Disko Bugt are an important control on the benthic foraminiferal assemblage zones. Where the warm and saline West Greenland Current water mass impinges on the seafloor, the assemblage is dominated by *A. glomerata, T. earlandi, R. fusiformis* and *Reophax pilulifer*. Sites with the cold, lower salinity Polar Water mass at the seafloor are dominated by *S. biformis* and *A. glomerata*, with common *Cuneata arctica* and *C. crassimargo*. In shallow locations with a relatively warm and low salinity surface water mass and coarse sediments the fauna is dominated by *Cibicides lobatulus*. In similar hydrographic locations with fine-grained sediments a mixed faunal assemblage dominated by *Ammoscalaria pseudospiralis* and *Eggerella advena* is found.

INTRODUCTION

Studies of the present day distribution of foraminifera from high latitude continental shelves in recent decades have increased our understanding of these sensitive environments. In particular, such studies have provided contemporary analogues for paleoenvironmental reconstructions, increasing our understanding of the interaction between climate change and high-latitude environments (e.g., Osterman and Nelson, 1989; Bilodeau and others, 1994; Jennings and others, 1996; Polyak and Mikhailov, 1996; Jennings and others, 2002). There have, however, been few studies of foraminifera from the west Greenland margin. Herman and others (1972) investigated foraminifera from southwest Greenland fjord sediments; Feyling-Hanssen and Funder (1990) investigated the foraminiferal fauna from a number of sections near Thule in northwest Greenland; and Elberling and others (2003) used foraminiferal stratigraphy to investigate pollution in a west Greenland fjord. Studies have tended to concentrate on the east Greenland margin (e.g., Jennings and Helgadottir, 1994; Jennings and Weiner, 1996; Madsen and Knudsen, 1994) and the Canadian Arctic and Arctic Ocean (e.g., Vilks, 1969, 1980, 1989; Osterman, 1984; Schafer and Cole, 1986; Schroder-Adams and others, 1990a; Scott and Vilks, 1991; Bilodeau and others, 1994; Wollenburg and Mackensen, 1998a, 1998b). In this paper, foraminiferal, conductivity-temperature-depth profiles (CTD) and sedimentological data are presented from a large marine embayment, Disko Bugt, along the west Greenland margin and the association of faunal assemblages with environmental and sedimentological variables is investigated. Disko Bugt is a particularly interesting location to investigate due to the relatively large proportion of the Greenland ice sheet that drains out through this section of the west coast. Disko Bugt receives the output from Jakobshavn Isbrae, one of the fastest moving ice streams in the world, draining approximately 7% of the Greenland ice sheet (Clarke and Echelmeyer, 1996; Bindschadler, 1984). Disko Bugt is, therefore, one of the most important outlets of meltwater and icebergs from the Greenland Ice Sheet. Deep and shallow water circulation are highly sensitive to such meltwater fluxes. This area is also close to the Labrador Sea, which, along with the Nordic Seas, is the main area of deepwater formation at the present day in the Northern Hemisphere (e.g., Hillaire-Marcel and others, 2001). It is, therefore, important to understand the link between iceberg and meltwater flux from Disko Bugt and the impact on ocean circulation. This study provides baseline data that can be used as a basis for paleoenvironmental reconstruction from core material collected from Disko Bugt.

THE STUDY AREA

Disko Bugt is a large embayment in the west coast of Greenland (Fig. 1). The embayment is relatively shallow, with water depths ranging from 200 m to 400 m, but with a trough up to 990 m deep at its western edge. This deepwater trough, "Egedesminde Dyb" (Fig. 2), extends beyond Disko Bugt towards a major fan system at the edge of the continental shelf (Brett and Zarudzki, 1979). At the last glacial maximum, the Greenland Ice Sheet extended west beyond Disko Bugt some distance across the continental shelf (Funder and Hansen, 1996). Egedesminde Dyb was most likely produced by glacial erosion by the Jakobshavn Icestream during such periods of ice extension (Long and Roberts, 2003). Indeed a series of ridges midway across the continental shelf seaward of the entrance to Disko Bugt have been interpreted as moraines marking ice-limit positions during previous glaciations (Brett and Zarudzki, 1979). Some of the major fjord systems draining the inland ice are also deeper than 600 m; for example, Torssukatak is over 800 m (northern Disko Bugt) and Jakobshavn Isfjord, emptying into central Disko Bugt, is over 1000 m deep in places.

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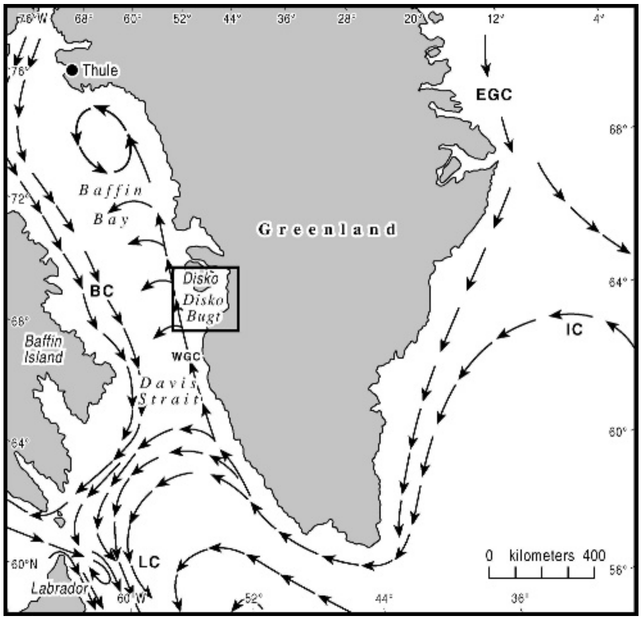

FIGURE 1. Location map showing position of the study area, Disko Bugt, along the west coast of Greenland and the surface current circulation system in the area. EGC – East Greenland Current, IC – Irminger Current, WGC – West Greenland Current, BC – Baffin Current, LC – Labrador Current.

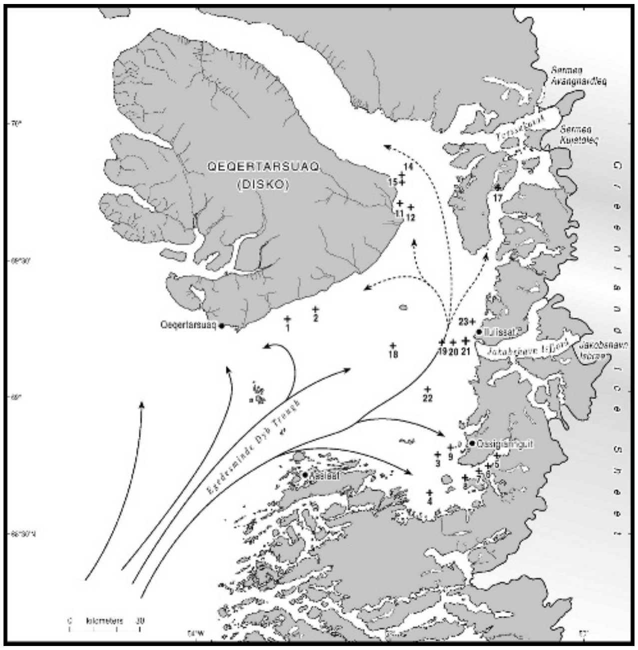

FIGURE 2. Map of Disko Bugt showing the position of the 20 samples collected and analyzed in this study. The arrows show the flow of the WGC into and throughout Disko Bugt: solid arrow indicates WGC flow at the surface and at depth; dashed arrow indicates WGC flowing below meltwater from Jakobshavn Isfjord (adapted from Andersen, 1981).

The northward-flowing West Greenland Current (WGC) dominates the present day surface ocean circulation in this area (Fig. 1). The WGC forms from two distinct currents found off southern and eastern Greenland, the cold and relatively fresh East Greenland Current (EGC), originating from the Arctic Ocean, and the warm relatively saline Irminger Current (IC), an extension of the North Atlantic Current (Andersen, 1981). On rounding Cape Farvel (the southern tip of Greenland), these two currents mix to form the WGC, which then flows through Davis Strait into Baffin Bay. A cyclonic gyre forms in Baffin Bay as the WGC flows north then turns west at several locations and mixes with the cold and relatively fresh water Baffin Current. The Baffin Current enters Baffin Bay from the Arctic Ocean via several narrow straits (Barrow Strait, Smith Sound, Jones Sound and Lancaster Sound; Ingram and Prinsenberg, 1998), flows south along the coast of Baffin Island, and mixes with the WGC and Hudson Strait water to form the Labrador Current south of the Davis Strait. The WGC is not fully mixed on rounding Cape Farvel; a poorly mixed component of the EGC actually flows northwards as a shallow coastal current termed Polar Water by Buch (1993). The IC component flows northwards below and to the west of this Polar Water and is bounded to the west by the relatively cold Baffin Current (BC). The two water masses continue to mix within the WGC on their journey northwards, but can still be distinguished to the southwest of Disko Bugt (Andersen, 1981). Off southern Greenland, the main core of the IC component of the WGC has a temperature of 4–7.3 °C and salinity close to 35 psu; by the time it reaches the latitude of Disko Bugt, due to cooling and mixing with the EGC component, it has a temperature of 2.5–3.5 °C and salinity of 34.5–34.8 psu (Andersen, 1981). The coastal EGC component also receives input of relatively cold and fresh water from the western margins of Greenland and has temperatures ranging from 1–3 °C and salinity of 32–33.7 psu (Andersen, 1981; Buch and Stein, 1989; Buch, 2000). Water circulation and the water masses within Disko Bugt are heavily influenced by the components of the WGC entering the bay from the southwest shown in figure 2 (Andersen, 1981). Due to the relatively shallow nature of the embayment, the colder deeper water within Baffin Bay, the Baffin Bay Deep Water (Osterman and Nelson, 1989), does not penetrate Disko Bugt. Disko Bugt is also influenced by the annual formation of sea ice during December–January and melting by April–May (Andersen, 1981), and significant meltwater flux from coastal glaciers and icebergs. Based on measurements from 1971 to 2000, on average, sea ice forms in Disko Bugt from mid to late December, reaches a southern maximum position of approximately 65 °N by late February, then retreats from Disko Bugt during late April to May (Environment Canada, 2002). The melting of icebergs and sea ice produces a steep halocline and thermocline during summer, with fresher and colder water down to between 150 and 200 m and warmer more-saline deeper water (Andersen, 1981). Autumn storminess and subsequent formation of sea ice break down the halocline and thermocline.

MATERIAL AND METHODS

The samples used in this study were collected during August and September 1999 during a cruise on the Danish research vessel *Porsild*. Grab samples were collected in Disko Bugt using a Van Veen sampler at each of the sample sites shown in figure 2.

Foraminiferal Analysis

The grab samples were sub-sampled for microfossil analysis in the field and stored in a solution of ethanol and Rose Bengal stain. In the laboratory, a standard volume of sediment (10 ml) was sieved at 63 µm, and foraminifera counted from the wet residue fraction coarser than 63 µm (samples were counted wet to reduce any loss, caused by drying, of the more fragile arenaceous species, as advocated by Scott and Vilks, 1991). Foraminifera from high latitude areas have been counted from various size fractions, and there has been some debate about the size fraction most suitable for counting; coarser than 63 µm, 100 µm or 125 µm (Schröder and others, 1987; Jennings and Helgadottir, 1994). In this study, the use of the coarser than 63 µm fraction is advocated for two reasons; firstly to allow comparability with other studies from the Baffin Bay-Canadian Arctic region and northwest Atlantic high latitudes in general (e.g., Williamson and others, 1984; Schafer and Cole, 1986; Vilks and Deonarine, 1988; Schröder-Adams and others, 1990a, 1990b; Scott and Vilks, 1991); secondly for the practical reason that foraminiferal absolute abundances are relatively low in this area. The use of the finer sieve fraction in this study will have an influence on comparison with studies using a coarser fraction, predominantly those from the eastern or "European" Arctic (e.g., Madsen and Knudsen, 1994; Hald and Korsun, 1997; Rytter and others, 2002; Husum and Hald, 2004). The finer fraction used in this study will produce a relatively higher proportion of smaller taxa such as *Cuneata arctica, Textularia earlandi, Spiroplectammina biformis* and *Reophax gracilis*. Whilst direct comparison with studies using a coarser fraction may not be possible, general comparisons between the fauna can still provide useful information and are made in the discussion.

Where possible at least 300 specimens were counted from each sample, although in some samples with low abundances this was not possible (counts of over 100 were made from all samples). Although the samples were stained with rose Bengal to identify living specimens, statistical analysis and discussion of assemblages is based on the total (living plus dead) specimens. This is due to problems identifying live specimens from the samples. It proved difficult to identify whether many of the agglutinated specimens had taken up the stain. Since the fauna in Disko Bugt is dominated by agglutinated specimens, it was decided to use total specimens in analysis. The use of live, dead or total assemblages has been discussed extensively in the literature, and it has been argued that total assemblages are more likely to be comparable to fossil assemblages, and therefore of more use in environmental reconstruction (Scott and Medioli, 1980; Jennings and Helgadottir, 1994; Hald and Korsun, 1997). However, other studies have argued that to provide a full understanding of the relationship between fauna and environmental variables and also possible post-mortem changes in the fauna, the live and dead fauna should be evaluated separately (Murray, 1982; Murray and Alve, 1999; Murray, 2000). Unfortunately, due to the problems mentioned above in this study, only total assemblages could be evaluated.

Environmental Variables

Eight environmental variables were recorded for each site [water depth, bottom water temperature, bottom water salinity, percent of clay, silt and sand, total organic carbon (TOC) and total nitrogen (TN)]. During the cruise, water depth was measured at each site and a CTD hydrographic profile collected using a Seabird Electronics (SeaLogger 25) system. Data collected from the CTD included temperature and salinity. Clay, silt and sand fractions were measured in the laboratory using a Coulter Counter laser granulometer. Total organic carbon was measured using a Thermo Finnigan Total Carbon Analyzer with solids module. Total nitrogen was measured using a Costech Instruments elemental combustion system. For both TOC and TN, samples were freeze-dried and ball-milled to produce a homogeneous sample for analysis.

Data Analysis

Cluster analysis and detrended correpondence analysis (DCA) were used to analyze the benthic foraminiferal assemblage data. Only species that reach an abundance of >2% in at least 1 sample were used in data analysis. Unconstrained incremental sum-of-squares cluster analysis, based on unweighted Euclidean distance, was used to classify the samples into homogeneous clusters (Prentice, 1986; Van Tongeren, 1987). Cluster analysis, which is an effective way of classifying the samples according to the foraminiferal assemblage, was carried out using the TILIA program (Grimm, 1987, 1993).

Detrended correspondence analysis was applied to represent samples as points in a multi-dimensional space, in which similar samples are located together, while dissimilar samples tend to be dispersed. Detrended correspondence analysis provides a means of evaluating the reliability of cluster analysis (Prentice, 1986), and was carried out using the CANOCO program, version 4.51 (Ter Braak, 1988).

The relationship between the 8 environmental variables and the foraminiferal species data was investigated using canonical correspondence analysis (CCA). Canonical correspondence analysis is used to extract synthetic environmental gradients from ecological datasets (Ter Braak, 1986). The independence and relative strength of individual environmental gradients were estimated using a series of partial CCAs (Borcard and others, 1992). The significance of the relationship between species and environmental variables calculated using CCA was tested using a Monte Carlo permutations test to calculate the F-ratio and P-value based on the sum of all canonical eigenvalues. The CCA analyses used the CANOCO program, release 4.51 (Ter Braak, 1988).

RESULTS

The Water Masses of Disko Bugt

The CTD data (Fig. 3) show a relatively consistent pattern throughout Disko Bugt. Three distinct water masses can be identified based on salinity and temperature characteristics that broadly correspond to the water masses identified by Andersen (1981) and Buch and Stein (1989) discussed earlier. These are surface water (temperature 4–8 °C, salinity below 33.4 psu) generally found from 0–50 m, but as deep as 100 m; Polar Water (temperature 1–3 °C, salinity 33–33.9 psu) with varying thickness and position in the water column between 50–280 m depending on location; WGC water (temperature 2.5–4 °C, salinity > 34 psu) found below 200–280 m throughout Disko Bugt. The relative thickness of these water masses is controlled by the location within Disko Bugt. The depth and gradient of the seasonal thermocline between the Polar Water and surface water is variable. The surface water consists of low salinity meltwater from seasonal sea ice, icebergs and glacier melt that is considerably warmer than Polar Water due to heating by solar insolation. More exposed areas (e.g., sites 1, 2 and 18) have a shallow and steep thermocline with a thin surface water layer while the more sheltered locations (e.g., sites 3, 4, 5, 6, 7, 8 and 9) have a substantial transitional zone down to 150 m with gradually decreasing temperature (Fig. 3). Sites close to Jakobshavn Isfjord, presently the major source of icebergs and meltwater into Disko Bugt, have a surface meltwater cap close to 0 °C with a very low salinity, < 30 psu (sites 21 and 23, labeled meltwater, MW, on Fig. 3). The core of the Polar Water below this surface water has a relatively consistent temperature and salinity signature. It represents the poorly mixed remnant of the EGC combined with meltwater from icebergs and glaciers from the western edge of the ice sheet. Stein (1991) and Buch (1993, 2000) identified this shallow (0–200 m) coastal remnant of the EGC flowing northwards at Fylla Bank off southwest Greenland. The WGC water below has a well-constrained temperature and salinity signature. The transition between the WGC and the Polar Water is relatively sharp in the southern sites, close to the point of entry of both water masses flowing into Disko Bugt from the southwest (e.g., sites 3–9). The more northern and exposed locations (e.g., sites 1, 2, 14, 15, 18 and 19) exhibit a gradual transition produced by the two water masses continuing to mix as they circulate around Disko Bugt. Indeed, a temperature-salinity plot of basal conditions at each site (Fig. 4) identifies a transitional water mass, here termed mixed WGC water, formed by the mixing of WGC water with Polar Water.

The contrasts in water mass thickness and characteristics, along with the variable bathymetry of Disko Bugt, have produced sample sites with a range of bottom water temperature and salinity (Fig. 4). For example, sites close to the mouth and to the north of Jakobshavn Isbrae tend to have a thicker Polar Water layer (close to the source of cold and low salinity water and influenced by Coriolis de-

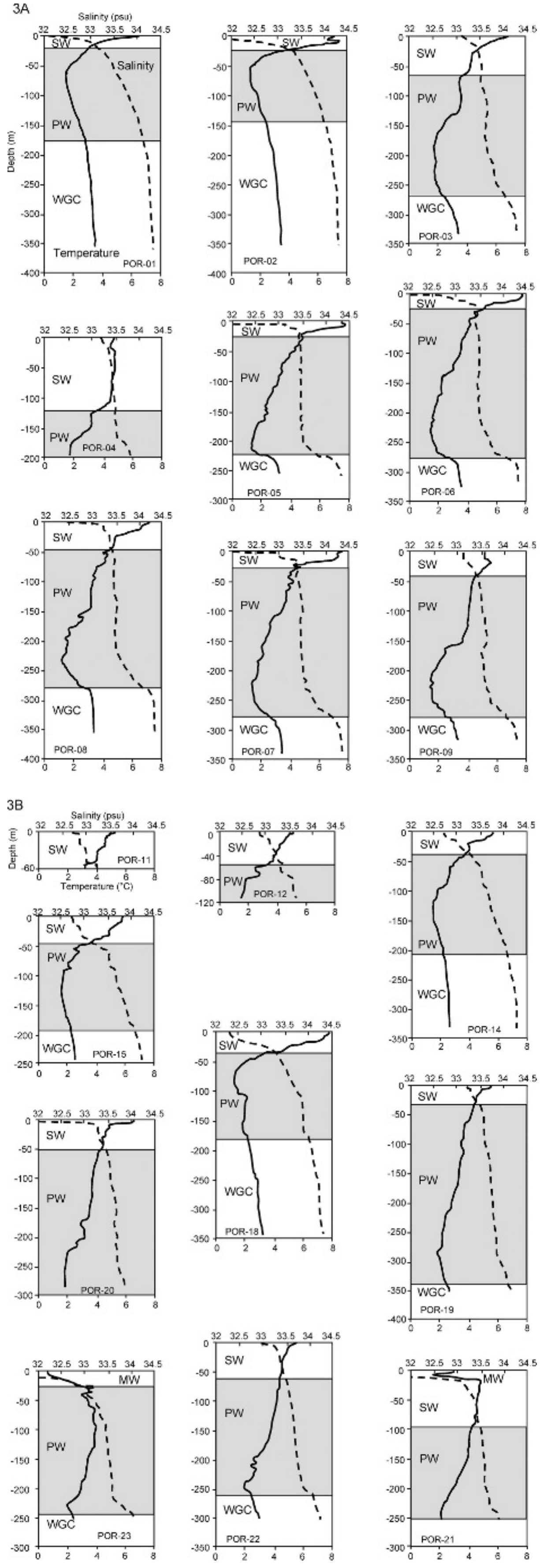

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FIGURE 3. Temperature (solid line) and salinity (dashed line) profiles from CTD data at sample locations in Disko Bugt. There is a clear subdivision between the surface water (relatively warm and low salinity, labeled SW), Polar Water (relatively cold and moderate salinity, shaded section in profiles labeled PW) and the WGC water (relatively warm and high salinity, labeled WGC). The thickness of these water masses varies considerably depending on the location in Disko Bugt. Furthermore, note the clear influence of surface meltwater at sites 21 and 23 close to Jakobshavn Isfjord (labeled MW).

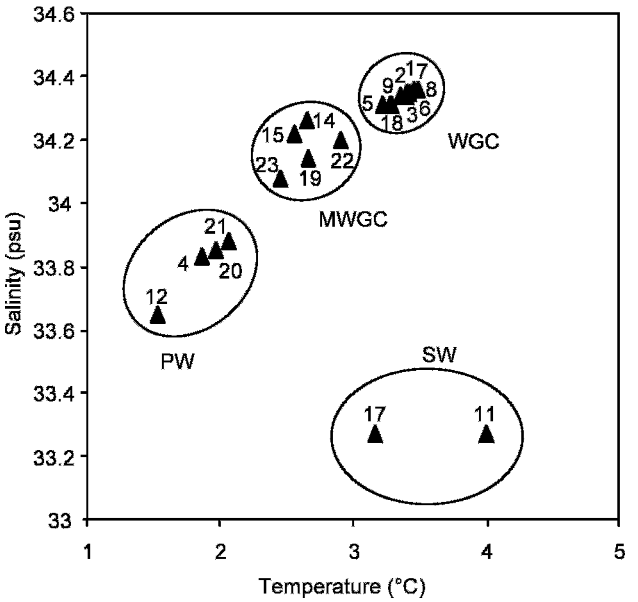

FIGURE 4. Temperature versus salinity biplot of basal-water characteristics from sample locations. The data can be grouped into four water masses that impinge on the seafloor at the sites sampled in Disko Bugt. These water masses are SW – surface water, PW – Polar Water, WGC – West Greenland Current water, MWGC – mixed West Greenland Current water. Samples are labeled.

flection), which impinges directly on the sea floor. The temperature-salinity plot (Fig. 4) illustrates this point – the sample sites can be split into groups based on the basal water mass characteristics. Samples have been collected from the three significant water masses identified from the CTD data along with the additional transitional water mass (mixed WGC water) identified from figure 4.

FORAMINIFERAL ANALYSIS

From the 20 samples studied, a total of 65 species of foraminifera were identified, 29 agglutinated and 36 calcareous species (see Appendix 1 for full faunal list). For statistical analysis, only species with a maximum abundance >2% were included (Fig. 5). The number of species included in statistical analysis was reduced to 30; 17 agglutinated and 13 calcareous species. The absolute abundances of foraminifera are relatively low ranging from 100 to 400 specimens per 10 ml of sediment (Table 1). In general, the assemblages are dominated by agglutinated species (66–100% of the assemblage, Table 1). The only exception is sample 11, which is dominated by calcareous species (76% of the assemblage). The most common agglutinated species include *Adercotryma glomerata*, *Cribrostomoides crassimargo, Reophax fusiformis, S. biformis* and *T. earlandi* (illustrated in Plate 1, figs. a, d, g, j and k, respectively). The most common calcareous species include *Cibicides lobatulus, Melonis barleeanum, Nonionellina labradorica* and *Islandiella helenae* (illustrated in Plate 2, figs. b, i and f). The relatively low abundance of calcareous foraminifera may in part be due to poor preservation. Poor preservation of calcareous tests was noted in most samples, recorded either as organic test linings, or by etched or partly dissolved specimens (see Plate 2, fig. k for an example of a partly dissolved specimen). Dissolution of calcareous fauna is a common problem in high latitude areas, associated with cold CO_2-rich Polar and Arctic waters (e.g., Aksu, 1983; Hald and Steinsund, 1992; Jennings and Helgadottir, 1994). Although low numbers of calcareous foraminifera are found in surface samples throughout Disko Bugt, sufficient numbers for assemblage analysis and radiocarbon dating have been found in Holocene sediments (e.g., Lloyd and others, 2005; Lloyd, 2006).

Faunal Assemblage Zones (FAZs)

Cluster analysis separates the samples into six distinct faunal assemblage zones (FAZs; Fig. 5). Detrended correspondence analysis supports this zonation; samples from the 6 cluster zones identified in figure 5 are grouped together on the DCA plot of sample scores from axis 1 plotted against axis 2 (Fig. 6). Different symbols are used for each FAZ in figure 6. The first two axes of the DCA explain 47.9% of the variance in the species data. The summary information from DCA is shown in Table 2. The spatial distribution of the six assemblage zones is shown in figure 7 and the dominant characteristics of each zone are described below.

FAZ 1: Faunal assemblage zone 1 contains 6 samples and is overwhelmingly dominated by agglutinated species (>85%). This zone is dominated by *S. biformis* (15–45%; Plate 1, fig. j) and *A. glomerata* (20–38%; Plate 1, fig. a). Other common species include *C. crassimargo* (7–21%; Pl. 1, fig. d), *C. arctica* (4–19%; Plate 1, fig. m), *Portatrochammina bipolaris* (1–14%; Plate 1, fig. c) and *Textularia torquata* (0–7%; Plate 1, fig. l). Samples from this zone are found in relatively shallow coastal areas along the eastern margins of Disko Island, immediately west of Jakobshavn Isfjord and in southeastern Disko Bugt (Fig. 7).

FAZ 2: Faunal assemblage zone 2, containing 4 samples, is dominated by agglutinated species but also has significant proportions of calcareous species (15–35%). The most abundant species is *A. glomerata* (18–27%), with the calcareous species *M. barleeanum* (10–15%) being the second most abundant species. Other common species include *P. bipolaris* (4–10%), *Saccammina difflugiformis* (5–7%, Plate 1, fig. i), *R. fusiformis* (3–10%) and variable amounts of *N. labradorica* (0–10%). Samples from this zone are found in towards the center of Disko Bugt (Fig. 7).

FAZ 3: Faunal assemblage zone 3 contains 6 samples and is dominated by agglutinated foraminifera (>80%). It is dominated by *A. glomerata* (16–35%), with *T. earlandi* (8–18%; Plate 1, fig. k), *R. fusiformis* (6–16%), *Reophax pilulifer* (1–10%, Plate 1; fig. h) and *C. crassimargo* (3–13%) also common. The calcareous species *M. barleeanum* and *N. labradorica* are present in low abundances through this zone. Samples from this zone are found in two groups, just south of Disko Island and in coastal and fjord areas in southeast Disko Bugt (Fig. 7).

FAZ 4: Faunal assemblage zone 4 contains 2 samples, and is dominated by agglutinated specimens (85–95%), *T. earlandi* (48–55%) in particular. Other species common in this zone include *I. helenae* (3–7%; Plate 2, fig. f), *R. gracilis*

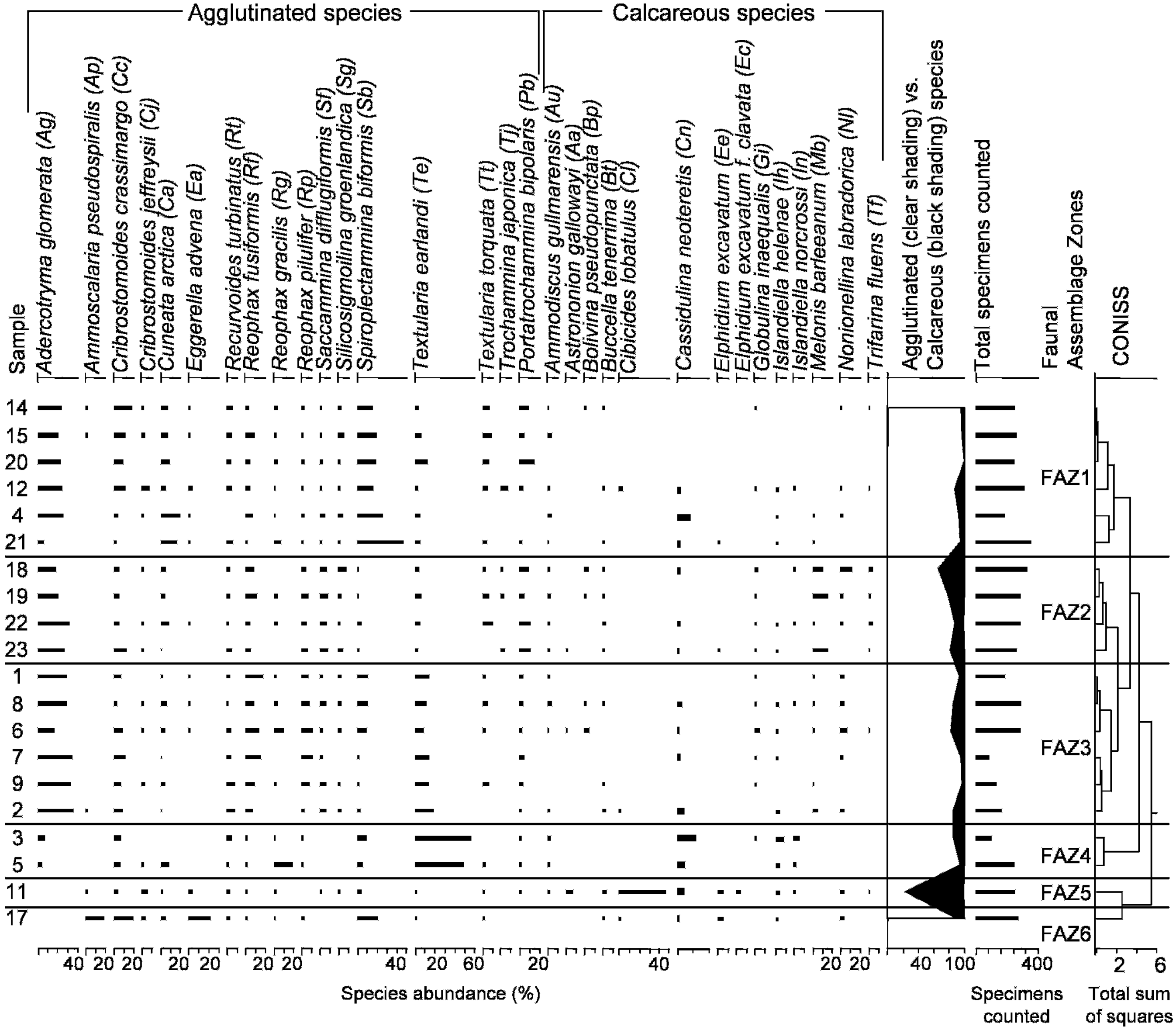

FIGURE 5. Foraminiferal assemblages from the sites in Disko Bugt, only species with an abundance ≥2% are included. The samples have been reordered into the discrete faunal assemblage zones (FAZs) identified from the cluster analysis and DCA.

(1–18%), *S. biformis* (5–8%), and *C. crassimargo* (5–7%). Samples from zone 4 are found in close association with samples from zone 3 in southeastern Disko Bugt (Fig. 7).

FAZ 5: Faunal assemblage zone 5 contains 1 sample (11), and is the only zone that is dominated by calcareous specimens (76%), predominantly *C. lobatulus* (46%; Plate 2, fig. b). This zone has a high diversity of species and contains minor abundances of *Astrononion gallowayi* (6.2%; Plate 2, fig. a) and *Elphidium excavatum* forma *clavata* (3.6%; Plate 2, figs. g, h) amongst many other species. The single sample from this zone comes from a shallow coastal area immediately east of Disko Island (Fig. 7).

FAZ 6: Faunal assemblage zone 6 also contains only 1 sample (17) and is dominated by agglutinated species (80%). There are 4 co-dominant species in this zone; *Ammoscalaria pseudospiralis* (17.5%; Plate 1, fig. b), *C. crassimargo* (19.3%), *Eggerella advena* (21.4%; Plate 1, fig. e) and *S. biformis* (19.6%). The single sample from this zone comes from a shallow basin on the eastern margins of an island in northeastern Disko Bugt (Fig. 7).

RELATIONSHIP BETWEEN FAUNA AND ENVIRONMENTAL VARIABLES

The environmental variables measured for each sample are presented in Table 3. Canonical correspondence analysis was used to investigate the relationship between the environmental variables and the ecological data. The results of the CCA are summarized in Table 4. The sum of all eigenvalues is the sum of the length of the maximized spread of species along hypothetical environmental gradients. The sum of all canonical eigenvalues is the sum of the maximized spread along environmental gradients, which is a linear combination of the measured environmental

TABLE 1. Relative abundance (%) of foraminifera in samples studied. Only species with an abundance ≥ 1% included.

Sample	1	2	3	4	5	6	7	8	9	11	12	14	15	17	18	19	20	21	22	23
Adercotryma glomerata	28.1	37.7	6.7	23.7	3.3	16.2	34.7	27.6	33.5	0	23.9	22.9	19.8	0	18.2	20.2	21.7	5.7	31.4	26.5
Ammoscalaria pseudospiralis	0	1.1	0	0	0	0	0	0	0	0.7	0	1	0.6	17.5	0	0	0	0	0	0
Cribrostomoides crassimargo	9.2	15.3	10.8	3.3	5	9.9	12.9	2.5	7.1	2.9	12.6	20.9	13.3	19.3	3.9	4.8	8.6	1.8	4.3	14.3
Cribrostomoides jeffreysii	0	0	0	0.4	0.3	0.6	0	0.3	1.3	4.2	6.3	0.3	1.5	2.4	0.7	0	0	0	0.9	0.9
Cuneata arctica	1.3	0.5	0	17.8	7.9	3.1	1	5.3	3.9	1.6	4.2	6.9	7.1	4.7	4.2	4	8.2	16	7.2	0.6
Eggerella advena	0.9	0	0	0.4	0	0.3	0	0.3	0	3.3	3.2	0.7	0.9	21.4	0	0	0	0.9	0.3	0
Recurvoides turbinatus	0	0	0.8	0	1.7	0.3	1	0.6	7.7	2	1.6	2.3	1.2	2.1	2.2	2	3	5.3	0.9	1.2
Reophax fusiformis	16.2	0.5	0.8	11.6	1.7	12.2	14.9	7.2	5.2	1.3	3.4	2.6	8.7	1.2	6.9	10	3	1.1	3.2	4
Reophax gracilis	1.3	0	0.8	0.4	18.2	8.2	0	1.9	1.9	1	0.3	2	1.9	0.3	0	2.3	2.6	6.4	2.9	0
Reophax pilulifer	6.1	1.6	0.8	1.2	0.7	9.7	9.9	6.4	7.1	0	0.3	1.3	0.6	1.5	2.5	6	1.3	0.9	3.5	4.4
Saccammina diflugiformis	1.3	4.9	0	3.3	0	1.4	2	4.2	5.2	0.7	0.3	0.7	0.6	0	5.4	7.1	2	0.7	6.1	6.9
Silicosigmoilina groenlandica	1.8	1.6	0	3.3	0	1.4	0	1.1	0.6	0.7	0.3	1.6	4.3	0	6.4	1.7	0.7	0.2	0.9	3.4
Spiroplectammina biformis	9.6	19.7	8.3	7.1	4.6	8.5	2	9.5	14.8	3.3	16.1	15.4	19.2	19.6	0.7	0.3	17.4	45.3	3.2	1.9
Textularia earlandi	13.6	2.7	55	20.7	48.7	8	13.9	10.6	0	0.7	2.4	2.3	5.6	0.6	3.9	6	11.5	4.6	4.3	2.8
Textularia torquata	1.3	0	0	0	1.7	1.4	0	3.3	5.2	0.3	3.9	5.6	7.4	1.2	2.2	4.8	4.9	3	9.2	0
Trochammina japonica	0	0	0	0	0	0	0	0	0	0	5.8	0	0	0	0.2	1.7	0	0	0	3.1
Trochammina nana	2.2	0.5	0.8	0	0.3	1.7	4	3.1	3.2	1	3.2	7.8	3.4	0	7.6	4	13.8	2.1	9.5	10
Ammodiscus gullmarensis	0.9	0.5	1.7	2.5	1	0.3	0	2.5	0	1.3	0.8	0.3	3.1	0	1.2	1.4	0	0.2	1.2	0.6
Astrononion gallowayi	0	0	0	0	0	0.3	0	0	0	6.2	0	0	0	0	0	0	0	0	0	0.3
Bolivina pseudopunctata	0	0	0	0	0	3.7	0	0.6	0	0	0	0.3	0	0	3	1.1	0	0	0	0
Buccella tenerrima	0	0	0	0	0	0	0	0.3	1.3	2.6	1.1	0.7	0	0.3	0.7	0.3	0	0.5	2	0.9
Cassidulina reniforme	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0.2	0	0	0	0	0
Cassidulina neoteretis	0	3.3	10.8	0.8	4	0.3	1	2.2	0	3.6	1.8	0	0	0.3	0.7	0	0	0.7	0.6	0.3
Cibicides lobatulus	0	0.5	0	0	0	0	0	0	0	45.9	3.2	0	0	0.3	0	0	0	0	0	0
Elphidium excavatum	0	0	0	0	0	0	0	0	0	3.6	0	0	0	4.2	0	0	0	0.2	0	0.6
E. excavatum f. *clavata*	0	0	0	0	0	0	0	0	0	2.6	0	0	0	0	0	0	0	0	0	0
Elphidium incertum	0	0	0	0	0	0	0	0	0	1.3	0	0	0	0	0	0	0	0	0	0
Globulina inaequalis	0.4	0	0.8	0	0	3.4	1	0.3	0.6	0	0.8	0.3	0	0	2	0.6	0	0	0.6	0.3
Guttulina sp.	0	0	0	0	0	0	0	0	0	1.3	0	0	0	0	0.2	0	0	0	0	0
Melonis barleeanum	1.8	4.9	0	1.2	0	1.7	0	1.1	0.6	0	0	0	0	0	10.1	14.5	0	1.4	2	14.6
Nonion labradoricum	2.6	2.7	0	2.1	0	5.7	2	2.8	0	3.3	0.3	0.3	0	2.7	10.6	1.4	0	0	1.7	0
Trifarina fluens	0	0	0	0	0	0.3	0	0	0	0.3	0.3	0.3	0	0	3	0.6	0	0	2.9	0.3
Agglutinated species (%)	94.3	86.3	86.7	93.4	95	83	96	86.4	97.4	23.5	87.6	96.4	96.9	91.7	66.7	79.8	100	95.2	87.6	81.9
Calcareous species (%)	5.7	13.7	13.3	6.6	5	17	4	13.6	2.6	76.2	12.4	3.6	3.1	8.3	33.3	20.2	0	4.8	11.8	18.1
Total specimens counted	228	183	120	241	302	352	101	359	155	307	380	306	323	337	406	351	304	437	347	321

variables. By comparing these two values, it is possible to ascertain how well the environmental variables measured explain the data. The environmental variables measured in this study explain 48.5% of the variance in foraminiferal data. A combination of CCA axes 1 and 2 explain 41.1% of the foraminiferal data (eigenvalues 0.524 and 0.216, respectively; Table 4). To determine the individual contribution of each environmental variable in the analysis, a series of partial CCAs were carried out (Borcard and others, 1992; Table 5). The percentage contribution can be calculated by comparing the eigenvalues of the partial CCA to the sum of the eigenvalues from the main CCA. The partial CCAs show that the most significant individual contributions are made by bottom-water salinity and water depth (20.4% and 20% respectively) with all other variables contributing < 10% each. This suggests that water mass characteristics are an important control on faunal distribution measured in this study.

The statistical significance of the relationship between the species and environmental variables identified by the CCA is evaluated using a Monte Carlo permutations test (Ter Braak and Smilauer, 2002). The test statistic (F-ratio) produced by a test of significance of all canonical axes is 1.610 and the P-value is 0.05. This indicates that the results of the CCA are significant at the 5% level.

The environmental, species and sample values generated by CCA for the first 2 axes are plotted in figure 8. The length of the arrows approximates the relative importance of the environmental variables in explaining the data and the direction demonstrates the approximate correlation to the ordination axis, other environmental variables, species and samples. The correlation of environmental variables with axes 1 and 2 (Fig. 8a) indicates that salinity and depth are negatively correlated with axis 1, sand and temperature are positively correlated with axis 1, clay and silt are positively correlated with axis 2 and nitrogen and carbon are negatively correlated with axis 2. On the sample–environment biplot (Fig. 8b), samples plotting to the right tend to be from shallow, low-salinity areas (e.g., samples 11, 17 and 12) while those to the left are from deeper more saline locations. Samples plotting towards the bottom of Fig. 8b are dominated by sandy sediments (e.g., samples 23, 11 and 12) and those towards the top from clay- and silt-dominated sediments (e.g., samples 4, 5, 17 and 21). On the species - environment biplot (Fig. 8a), the position of a species projected perpendicularly onto the environmental arrows approximate their weighted average optima along each environmental variable (Fig. 8a). Species tolerances of particular environmental variables can be identified from this biplot. *Ammoscalaria pseudospiralis, E. advena, E. excavatum, C. lobatulus, E. excavatum* f. *clavata* and *A.*

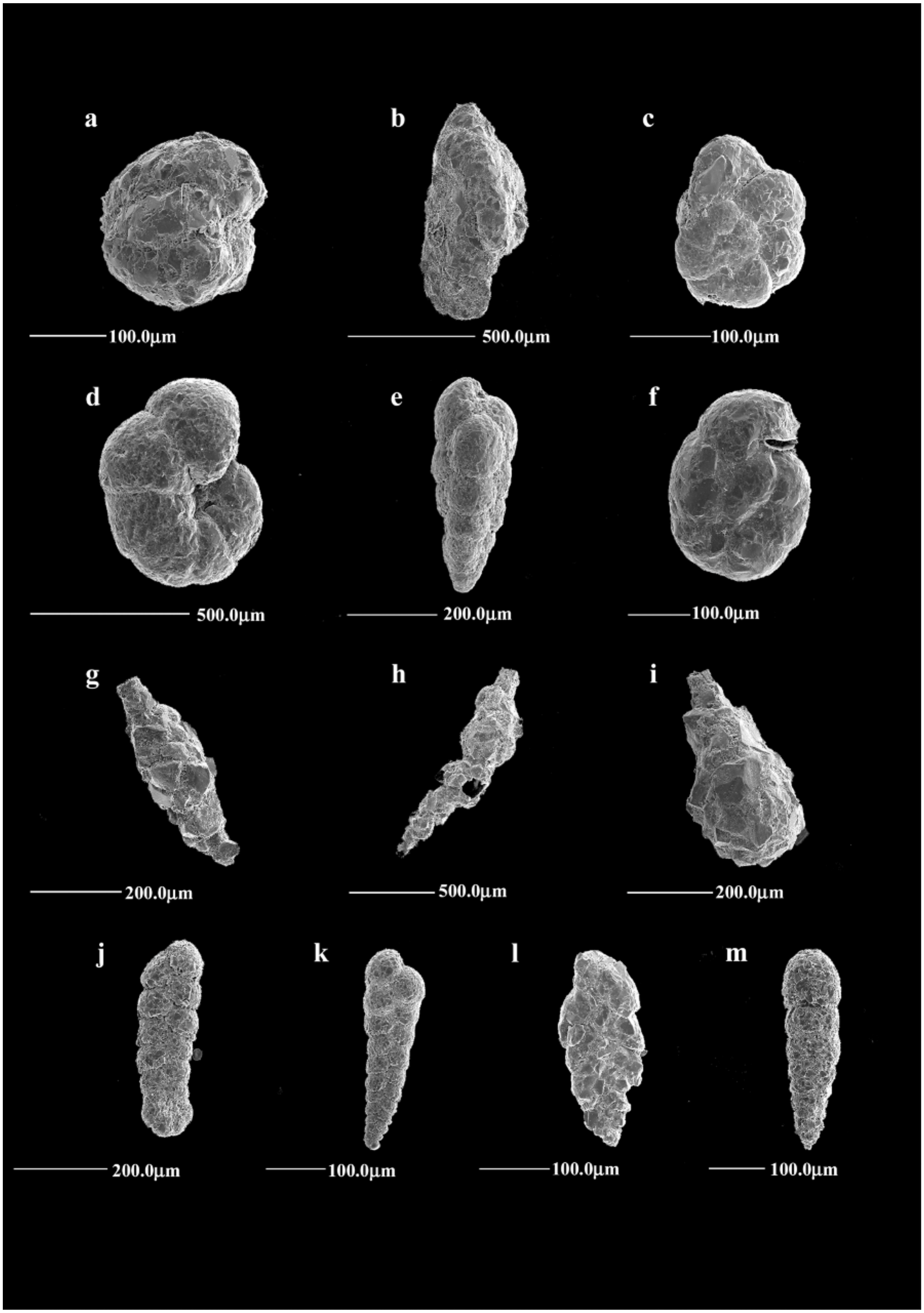

PLATE 1

Selected agglutinated foraminifera from Disko Bugt. Scanning electron microscope photographs. **a** *Adercotryma glomerata* (Brady), **b** *Ammoscalaria pseudospiralis* (Williamson), **c** *Portatrochammina bipolaris* Brady, **d** *Cribrostomoides crassimargo* (Norman), **e** *Eggerella advena* Cushman, **f** *Recurvoides turbinatus* (Brady), **g** *Reophax fusiformis* (Williamson), **h** *Reophax pilulifer* Brady, **i** *Saccammina difflugiformis* (Brady), **j** *Spiroplectammina biformis* (Parker and Jones), **k** *Textularia earlandi* Phleger, **l** *Textularia torquata* Parker, **m** *Cuneata arctica* (Brady).

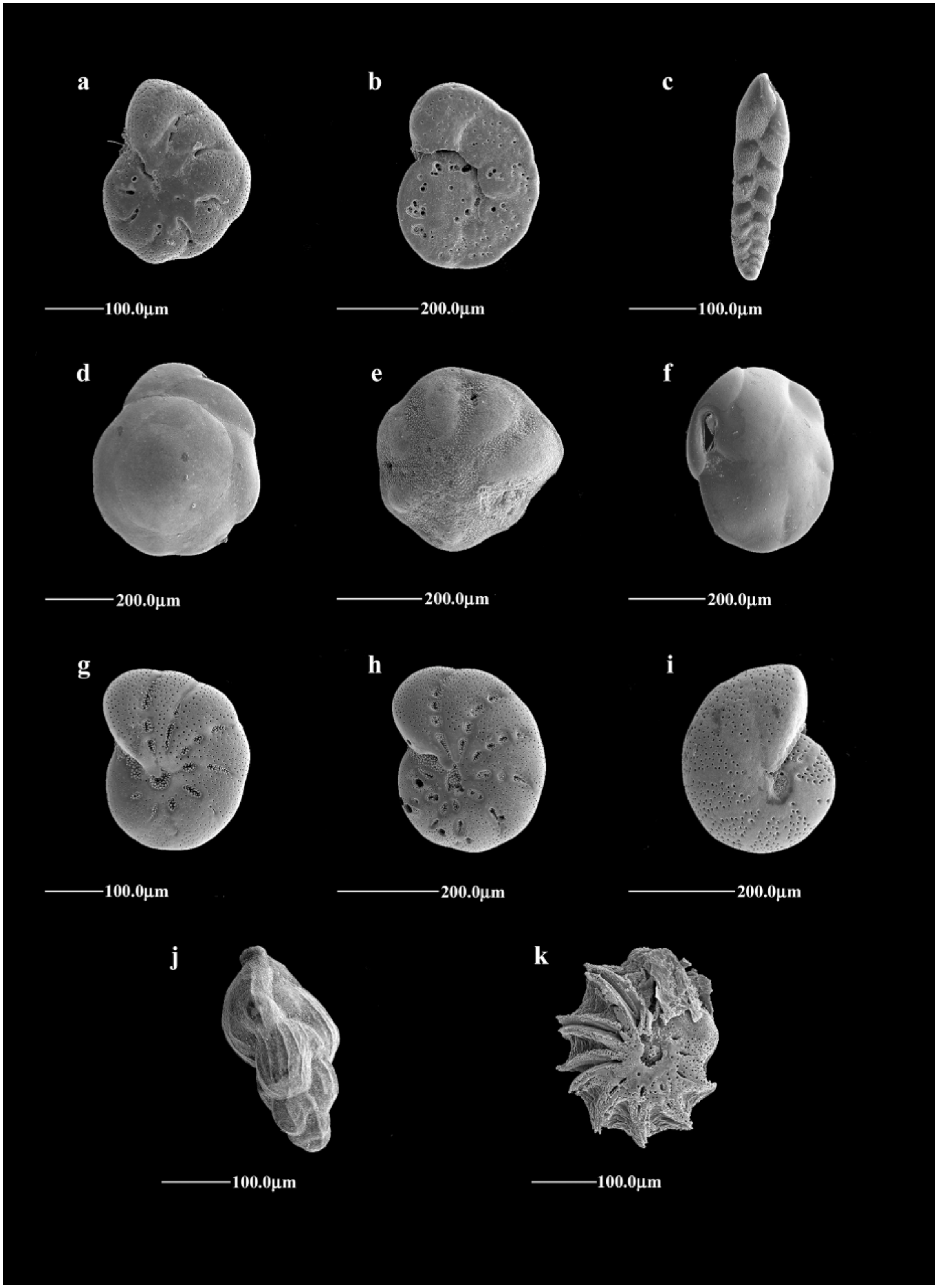

PLATE 2

Selected calcareous foraminifera from Disko Bugt, scanning electron microscope photographs. **a** *Astrononion gallowayi* Loeblich and Tappan, **b** *Cibicides lobatulus* (Walker and Jacob), spiral view, **c** *Bolivina pseudopunctata* Höglund, **d, e** *Buccella tenerrima* (Brady), **d** umbilical view, **e** spiral view, **f** *Islandiella helenae* Feyling-Hanssen and Buzas, **g, h** *Elphidium excavatum* (Terquem) f. *clavata* Cushman, **i** *Melonis barleeanum* (Williamson), **j** *Trifarina fluens* (Todd), **k** Unidentified corroded specimen.

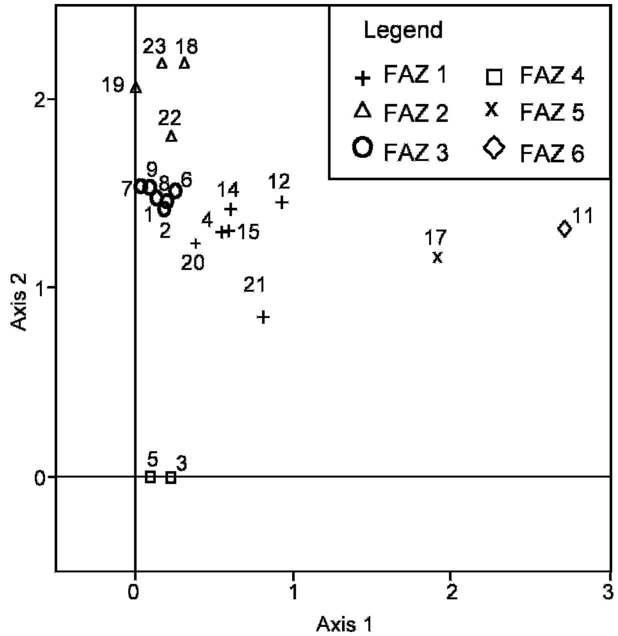

FIGURE 6. Detrended-correspondence-analysis biplot of sample scores for axis 1 and axis 2. The samples are labeled and different symbols are used for each faunal assemblage zone as identified by cluster analysis. The clear grouping of samples by zone supports the zonation produced by cluster analysis.

gallowayi all prefer shallow, low-salinity water, the first two preferring fine-grained sediments, while the last three prefer sand-rich sediments. *Melonis barleeanum, Trochammina japonica* and *T. fluens* prefer higher levels of carbon and nitrogen. *Reophax gracilis, C. arctica* and *T. earlandi* prefer clay and silt-rich sediments.

DISCUSSION

FACTORS CONTROLLING FAUNAL ASSEMBLAGE ZONES IN DISKO BUGT

The CCA results have shown that of the 8 environmental variables measured in this study bottom-water salinity and water depth are the most important variables controlling faunal assemblages in Disko Bugt (Table 5). Sediment substrate (clay and sand) is next in importance, with bottom-water temperature, TOC and TN less important. Other studies of foraminifera in high-latitude fjord and shelf areas have found a range of environmental variables influencing their distribution. Water mass characteristics are commonly identified as important variables, particularly salinity, temperature and dissolved oxygen content (e.g., Schafer and Cole, 1986; Osterman and Nelson, 1989, Hunt and Corliss, 1993; Jennings and Helgadottir, 1994; Rytter and others, 2002; Husum and Hald, 2004; Jennings and others, 2004). Other important factors that have also been identified include food supply and substrate texture (Jennings and Helgadottir, 1994; Korsun and Hald, 1998; Husum and Hald, 2004; Jennings and others, 2004); glacial proximity (Nagy, 1984; Vilks and others, 1989; Korsun and Hald, 1998) and duration of sea-ice cover (Schröder-Adams and others, 1990a, 1990b, Osterman and others, 1999).

TABLE 2. Summary of DCA results of foraminiferal data from the samples analyzed.

Axis	1	2	3	4
Eigenvalues	0.585	0.27	0.073	0.027
Lengths of gradient	2.695	2.197	1.195	1.497
Cumulative % variance of species data	32.8	47.9	51.9	53.5
Sum of all eigenvalues				1.786

Not all of these variables have been measured in this study, some of the variability seen in the faunal data may be due to these unmeasured variables. Variation in sea-ice cover is one of the variables that has not been directly measured. Observations of duration of sea-ice cover in the Baffin Bay and Davis Strait area show relatively rapid formation and break-up of sea ice in Disko Bugt (Environment Canada, 2002). The relatively small geographical range of sample locations suggests that variations in sea-ice cover between sites would be small, so is unlikely to produce major variation in assemblages between samples. Schröder-Adams and others (1990a) identified a fauna similar to that of this study characterized by poor calcareous preservation and dominance of agglutinated fauna (species such as *S. biformis, C. crassimargo, A. glomerata* and *S. difflugiformis*) from Lancaster Sound and Baffin Bay. They suggested the relatively long ice-free summer period and subsequent increase in meltwater flux compared to the Arctic Ocean influenced dissolution of the calcareous fauna. A similar situation may partially explain the fauna seen in Disko Bugt, large volumes of meltwater produced by sea ice and glacial flux influencing preservation and water mass characteristics. Seasonal sea-ice cover almost certainly influences the fauna preserved in Disko Bugt, but is unlikely to explain variation in fauna found within the area.

The possible influence of proximity to glaciers has also not been directly measured in this study, but can be assessed qualitatively. The main influence of glaciers would be supply of meltwater and sediment. The main tidewater glaciers in Disko Bugt that are likely to have an influence on fauna are Jakobshavn Isbrae, Sermeq Kujatdleq and Sermeq Avangnardleq (Fig. 2). The influence of glacier proximity can be seen in lower bottom-water salinity and temperature close to these tidewater glaciers. This is particularly apparent in sites close to Jakobshavn Isfjord (sites 20 and 21, FAZ 1, Fig. 7). There does not seem to be a clear influence of glacier proximity on particle size, however. The position of glaciers in Disko Bugt may well influence the fauna, but because the major influence of glacier proximity is on water temperature and salinity (hence water-mass characteristics), it is actually taken into account by CTD measurements.

The dominant influence of bottom-water salinity (hence water-mass characteristics) on faunal distribution in Disko Bugt is supported by the bottom-water temperature-salinity biplot (Fig. 4). This highlights the dominant role salinity plays in characterizing water masses in Disko Bugt. The WGC, Polar Water and surface water are clearly differentiated based on salinity along with the transitional water mass (mixed WGC water). Water depth also has an

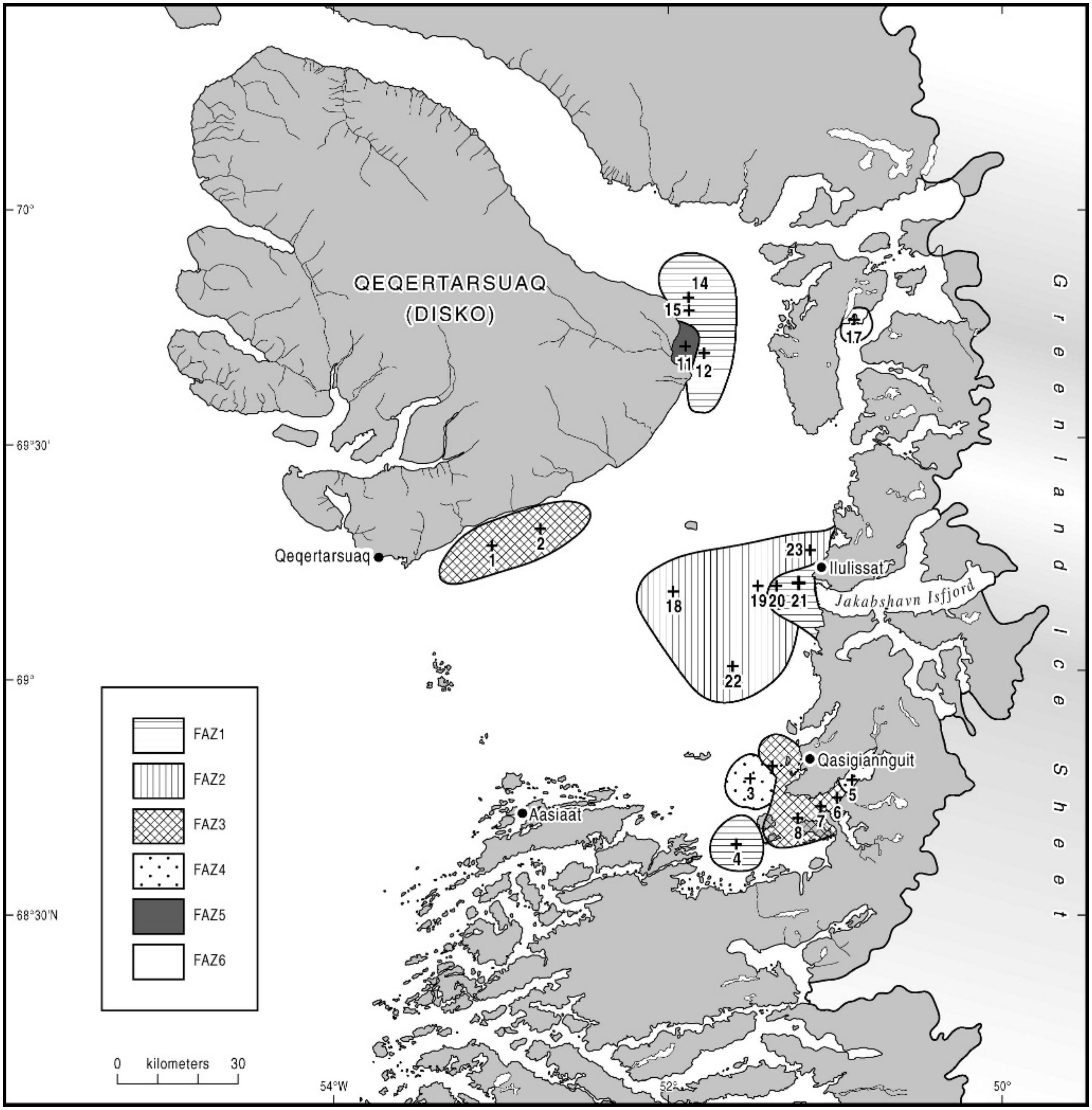

FIGURE 7. Spatial distribution of faunal assemblage zones in Disko Bugt identified by the cluster analysis and DCA.

important influence on bottom water temperature and salinity and, hence, indirectly has an influence on fauna. For this reason it is included as an environmental variable in the CCA. Faunal assemblage zones 5 and 6 identified in cluster analysis and DCA are formed from single samples and are found within the surface water (samples 11 and 17, Fig. 4) and are characterized by shallow water and lowest-salinity values. Several of the important species in these zones are commonly associated with relatively shallow water (see discussion below). The other four FAZs also show a good correlation to water mass characteristics: FAZ 1 incorporates all the samples from the Polar Water along with two samples from the mixed WGC, FAZ 2 contains the remaining three samples from the mixed WGC water and one sample from the WGC water, and FAZs 3 and 4 contain samples found exclusively within the WGC water.

The CCA results show substrate (particularly percent clay and sand) also has an influence on the Disko Bugt fauna. This is most clearly seen in high levels of sand from sample 11 (FAZ 5) differentiating this sample. FAZ 4 also shows relatively high levels of clay, while FAZ 1 is dominated by relatively high levels of sand.

Food supply, assessed in this study through measurement of TOC and TN, also has an influence on faunal assemblage zones. The highest values for both TOC and TN are found in FAZ 3 (average TOC, 1.4%; TN, 0.18%).

TABLE 3. Environmental variables for all sites used in the CCA.

Sample	Depth (m)	Bottom Water Temper-ature (°C)	Bottom Water Salinity (psu)	Total Nitrogen (%)	Total Organic Carbon (%)	Clay (%)	Silt (%)	Sand (%)
1	356	3.4	34.35	0.19	1.44	25.8	69.9	4.3
2	355	3.36	34.34	0.18	1.67	25.6	71.7	2.7
3	331	3.4	34.34	0.22	1.58	53.2	44.7	2.1
4	198	1.86	33.83	0.22	1.17	50.8	46.6	2.6
5	260	3.22	34.31	0.10	0.69	54.8	43.8	1.4
6	327	3.42	34.35	0.16	1.16	46.8	50.4	2.8
7	338	3.46	34.36	0.17	0.89	52.2	46.1	1.7
8	358	3.49	34.36	0.19	1.55	56.9	41.7	1.4
9	318	3.29	34.31	0.20	1.68	52.4	45.2	2
11	60	3.17	33.27	0.08	0.74	16.2	37.5	42.6
12	112	1.53	33.65	0.07	0.44	9.1	24.2	60.2
14	331	2.65	34.26	0.12	1.00	22.2	45.6	28.8
15	245	2.56	34.22	0.10	0.80	17	42.8	38.6
17	20	4	33.27	0.14	0.83	41.9	51.3	6.8
18	343	3.28	34.31	0.20	1.31	35.4	52.3	12.3
19	353	2.66	34.14	0.20	1.09	40.8	58.3	0.9
20	286	1.97	33.85	0.10	0.92	45.3	52	2.7
21	254	2.06	33.88	0.07	0.55	48.4	51.6	0
22	302	2.91	34.2	0.22	1.39	45.6	51.4	3
23	253	2.45	34.08	0.05	0.29	16.4	20.8	58.4

FAZs 2 and 4 also have relatively high levels of TOC and TN compared to FAZs 1, 5 and 6. This might also be related to the water-mass characteristics. Faunal assemblage zones 2, 3 and 4 with higher TOC and TN levels are from WGC waters (organic material and nutrients carried from the North Atlantic) while FAZs 1, 5 and 6 with lower values are from Polar Water and surface water (lower organic material and nutrients from Arctic sourced EGC waters and also diluted by meltwater influx).

RELATIONSHIP BETWEEN FORAMINIFERA AND ENVIRONMENTAL VARIABLES

The two samples from the surface water mass shown in Fig. 4, samples 11 and 17, form the single sampled FAZ 5 and FAZ 6. Faunal assemblage zone 5 (Sample 11) is dominated by *C. lobatulus* (Fig. 5). *Cibicides lobatulus* is commonly found in relatively shallow-water, high-energy environments, and is often found associated with coarse-grained sediments (e.g., Hald and Steinsund, 1992; Jennings and Helgadottir, 1994; Hald and Korsun, 1997; Polyak and others, 2002). The two other species closely associated with this zone (Figs. 5, 8a and 8b), *Elphidium excavatum* f. *clavata* and *Astrononion gallowayi*, are commonly found in relatively cold, low-salinity waters, often associated with proximal glaciomarine conditions (Vilks, 1981; Osterman and Nelson, 1989; Hald and Korsun, 1997; Korsun and Hald, 2000; Polyak and others 2002; Husum and Hald, 2004). Low water salinity and temperature is consistent with the occurrence of this assemblage zone in Disko Bugt in a shallow coastal location with abundant sand under the influence of low-salinity surface water (most likely influenced by meltwater from the nearby ice cap on Disko Island, Fig. 7). Faunal assemblage zone 6 (Sample 17) is characterized by relatively high abundances of two species rare in all others samples – *E. advena* and *A. pseudospiralis* (Fig. 5). These species are commonly found in relatively shallow waters, e.g., Vilks and Deonarine (1988) report *E. advena* common in water depths of 50–60 m, and are clearly associated with shallow waters in Disko Bugt. The relatively high abundance of *S. biformis* in FAZ 6 attests to the relatively low-salinity nature of the surface water in this area.

TABLE 4. Summary of CCA results of foraminiferal and environmental data from all samples analyzed.

Axes	1	2	3	4
Eigenvalues	0.524	0.216	0.095	0.04
Species-environment correlations	0.97	0.858	0.698	0.645
Cumulative % variance;				
of species data	29.1	41.1	46.3	48.5
of species-environment relation	53.9	76.1	85.9	90
Sum of all eigenvalues				1.802
Sum of all canonical eigenvalues				0.972

Faunal assemblage zone 1 contains all of the samples found under the influence of the Polar Water mass (Fig. 4) along with two samples from the mixed WGC water mass (samples 14 and 15). Notably, these samples are dominated by *S. biformis* with *C. arctica* also common. Korsun and Hald (2000) find *S. biformis* in a glaciomarine environment from a Svarlbard glacial fed fjord; it is one of the first arenaceaous species to appear moving away from the glacier (along with *T. earlandi*). Schafer and Cole (1986) found *C. arctica* (called *Reophax arctica*) in fjords of eastern Baffin Island influenced by cold arctic waters. The abundance of these species in FAZ1, characterized by relatively cold and low-salinity waters, is in agreement with previous studies where these species are common in high-latitude locations under the influence of cold arctic waters and also in glaciomarine conditions (e.g., Vilks, 1964; Schafer and Cole, 1986; Madsen and Knudsen, 1994; Jennings and Helgadottir, 1994; Hald and Korsun, 1997; Korsun and Hald, 1998; Korsun and Hald, 2000). However, the relatively high abundance of *A. glomerata* in this zone, a species often found associated with "Atlantic" sourced waters in high latitudes (e.g., Hald and Korsun, 1997), highlights the influence of Atlantic

TABLE 5. Results of the partial CCA performed to investigate the importance of individual environmental variables.

Environmental variable	Sum of eigenvalues of partial CCA	% of total explained variance explained by environmental variables
Bottom water salinity	0.37	20.4
Depth	0.36	20
Clay content	0.17	9.4
Sand content	0.15	8.3
Bottom water temperature	0.08	4.4
Total organic carbon	0.07	3.9
Total nitrogen	0.07	3.9
Silt content	0.06	3.2
Inter-correlations		26.5
Sum of all eigenvalues	1.802	

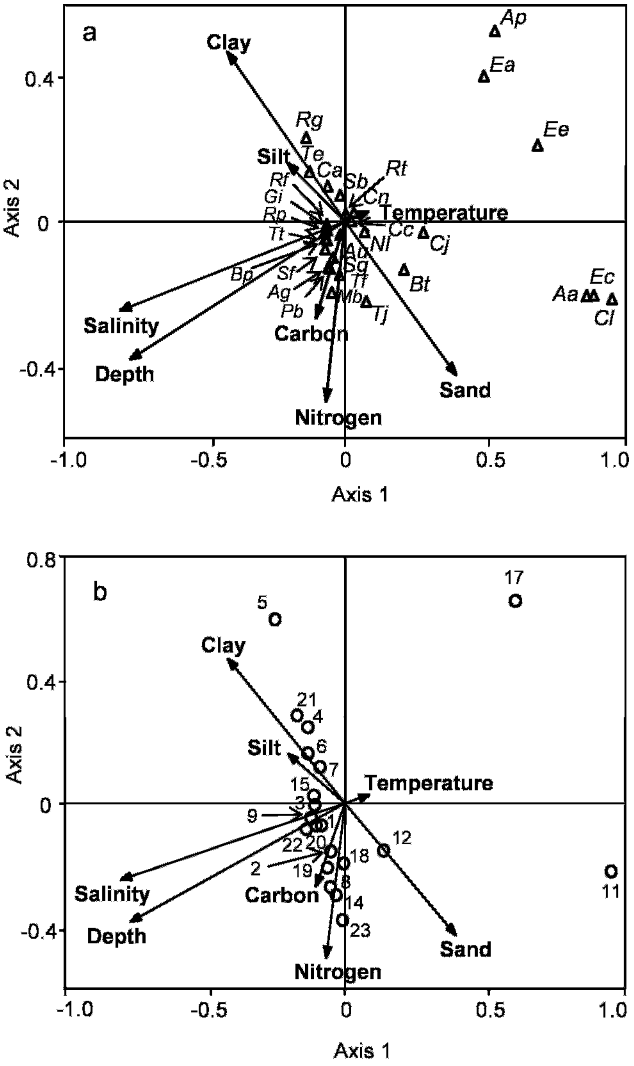

FIGURE 8. Canonical-correspondence-analysis biplots of (a) foraminiferal species – environment and (b) sample – environment. Only species with abundance >2% are included. For species abbreviations see Fig. 5. The relative length of arrows represents the importance of individual environmental variables and the direction represents their correlation with the CCA axes 1 and 2.

water at locations in this zone. This is not surprising given the dominance of the WGC on the present day circulation system in Disko Bugt. It is likely to be the result of partial mixing of the warmer IC component of the WGC with the relatively cold EGC component that forms the Polar Water mass in Disko Bugt (identified from the CTD data, Figs. 3 and 4).

Faunal assemblage zone 2 contains the three other samples found within the influence of mixed WGC waters along with sample 18 influenced by the main body of the WGC. These samples, and also the samples from FAZ 3 (all samples within the WGC field, Fig. 4), are dominated by *A. glomerata*, but also have significant abundances of *S. difflugiformis, R. pilulifer* and *R. fusiformis*. All these species are common in high-latitude areas influenced by Atlantic-sourced waters with relatively high salinity (Vilks, 1980; Bilodeau and others, 1994; Jennings and Helgadottir, 1994; Hald and Korsun, 1997). The calcareous species *M. barleeanum* and *N. labradorica* are also common in FAZs 2 and 3, both species are closely linked to the availability of organic matter (e.g., Wollenberg and Mackensen, 1998; Rytter and others, 2002; Jennings and others, 2004). *Melonis barleeanum* is an infaunal species that feeds on buried organic matter (Corliss, 1985, 1991) while *N. labradorica* is common in areas of high productivity (Polyak and others, 2002) and areas with fresh phytodetritus (Hald and Steinsund, 1992). Both species are associated with the highest levels of TOC and TN in the Disko Bugt samples. Their abundance here is to a large extent controlled by availability of organic material, but this is influenced in Disko Bugt by the distribution of water masses. Higher TOC levels and TN are associated with a stronger influx of Atlantic-sourced WGC waters. This linked association with organic matter and Atlantic-sourced waters has been seen in Baffin Island fjords (Schafer and Cole, 1986), east Greenland fjords and shelf (Jennings and Helgadottir, 1994), Svalbard fjords (Hald and Korsun, 1997), and the north Icelandic shelf (Jennings and others, 2004). The occurrence of *C. arctica* and *P. bipolaris* in moderate abundances in FAZ 2 suggests the influence of the slightly colder, less-saline Polar Water on these samples (supported by the grouping of most of these samples in the mixed WGC field of Fig. 4). Vilks (1989) and Jennings and Helgadottir (1994) found *P. bipolaris* under polar waters in the Canadian Arctic and fjords of eastern Greenland, respectively.

Samples from FAZ 3 and FAZ 4 are all found in areas within the influence of the WGC. In general, samples from FAZ 3 have a higher proportion of species commonly found under the influence of Atlantic-sourced water compared to the other samples from Disko Bugt (e.g., *A. glomerata*, *S. difflugiformis, R. pilulifer* and *R. fusiformis*). Faunal assemblage zone 4 has a rather different fauna dominated by *T. earlandi* with a much lower abundance of *A. glomerata*. Many studies from high latitudes find *T. earlandi* associated with *S. biformis* and common in areas influenced by relatively cold, low-salinity Arctic water and often in glaciomarine environments (e.g., Schafer and Cole, 1986; Jennings and Helgadottir, 1994; Madsen and Knudsen, 1994; Korsun and Hald, 2000). In Disko Bugt, these two species have slightly differing ecological preferences. *Spiroplectammina biformis* is dominant under the influence of colder less-saline bottom water, while *T. earlandi* has a higher abundance in areas with a stronger Atlantic water influence (FAZs 3 and 4). *Textularia earlandi* dominates FAZ 4. Samples from this zone have an average bottom water temperature of 3.3°C and salinity of 34.3 psu while *S. biformis* dominates FAZ 1 with lower average bottom-water temperature and salinity values of 2.1 °C and 33.9 psu, respectively. However, a stronger control on the distribution of *T. earlandi* appears to be substrate rather than water-mass characteristics with a strong affinity for fine grained sediments. Faunal assemblage zone 4 has the highest average clay composition (54%). Faunal assemblage zone 3 also has moderately high abundances of *T. earlandi*, and the second highest average clay composition (43.4%). This interpretation is supported by the CCA results. *T. earlandi* plots very close to the clay arrow in figure 8a, suggesting clay is an important environmental variable controlling the distribution of this species.

Most of the samples from Disko Bugt have relatively high abundances of *A. glomerata* (the exception being the very shallow samples 11 and 17). This species is widespread on continental shelf areas of high latitudes, and is commonly found associated with Atlantic-sourced waters (sometimes described as "transformed" Atlantic water, e.g., Hald and Korsun, 1997). The abundance of this species, along with the relatively low abundance of cold glaciomarine species such as *E. excavatum* forma *clavata* and the near absence of the common Polar Water species *Cassidulina reniforme*, in the present day samples from Disko Bugt suggests Atlantic-sourced waters (from the IC) have an influence throughout Disko Bugt, even within the water mass defined here as Polar Water. The only exception to this is within the shallow surface waters dominated by low-salinity glacial meltwater. The abundance of *C. reniforme* may also be lower than expected due to greater dissolution than other calcareous species due to the relatively small size and thin wall of this species.

The faunal data presented here show that agglutinated foraminifera are very important discriminators of environmental conditions in Disko Bugt. Past studies of fossil material collected from high latitudes often focus on the calcareous faunal component due to poor preservation of agglutinated taxa (e.g., Elverhøi and others, 1980; Bennike and others, 1994; Vosgerau and others, 1994). However, the importance of agglutinated foraminifera in paleoenvironmental reconstruction is highlighted by recent studies of Holocene sediments collected from Disko Bugt (e.g., Lloyd and others, 2005; Lloyd, 2006). Fossil material collected from Disko Bugt tends to have good preservation of agglutinated fauna and rather variable preservation of calcareous fauna. Indeed, Jennings and Helgadottir (1994) discuss the differential preservation of agglutinated versus calcareous foraminifera in different water masses in high latitudes, highlighting the importance of including the agglutinated fauna in studies from high-latitude continental shelves.

The data presented here suggest that foraminifera are a suitable proxy to identify changes in water-mass characteristics in the Disko Bugt area from recently collected gravity and piston cores (e.g., Lloyd and others, 2005; Lloyd, 2006). In particular there is a clear differentiation between a fauna indicative of relatively saline and warm WGC waters and a fauna indicative of relatively lower-salinity and colder meltwater or Polar Water. It is, therefore, possible to reconstruct changes in the strength of the WGC, and also the relative contribution of the EGC and IC components of the WGC through identification of changes in relative bottom water salinity conditions.

CONCLUSIONS

Based on the analysis of 20 samples from Disko Bugt on the west Greenland margin the following conclusions can be made:

1. A wide range of both agglutinated and calcareous foraminiferal species are found throughout Disko Bugt at the present day, but the fauna is dominated by agglutinated species. Cluster analysis and DCA identify 6 faunal assemblage zones.
2. The relationship between environmental variables and foraminifera was investigated using CCA. The environmental variables measured in this study explain 48.5% of the variance in foraminiferal data. The most important variables are bottom-water salinity and water depth, explaining 20.4% and 20% of the explained variance in foraminiferal data, respectively.
3. Based on the CCA, foraminifera in Disko Bugt appear to be controlled most strongly by water mass characteristics at the sea floor. Shallow water environments within the relatively warm, low-salinity surface water are dominated by *C. lobatulus* in areas of coarse sediment and a mixed assemblage with high abundances of *A. pseudospiralis* and *E. advena* in finer-grained sediments. Sites influenced by the colder, low-salinity Polar Water (the poorly mixed East Greenland Current component of the West Greenland Current) are dominated by *S. biformis*, with *A. glomerata* and *C. arctica* also common. Sites influenced by the warmer, more-saline West Greenland Current water mass are dominated by *A. glomerata*, with high abundances of *R. fusiformis, R. pilulifer* and *T. earlandi* (the dominant species in finer grained sediments). The mixed West Greenland Current water mass identified from the CTD data, forming a transition between Polar Water and WGC water, is less well-defined by foraminiferal data, but is dominated by *A. glomerata*, with moderate and variable abundances of *M. barleeanum, P. bipolaris, C. arctica* and *S. biformis*.
4. This modern faunal dataset provides a basis for reconstructing changes in the oceanography, in particular the relative strength of the WGC (and the relative proportion of the EGC component of the WGC) from a series of gravity cores and piston cores collected from Disko Bugt.

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APPENDIX 1

Species list

Agglutinated species
Adercotryma glomerata (Brady, 1878)
Ammoscalaria pseudospiralis (Williamson, 1858)
Ammotium spp.
Cribrostomoides crassimargo (Norman, 1892)
Cribrostomoides jeffreysii (Williamson, 1858)
Cuneata arctica (Brady, 1881)
Eggerella advena Cushman, 1922
Hyperammina elongata Brady, 1878
Recurvoides turbinatus (Brady, 1881)
Reophax bilocularis Flint, 1899
Reophax dentaliniformis Brady, 1881
Reophax fusiformis (Williamson, 1858)
Reophax gracilis (Brady, 1881)
Reophax guttifer (Brady, 1881)
Reophax nana (Rhumbler, 1913)
Reophax nodulosus Brady, 1879
Reophax pilulifer Brady, 1884
Reophax sp.
Rhabdammina sp.
Saccammina difflugiformis (Brady, 1879)
Saccammina sp.
Silicosigmoilina groenlandica (Cushman, 1933)
Spiroplectammina biformis (Parker and Jones, 1865)
Textularia earlandi Phleger, 1952
Textularia torquata Parker, 1952
Thurammina papillata Brady, 1879
Trochammina japonica Ishiwada, 1950
Portatrochammina bipolaris Brady, 1881
Trochammina nitida Brady, 1881
Trochammina rotaliniformis (Wright, 1911)
Calcareous species
Ammodiscus gullmarensis (Höglund, 1947)
Astrononion gallowayi Loeblich and Tappan, 1953
Bolivina pseudopunctata Höglund, 1947
Buccella frigida (Cushman, 1922)
Buccella tenerrima (Brady, 1950)
Bulimina elongate d'Orbigny, 1826
Buliminella elegantissima (d'Orbigny, 1839)
Cassidulina reniforme Nørvang, 1945
Cassidulina neoteretis Tappan, 1951
Cibicides lobatulus (Walker and Jacob, 1798)
Dentalina baggi Galloway and Wissler, 1927
Dentalina frobisherensis Loeblich and Tappan, 1953
Dentalina sp.
Elphidium excavatum (Terquem, 1876)
Elphidium excavatum (Terquem) f. *clavata* Cushman, 1944
Elphidium incertum (Williamson, 1858)
Elphidium sp.
Elphidium williamsoni Haynes, 1973
Epistominella vitrea Parker, 1953
Globulina inaequalis Reuss, 1930
Guttulina sp.
Islandiella helenae Feyling-Hanssen and Buzas, 1976
Islandiella norcrossi (Cushman, 1933)
Lagena sp.
Melonis barleeanum (Williamson, 1858)
Nonionellina labradorica (Dawson, 1860)
Nonionella turgida (Williamson, 1858)
Oridosalis tener (Brady, 1884)
Quinqueloculina seminulum (Linné, 1758)
Quinqueloculina sp.
Quinqueloculina stalkeri (Loeblich and Tappan, 1953)
Stainforthia concava Höglund, 1947
Stainforthia feylingi Knudsen and Seidenkrantz, 1994
Stainforthia loeblichi (Feyling-Hanssen, 1954)
Trifarina fluens (Todd, 1947)
Triloculina trihedral Loeblich and Tappan, 1953