Recent foraminifera in glaciomarine sediments from three arctic fjords of Novaja Zemlja and Svalbard

S. A. KORSUN, I. A. POGODINA, S. L. FORMAN AND D. J. LUBINSKI

Korsun, S. A., Pogodina, I. A., Forman, S. L. & Lubinski, D. J. 1995: Recent foraminifera in glaciomarine sediments from three arctic fjords of Novaja Zemlja and Svalbard. *Polar Research, 14(1)*, 15–31.

Foraminifera were examined in recent (< 100 years) fine-grained glaciomarine muds from surface sediments and cores from Nordensheld Bay, Novaja Zemlja, and Hornsund and Bellsund, Spitsbergen. This study presents the first data on modern foraminifera distribution for fjord environments in Novaja Zemlja, Russia. The data are interpreted with reference to the distribution of foraminiferal near Svalbard and the Barents Sea. In Nordensheld Bay, live and dead *Nonionellina labradorica* and *Islandiella norcrossi* are most abundant in the outer fjord. *Cassidulina reniforme* and Allogromiina spp. dominate in the middle and inner fjord. The dominant species are dissimilar to species occurring in other areas of the Barents Sea region, with the exception of Svalbard fjords. The number of live foraminifera (24 to 122 tests/10 cm^3) in outer and middle Nordensheld Bay corresponds with values known from the open Barents Sea. However, the biomass (0.03 mg/10 cm^3) is two orders of magnitude less due to smaller foraminiferal test size, which in glaciomarine sediments reflects the absence of larger species, paucity of large specimens, and high occurrence of juvenile foraminifera. The smaller size indicates an opportunistic response to environmental stress due to glacier proximity. The presence of *Quinqueloculina stalkeri* is diagnostic of glaciomarine environments in fjords of Novaja Zemlja and Svalbard.

S. A. Korsun and I. A. Pogodina, Murmansk marine Biological Institute, 17 Vladimirskaya St., Murmansk 180023, Russia; S. L. Forman, Byrd Polar Research Center and Department of Geological Sciences, The Ohio State University, Columbus, Ohio 43210-1002, U.S.A.; D. J. Lubinski, Institute for Arctic and Alpine Research and Department of Geological Sciences, University of Colorado, Boulder, Colorado 80309-0450, U.S.A. (Direct correspondence to S. L. Forman).

Introduction

Studies of foraminifera from recent glaciomarine sediments provide insights into the environmental significance of taxa and potentially improved paleoenvironmental inferences for fossil faunas. A number of studies have examined benthic foraminifera from Svalbard fjords (Goës 1892, 1894; Kiær 1899; Feyling-Hanssen 1964; Nagy 1965; Rouvillois 1966; Luczkowska 1975; Elverhøi et al. 1980; Kirienko 1984; Hansen & Knudsen 1992; Hald & Korsun unpublished). In contrast, foraminiferal faunas from the subpolar fjords of Novaja Zemlja have not been investigated except for a study of reworked fauna from sea ice and icebergs (Potekhina et al. 1991).

Glacier proximal foraminiferal assemblages in Svalbard fjords are typically dominated by the calcareous species *Cassidulina reniforme* and/or *Elphidium clavatum* and have low values for faunal diversity, planktic/benthic ratio, and number of tests (Nagy 1965; Luczkowska 1975; Elverhøi et al. 1980; Kirienko 1984; Hansen & Knudsen 1992; Hald & Korsun unpublished). These assemblages are common in late Pleistocene records from the southwestern Barents Sea and Norwegian shelf and are assumed to indicate glacier proximity. The *C. reniforme-E. clavatum* assemblages are replaced upcore, near the Pleistocene/Holocene transition, by a variety of other assemblages which indicate full marine conditions and penetration of warm Atlantic Water into the area (e.g. Østby & Nagy 1982; Vorren et al. 1984; Hald et al. 1989). In contrast, foraminiferal assemblages from Holocene marine-muds in the northern Barents Sea are often similar to faunas from glacio-marine sediments of Svalbard fjords, with co-dominance of *C. reniforme* and *E. clavatum*, and low faunal diversity, planktic/benthic ratio, and number of tests (Sakharova & Korsun 1989; Spiridonov et al. 1992; Korsun et al. 1994).

Our analysis of eight modern samples from Nordensheld Bay provide new data on the distribution of foraminifera in Novaja Zemlja fjords. These data comprise a basis for comparing and possibly extending established relations between modern foraminifera in a Novaja Zemlja fjord with other areas in the Barents Sea region. Foraminiferal test size and minor species composition for glaciomarine sediments from Nordensheld Bay, Novaja Zemlja, and Hornsund and Bellsund, Spitsbergen, were analysed to further evaluate the differences between foraminiferal faunas of the open northern Barents Sea and glaciated fjord environments on the adjacent archipelagos.

Hydrographic and sediment settings

Hornsund and Bellsund, Svalbard

The West Spitsbergen Current, a northern branch of the Gulf Stream, transports relatively warm and saline (T > 1°C and S = 34.7‰) Atlantic Water along the western coast of Svalbard (Fig. 1). This water penetrates often at depth into fjords along the western coast of Spitsbergen,

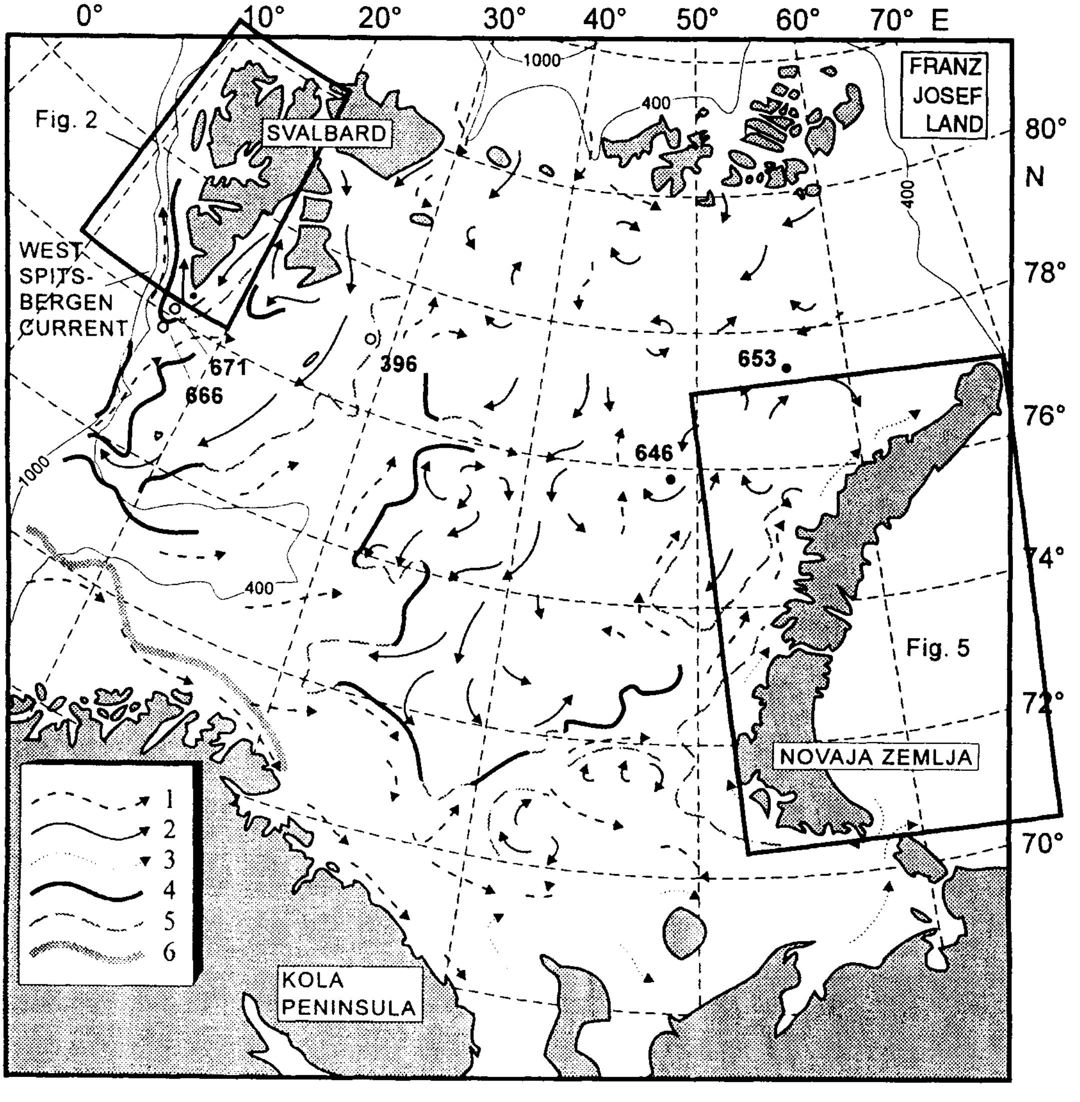

Fig. 1. The Barents Sea region: Atlantic (1), Arctic (2), and Coastal (3) surface currents (Tantsiura 1973, simplified); convergence zone (4) and mixing zone (5) of the Polar Front (Tantsiura 1973); Boreal/Arctic zoogeographic boundary of benthic foraminifera (6) (Digas 1970).

including Hornsund and Bellsund. During the winter, sea ice covers the fjord head and rarely extends to the open sea (Vinje & Kvambekk 1991). Associated with sea ice formation at the fjord head is descending cold and saline (T < 0°C and S > 35‰) water. The summer melting of adjacent glaciers is a source of a low salinity (>20‰) surface layer in the upper 5 to 15 m (Norman 1987; Weslawski et al. 1991).

The sedimentation rate decreases exponentially from many glacier termini on western Spitsbergen (Elverhøi et al. 1983; Boulton 1990). All three sampling sites are situated in the vicinity of calving glaciers (Figs 2, 3 and 4) and within an area of meltwater discharge (August 1990). The concentration of suspended sediment at sampling site Ho-3 in Hornsund, Spitsbergen, ca. 0.5 km from the Hansbreen outlet, was about 300 mg/l in the surface water in July 1983 (Görlich et al. 1987). Sedimentation rate in the glacier-proximal zone usually does not exceed 350 mm/yr within 0.3 km from the Hansbreen outlet and is less that 1 mm/yr in the glacier-distal zone, approximately >5 km from the glacier termini in Hornsund (Görlich et al. 1987).

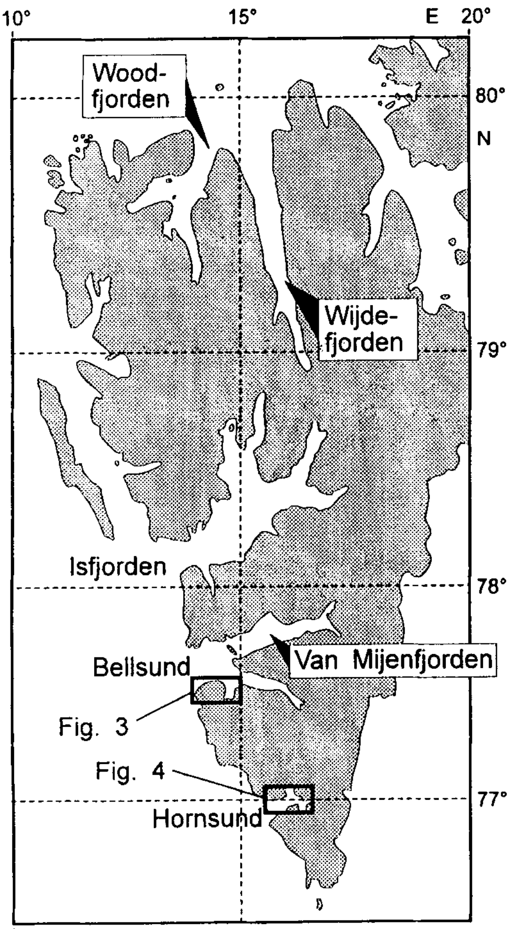

Fig. 2. Spitsbergen and location of study sites in Bellsund and Hornsund.

Nordensheld Bay, Novaja Zemlja

There is little information on water masses in the Nordensheld Bay area, Novaja Zemlja ("Nordensheld" is a double transliteration, Norwegian from Russian to Latin, of G. Nordenskjøld name). The Barents Sea shelf in the vicinity of Nordensheld Bay is occupied by cold Arctic Water (T = −1°C and S = 34.8‰). Nordensheld Bay and the adjacent shelf are usually covered by sea ice for at least six months of the year. (Murmansk Hydrometeorological Survey 1988; Vinje & Kvambekk 1991). The only summer hydrographic profile is at site 874, which shows a lower salinity surface layer (0–10 m; 31.3–31.5‰) and normal marine values for bottom waters (34.8‰) (Chinarina 1992).

At the head of Nordensheld Bay is the large calving Nordensheld Glacier (Fig 6). An extensive meltwater system emanating from the glacier terminus delivers turbid fresh water to the fjord. Although the exact sediment concentration is not known for the sampling period, an earlier investigation during August/September 1984 measured a water column suspended sediment (fine silty-clay) concentration of 88 mg/l ca. 10 km from the glacier terminus (Aksyonov 1987). Glaciomarine sediments in the upper part of the fjord are characterised by 1 to 10 cm thick laminae of light gray silty-clay (Tarasov et al. 1993).

Material and methods

In Nordensheld Bay, northern Novaja Zemlja, four grab samples (896, 874, 894, and 895) and two gravity cores (894 and 895) were retrieved by the R/V DALNIE ZELENTSY in late August and early September 1991 and four additional box-core samples (68/31, 68/3, 68/32 and 68/33) were collected in August 1991. The distal samples (68/31, 68/3, 68/32, and 896) have diagenetic colour stratification, characterised by a 2-cm-thick light-olive

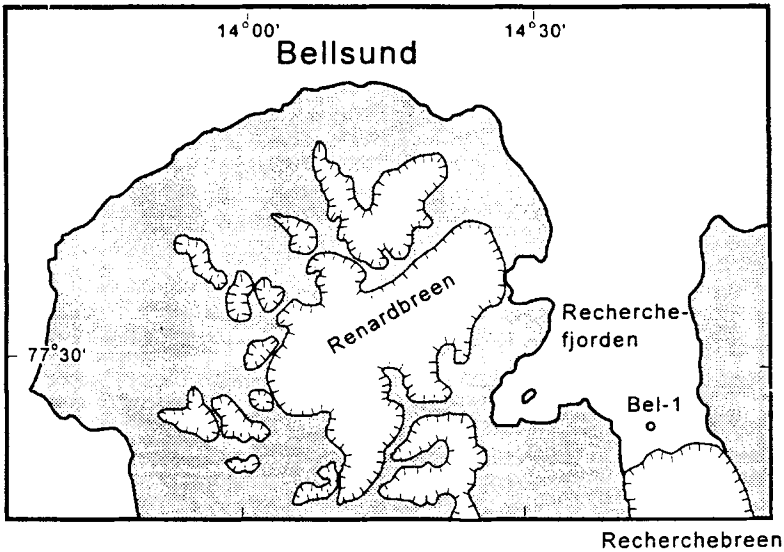

Fig. 3. Location of core Bel-1 in Bellsund, proximity to Recherchebreen.

oxidised surface-layer, overlying light-gray mud. Sediments, more proximal to the glacier (samples 874, 894, 68/33, and 895), do not have an oxidised layer but consist of light-gray mud. Both cores penetrated uniform laminated light-gray fine-grained glaciomarine sediments (Table 1; Figs. 5 and 6).

Three gravity cores (Bel-1, Ho-2, Ho-3) from Bellsund and Hornsund were obtained by the R/V POMOR in August 1990 (Fig. 2 and 3). The recovered glaciomarine sediment is light gray with a low sand and gravel content (0.5–3%).

The individual sediment cores were sampled at either 5, 10, or 20 cm intervals. The thickness of the sampled interval is 5 cm. The samples were dried, weighed, sieved (>0.063 mm), and floated with carbon tetrachloride to isolate foraminiferal tests. The number of foraminifera counted for each sample ranges from 100 to 350 specimens.

The greatest diameters of *C. reniforme* tests in core top samples (0–5 cm) of the fjord cores 894, 895, and Ho-2 and the previously studied cores 671, 666, and 396 from the open Barents Sea were measured to compare the mean test-size of an individual species in glaciomarine and marine sediments. *C. reniforme* were chosen for the analysis because of its abundance in both the fjord and Barents Sea samples. The greatest diameter

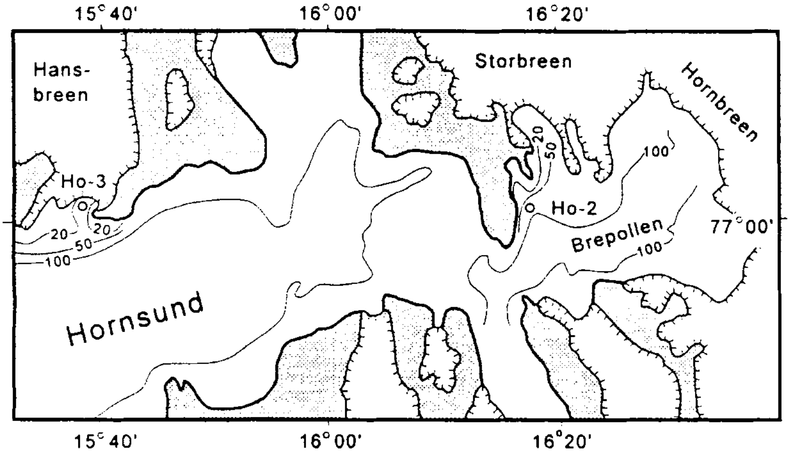

Fig. 4. Location of core Ho-2 in Hornsund.

Table 1. Station list

Station	Sediment Collected	Date	Depth (m)	Surface Sediment	General Location	Latitude N	Longitude E
				Samples investigated in this study			
68/3	Box Core	8/19/92	139	mud	Nordensheld Bay, Novaja Zemlja	75° 28.0′	56° 44.2′
68/31	Box Core	8/30/92	165	mud	" – "	75° 33.3′	56° 27.7′
68/32	Box Core	8/30/92	120	mud	" – "	75° 28.5′	57° 10.0′
68/33	Box Core	8/30/92	45	mud	" – "	75° 21.5′	57° 35.8′
874	Grab	8/18/91	76	mud	" – "	75° 22.0′	57° 29.0′
894	Grab	8/29/91	31	mud	" – "	75° 19.7′	57° 30.2′
895	Grab & Core	8/29/91	49	mud	" – "	75° 20.0′	57° 45.0′
896	Grab & Core	8/30/91	149	mud	" – "	75° 24.7′	57° 06.0′
Bel-1	Core		40	mud	Belsund, W Spitsbergen	77° 26.0′	14° 40.0′
Ho-2	Core		60	mud	Hornsund, W Spitsbergen	77° 04.0′	16° 17.0′
Ho-3	Core		30	mud	" – "	77° 04.0′	15° 38.0′
				Previously studied samples used for comparison			
653	Grab	10/15/87	290	mud	NE Barents Sea	77° 37.0′	55° 57.0′
646	Grab	10/12/87	200	sandy mud	" – "	75° 58.0′	48° 13.0′
396	Core		130	mud	South off Svalbard	76° 58.6′	28° 12.1′
666	Core		380	mud	" – "	75° 55.0′	15° 54.0′
671	Core		315	mud, pebbles	" – "	76° 10.0′	16° 21.0′

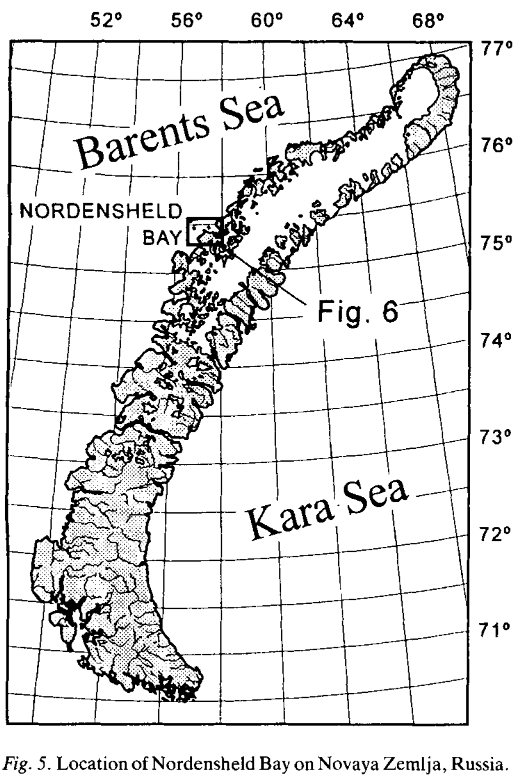

Fig. 5. Location of Nordensheld Bay on Novaya Zemlja, Russia.

was measured for a minimum of 20 tests for each sample. The location of the previously studied cores is shown in Fig. 1.

Foraminifera from eight modern samples (20–100 cm^3 of the upper 1 cm) were preserved with 80% ethanol (5:1 by volume), assuming dilution to 70% due to the sediment water content. The samples were stained for one day with Rose Bengal (1 g/l) and then wet sieved through 0.063 mm sieve. Four samples from box cores (68/31, 68/3, 68/32, and 68/33) were dried and floated as above. Live (stained) and dead (unstained) foraminifera were counted. The other four samples (896, 874, 894, and 895) were wet sieved to isolate the >1.0, 1.0–0.5, 0.5–0.25, 0.25–0.100 and 0.100–0.063 mm fractions of foraminiferal tests for a size class analysis and biomass measurements.

Biomass is evaluated by a cytoplasmic volume calculation for four different size fractions. In each fraction a biomass was estimated by the following formula:

$$W = 0.1 \times S^3 \times n,$$

where W = biomass, n = number of live foraminifera, and S = mean diameter of foraminifera

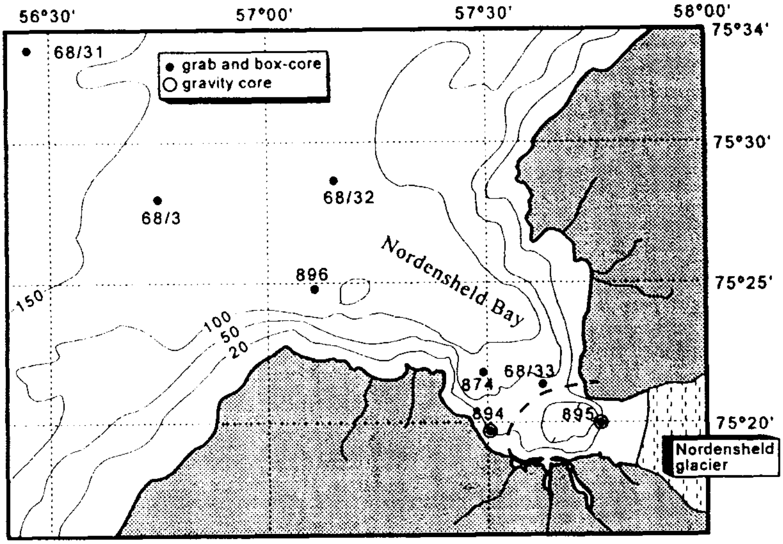

Fig. 6. Location of sampling sites in Nordensheld Bay, Novaya Zemlja, Russia.

(Korsun 1991). Means of the diameter (S value) for the following size fractions are: 0.0794 mm (0.063–0.1 mm fraction), 0.158 mm (0.1–0.25 mm fraction), 0.354 mm (0.25–0.5 mm fraction), and 0.707 mm (0.5–1.0 mm fraction). Two previously studied grab samples from northeastern Barents Sea (646 and 653) are used to illustrate differences in Nordensheld Bay.

The number of tests counted for each modern sample ranged from 35 to 416 specimens for total fauna from 17 to 148 specimens for live foraminifera. Total fauna is the sum of live and dead foraminifera in modern samples. We use the term 'fossil' for tests from the core samples, except for the core tops which are composed of live and dead foraminifera (total fauna).

Results

A total of 59 foraminiferal taxa are identified for samples from Novaja Zemlja and Svalbard (Table 2). Most of the species are characteristic of Arctic foraminiferal faunas of the Barents Sea region (Digas 1970). Foraminiferal fauna includes organic-walled Allogromiina spp., 23 arenaceous and 36 calcareous taxa. The only recent siliceous foraminifera known for the Barents Sea, *S. groenlandica*, was absent in our samples of glaciomarine sediments.

Modern foraminifera in Nordensheld Bay, Novaja Zemlja

Modern foraminifera were studied in eight surface sediment samples from Nordensheld Bay (Fig. 6; Tables 3 and 4). Live and dead *N. labradorica* and *I. norcrossi* are abundant in the outer fjord (sites 68/31, 68/3, and 68/32). *C. reniforme* and Allogromiina spp. dominate in the middle and inner fjord. *Q. stalkeri* occurs only in the middle and inner fjord. *S. biformis* and *E. clavatum* show unclear distribution patterns (Fig. 7).

The number of dead foraminifera comprises 152 to 170 tests/10 cm^3 in the inner fjord and decreases consistently toward the glacier from 46 to 1.5 tests/10 cm^3. The number of live foraminifera ranges from 24 to 122 tests/10 cm^3 in the outer and middle fjord and drops to between 3 and 6 tests/10 cm^3 in the two samples closest to the glacier terminus. Calcareous faunas make up 68 to 97% of live foraminifera in the outer fjord. In the middle and inner fjord, the percentage decreases from 77 to 8% toward the glacier, reflecting the increasing significance of Allogromiina spp. The percentages of dead calcareous foraminifera varies from 46 to 100% (Fig. 8) and does not show consistent trends with position in bay.

The total benthic fauna includes 12 to 35% of live specimens in the outer fjord; in the middle and inner fjord, the value exceeds 50%. The

Table 2. List of identified foraminiferal taxa

Adercotryma glomerata (Brady, 1878)	*Miliolinella* sp.
Allogromiina	*Neogloboquadrina pachyderma* (Ehrenberg, 1861)
Alveolophragmium crassimargo (Norman, 1892)	*Nonionella auricula* Heron-Allen & Earland, 1930
Ammodiscus sp.	*Nonionella turgida* (Williamson, 1858)
Ammotium cassis (Parker, 1870)	*Nonionellina labradorica* (Dawson, 1960)
Astrononion gallowayi Loeblich & Tappan, 1953	*Patellina corrugata* Williamson, 1858
Bolivina pseudopunctata Höglund, 1947	*Pelosina variabilis* Brady, 1879
Bolivina sp.	Polymorphinidae
Buccella frigida (Cushman, 1922)	*Proelphidium niveum* (Lafrenz, 1963)
Cassidulina reniforme Nørvang, 1945	*Protelphidium orbiculare* (Brady, 1881)
Cibicides lobatulus (Walker & Jacob, 1798)	*Proteonina* sp.
Cribrostomoides jeffreysi (Williamson, 1858)	*Psammosphaera* sp.2
Dentalina baggi Galloway & Wissler, 1927	*Quinqueloculina stalkeri* Loeblich & Tappan, 1953
Eggerella advena Cushman, 1922	*Recurvoides turbinatus* (Brady, 1881)
Elphidiella arctica (Parker & Jones, 1864)	*Reophax arctica* Brady, 1881
Elphidium albiumbilicatum (Weiss, 1954)	*Reophax atlantica* (Cushman, 1944)
Elphidium clavatum Cushman, 1930	*Reophax scorpiurus* Montfort, 1808
Elphidium subarcticum Cushman, 1944	*Reophax scottii* Chaster, 1892
Epistominella sp.	*Robertina arctica* d'Orbigny, 1846
Fissurina marginata (Montagu, 1803)	*Rosalina* spp.
Fissurina sp.	*Rotaliammina ochracea* (Williamson, 1858)
Gavelinopsis praegeri (Heron-Allen & Earland, 1913)	*Spiroplectammina biformis* (Parker & Jones, 1865)
Globobulimina turgida (Bailey, 1851)	*Stainforthia loeblichi* (Feyling-Hanssen, 1954)
Hippocrepinella alba Heron-Allen & Earland, 1932	*Stainforthia schreibersiana* Czjzek, 1848
Hyperammina subnodosa Brady, 1884	*Textularia earlandi* Phleger, 1952
Islandiella helenae Feyling-Hanssen & Buzas, 1976	*Textularia torquata* F. Parker, 1952
Islandiella norcrossi (Cushman, 1933)	*Trifarina fluens* (Todd, 1947)
Lagena gracillima (Seguenza, 1862)	*Trochammina nana* (Brady, 1881)
Lagena semilineata Wright, 1886	*Trochamminella atlantica* F. Parker, 1952
Melonis barleeanus (Williamson, 1858)	*Trochamminella bullata* Höglund, 1947
Miliolinella pyriformis Gudina, 1969	*Trochamminella* sp.

number of live species per sample decreases gradually toward the glacier. The number of dead species is 22 to 23 in the outer fjord and 2 to 8 in the middle and inner fjord. (Table 4; Fig. 8).

Foraminiferal biomass is evaluated for four samples (896, 874, 894, and 895) and ranges from 0.001 to 0.030 mg/10 cm^3. The lowest value is observed in the sample closest to the glacier terminus (Table 4). An analysis of size spectra in these four samples reveals that neither live nor dead foraminifera occur in sieve fractions greater than 0.25 mm.

Recent foraminifera in cores from Nordensheld Bay, Novaja Zemlja, and Hornsund and Bellsund, Svalbard

We infer that the sampled sediments in close proximity to present glacier margins were deposited in the last few hundred years. Sedimentation rates near core site Ho-3, Hornsund, are approximately 350 mm/yr (Görlich et al. 1987) and thus, the 60-cm-length of sampled sediments probably spans <10 years. The proximal core site 895 in Nordensheld Bay is located behind the end moraines of a presumed Little Ice Age advance of Nordensheld glacier (Fig. 6; Forman unpubl. data). We speculate that the sediments at site 895 were deposited after the glacier retreat ca. 1900 A.D. In the upper part of Nordensheld Bay, individual sediment laminae are from 1 to 10 cm thick. Tarasov et al. (1993) assumed that the laminations were seasonal, and thus the two studied cores may span decades or centuries. We estimate that the sedimentation rate for the cores studied is two to three orders of magnitude higher than in the central Barents Sea where the apparent Holocene sedimentation rate is approximately 0.1 mm/yr (Gataullin et al. 1993). The downcore distribution (Figs. 9 and 10) illustrates the general continuity and short term variations of taxa in these sediments.

The dominant species in the five studied cores are *C. reniforme* and *E. clavatum* (Figs. 9 and

Table 3. Number of live and dead foraminifera per 10 cm^3 in Nordensheld Bay, Novaja Zemlja

Station	68/31		68/3		68/32		896		874		894		68/33		895	
Live / Dead	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D
Allogromiina spp.	1.0	1.0	2.5	2.5	1.5	1.5	10.0		52.0		26.5	2.0	3.0	1.0	2.0	0.3
Hippocrepinella alba									6.0		10.5				0.4	
Psammosphaera sp.2											0.5					0.2
Proteonina sp.											18.0					
Pelosina variabilis				1.5												
Hyperammina subnodosa	0.5	0.5														
Ammodiscus sp.						0.5						0.5				
Reophax atlantica	2.0	3.5		1.0		1.0										
Reophax scorpiurus		3.0	0.5	1.5												
Reophax arctica							4.0	4.0								
Reophax scottii							2.0									
Ammotium cassis		8.5	0.5	2.0	0.5	0.5										
Alveolophragmium crassimargo	0.5	33.5		8.5	1.0	2.5										
Cribrostomoides jeffreysi		1.0														
Adercotryma glomerata	1.0	15.5		2.0		0.5										
Recurvoides turbinatus	1.0	6.0		2.5												
Trochamminella bullata		0.5				1.0										
Trochammina nana	1.0	10.5		2.0		2.5										
Spiroplectammina biformis	0.5	5.5		2.5		4.5	6.0	10.0								
Eggerella advena		3.0		2.5		0.5							0.7			
Cornuspira sp.		0.5														
Quinqueloqulina stalkeri							14.0	2.0	6.0	2.0	2.5	6.5		2.0		0.1
Miliolinella sp.											0.5					
Cibicides lobatulus		2.0		9.0	0.5	2.5	2.0					0.5		0.3		
Rosalina sp.											1.0					
Buccella frigida		7.5	1.0	6.0		1.5	4.0						0.3	0.3		
Nonionellina labradorica	14.0	27.0	10.5	21.5	41.0	10.5										
Astrononion gallowayi		4.5		2.0	0.5	3.0						0.5				
Protelphidium orbiculare				0.5		1.5										
Elphidium subarcticum				1.0		1.0										
Elphidium clavatum	0.5	6.5	6.5	28.5	6.5	34.5	2.0	2.0			6.5	1.5	1.0	0.3		0.4
Cassidulina reniforme		9.0	2.5	14.0	5.0	29.0	50.0	28.0	52.0	8.0	6.0	1.5	0.7	2.0	0.1	0.5

Table 3. Continued

Station	68/31 L	68/31 D	68/3 L	68/3 D	68/32 L	68/32 D	896 L	896 D	874 L	874 D	894 L	894 D	68/33 L	68/33 D	895 L	895 D
Islandiella norcrossi + *Islandiella helenae*		10.0	11.0	19.5	13.5	31.5										
Bolivina pseudopunctata					1.5	0.5										
Trifarina fluens			0.5	0.5												
Stainforthia loeblichi		0.5	0.5	1.0	2.5	3.0										
Stainforthia schreibersiana									6.0		1.5				0.1	
Globobulimina turgida	0.5															
Robertina arctica	0.5					0.5										
Dentalina baggi	0.5															
Lagena semilineata		0.5														

10). The arenaceous foraminiferan *S. biformis* and the calcareous foraminifera *Q. stalkeri*, *C. lobatulus*, *Buccella frigida*, and *N. labradorica* in some intervals comprise >15% of the fauna. The ambiguous morphology (2 or 3 chambers) of many small-sized (ca. 0.063 mm) juvenile tests preclude identification to genus. These smaller tests compose up to 50% of the fauna in certain levels and

Table 4. Faunal and environmental characteristics of the foraminiferal distribution in Nordensheld Bay, Novaja Zemlja (N/A = none analysed)

Station	68/31 L	68/31 D	68/3 L	68/3 D	68/32 L	68/32 D	896 L	896 D	874 L	874 D	894 L	894 D	68/33 L	68/33 D	895 L	895 D
Benthics/10 cm^3	23.5	170.0	47.0	151.5	87.5	165.5	94.0	46.0	122.0	10.0	73.5	13.5	5.7	6.0	2.6	1.5
% Calcareous foraminifera	68	46	93	81	97	91	77	70	52	100	24	78	35	83	8	67
Calc/10 cm^3	16.0	78.0	43.5	123.0	84.5	150.5	72.0	32.0	64.0	10.0	18.0	10.5	2.0	5.0	0.2	1.0
Live Calc./Total Calc.		0.17		0.26		0.36		0.69		0.86		0.63		0.29		0.17
Benthics Counted	47	320	72	264	148	268	47	23	61	5	147	27	17	18	26	15
No. of species, All	13	23	10	22	11	22	9	5	5	2	10	8	5	6	4	5
No. of species, Calcareous	5	10	7	11	8	12	5	3	3	2	6	5	3	5	2	3
% Live	12		24		35		67		92		84		49		63	
Biomass, mg/10 cm^3	N/A		N/A		N/A		0.021		0.030		0.029		N/A		0.001	
Planktics Counted (*Neogloboquadrina pachyderma* sin)		1														
Distance from glacier, km	48		36		25		24		12		10		7		3	
Sea depth, m	165		139		120		149		76		31		45		49	
% sediment fraction >0.063 mm	5.4		7.4		4.5		2.5		0.9		0.3		0.3		0.1	

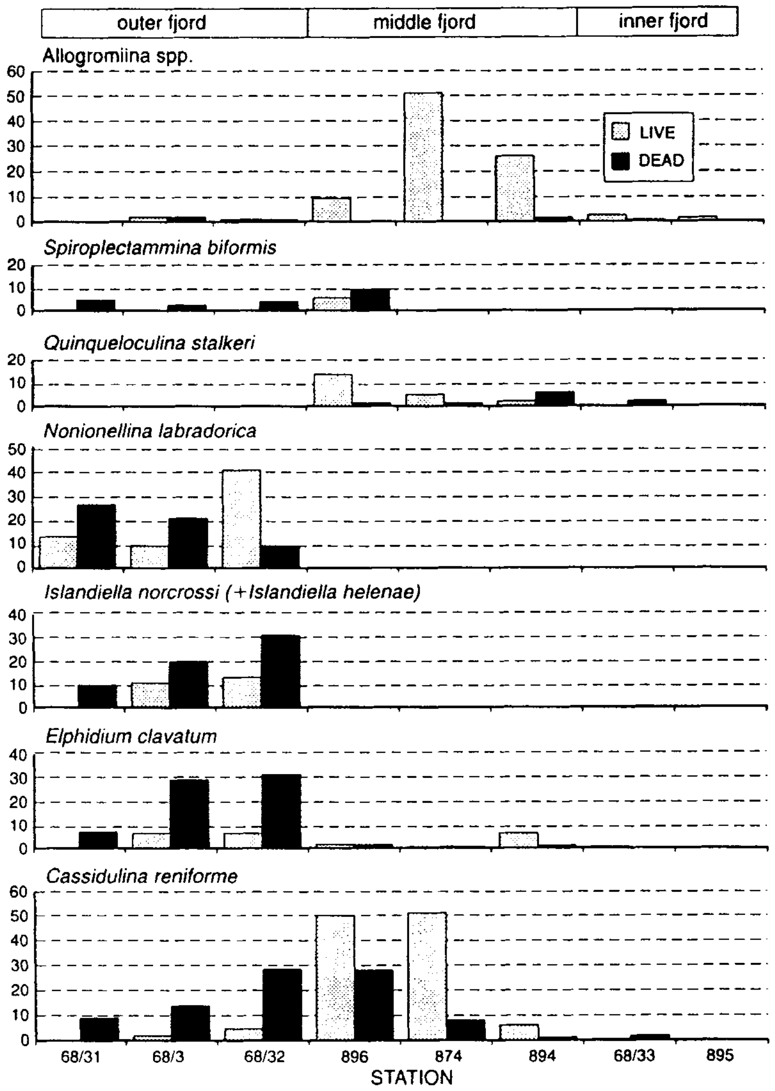

Fig. 7. The distribution of live dead benthic foraminifera (tests/10 cm^3) in Nordensheld Bay, Novaja Zemlja (collected in late August and early September 1990 and 1991).

are referred to as 'Varia uv.' (Figs. 9 and 10). The number of benthic species/sample and number of tests/100 g do not exhibit consistent downcore trends. Planktic foraminifera are rare in fjord sediments, reflecting the limited number of transported tests.

The abundance of foraminifera appears to increase with distance from the main outlet glacier in fjords on Spitsbergen and Novaja Zemlja. Cores Ho-3 and Be-1 from Hornsund and Bellsund collected within 0.5 km from the outlet glacier terminus at water depths of 30 m and 40 m, respectively, have a foraminifera abundance of < 100 test/100 g of sediment (Fig. 10). In contrast, core Ho-2, collected at ca. 2 km from the main outlet glacier at a water depth of 60 m has an abundance exceeding 200 tests/100 g (Fig. 10). A similar trend in foraminifera abundance is also recognised for glacier proximal and distal sites in Nordensheld Bay, Novaja Zemlja (Fig. 10).

Cassidulina reniforme *test size*

Initial observations indicated that tests of an individual species from fjord environments are smaller than tests from the Barents Sea. A series

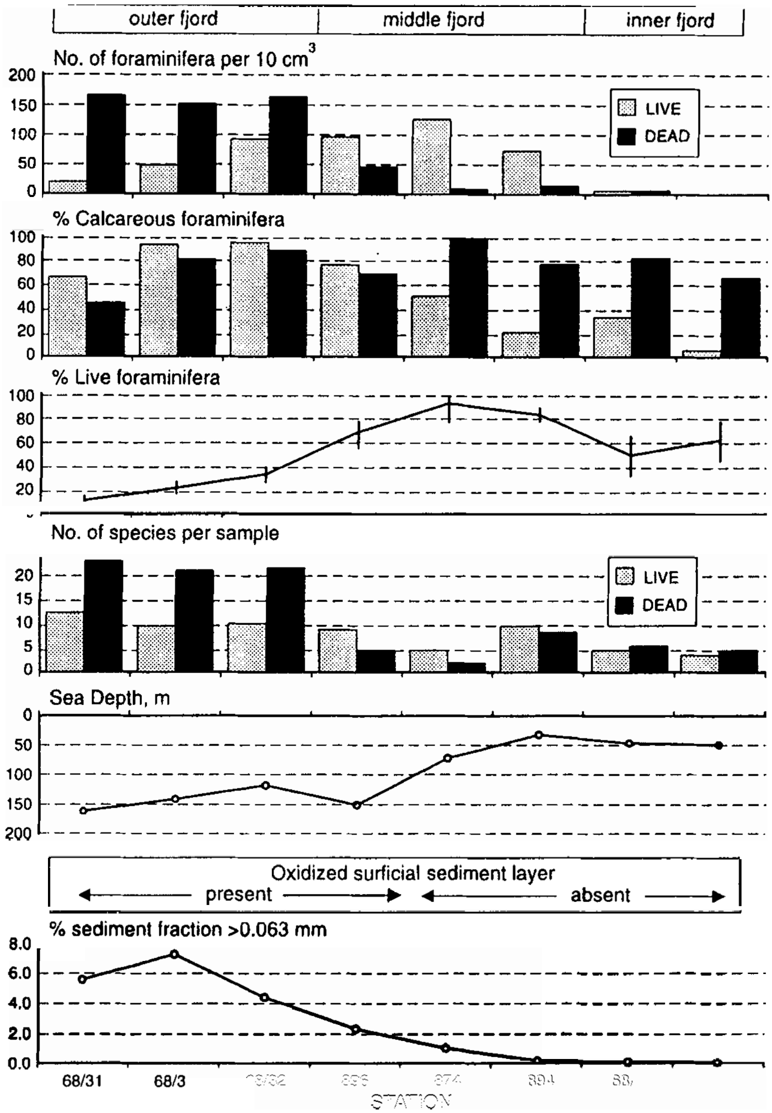

Fig. 8. Selected faunal and environmental characteristics of the foraminiferal distribution in Nordensheld Bay, Novaja Zemlja (collected in late August and early September 1991 and 1992).

of comparative measurements of *C. reniforme* tests from fjord and Barents Sea environments were undertaken to quantify these observations (Table 5). Intersample differences in mean test size for glaciomarine and marine sediments are insignificant (Fig. 11). In contrast, the difference between the mean of the greatest *C. reniforme* diameter from glaciomarine sediments and the mean value for marine sediments is significant at the highest standard confidence level, $t_{fact} = 6.20 > t_{0.001} = 3.29$. Tests are considerably larger in the Barents Sea, averaging at least 40 μm larger diameters than fjord specimens (Fig. 11).

There are distinctive differences between Nordensheld Bay foraminifera assemblages from the open Barents Sea and the coastal zone of Kola Peninsula, Svalbard, and Franz Josef Land. These near-shore areas are situated to the north of the Boreal-Arctic zoogeographic boundary of foraminifera (Fig. 1; Digas 1970). In comparison with Novaja Zemlja, the Svalbard fjords are similar in terms of presence of meltwater plums in the vicin-

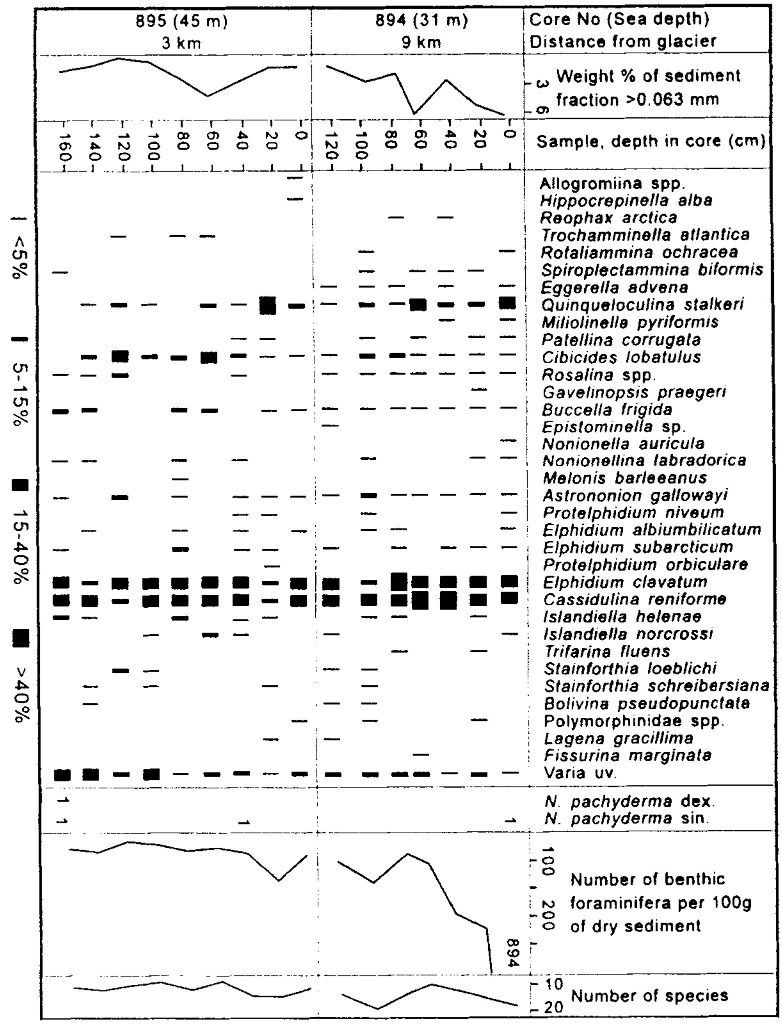

Fig. 9. Foraminiferal distribution in cores 895 and 894 from Nordensheld Bay, Navaja Zemlja.

ity of the subpolar glaciers. The Kola Peninsula does not have tidewater glaciers or any glaciers in vicinity of the coastline. Although Franz Josef Land is almost entirely covered by ice caps, these polar glaciers produce rare melt water plums.

In Nordensheld Bay, *N. labradorica* and *I. norcrossi* are the most abundant species in the outer fjord (68/31, 68/3, and 68/32). *C. reniforme* and Allogromiina spp. dominate foraminiferal fauna closer to Nordensheld glacier (Fig. 7). These taxa generally comprise a low percentage of the total foraminiferal fauna in the open Barents Sea (Digas 1970; Korsun et al. 1994), the coastal zone of the Kola Peninsula (Korsun 1986, 1992) and Franz Josef Land (Basov 1961; Lukina 1977).

There are broad similarities in the distribution of foraminifera in Nordensheld Bay and the fjords of Svalbard. *N. labradorica* and *C. reniforme* are two of six principal species identified from six fjords on western and northern Spitsbergen (Hald & Korsun, unpubl.). *C. reniforme* appears to inhabit environments closer to the fjord head while *N. labradorica* increases in abundance outfjord. *C. reniforme* is an opportunistic species and often dominates foraminiferal assemblages in stressed/unstable environments proximal to glacier discharge (e.g. Osterman & Nelson 1989). We assume that the substitution of *N. labradorica* and *I. norcrossi* by *C. reniforme* in Nordensheld Bay reflects increasing ecological instability toward the glacier.

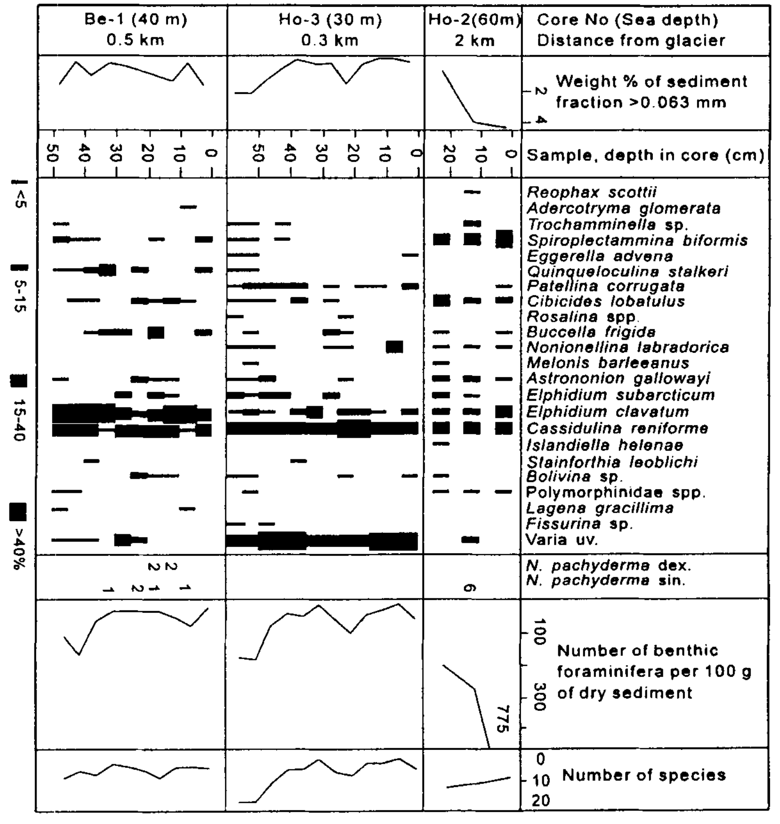

Fig. 10. Foraminiferal distribution in cores Be-1, Ho-3, and Ho-2 from Bellsund and Hornsund, Svalbard.

C. reniforme and another characteristic glacier-proximal calcerous species, *E. clavatum*, co-dominate fossil assemblages in the two Nordensheld cores (Fig. 9) and corresponding calcareous assemblages in grab samples 894 and 895 (Table 3). The dominant controls on the spatial distribution of *E. clavatum* in Nordensheld Bay remains unclear.

Number of live foraminifera and biomass in Nordensheld Bay

In outer and middle Nordensheld Bay (st. 68/31 through 894), the glaciomarine mud contains 24 to 122 live specimens/10 cm^3 (Fig. 8). This is similar to sandy and muddy sediments of the open Barents Sea where values mainly range from 25 to 200 with a mean of 90 tests/10 cm^3 (Korsun et

Table 5. A comparison of mean greatest diameter of *Cassidulina reniforme* test in glacimarine and marine sediments. x – diameter, SE – standard error, n – number of tests

Station	x (μm)	SE	n	General Location
		Marine sediments		
671	206.7	8.0	30	W Barents Sea
666	203.4	7.8	22	W Barents Sea
396	194.4	5.4	40	W Barents Sea
		Glacimarine sediments		
Ho-2	147.9	8.6	24	Hornsund, W Spitsbergen
894	168.5	6.8	50	Nordensheld Bay, N.Z.
895	161.4	11.5	22	Nordensheld Bay, N.Z.

Table 6. Number of calcareous foraminifera in grab and core samples from two sites in Nordensheld Bay, Novaja Zemlja (tests per 100 g dry sediment)

	Station 894	895
	Grab (0–1 cm)	
Total	200	8
Live	63%	17%
	Core	
mean ± SE	282 ± 100	54 ± 13
min	78	13
max	891	151
core top (0–5 cm)	891	52

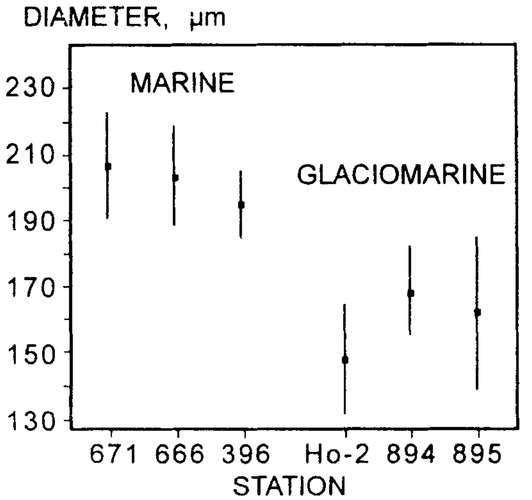

Fig. 11. Mean greatest diameter of the *Cassidulina reniforme* test in glaciomarine and marine sediments. Bar = 95% confidence interval.

al. 1994). In contrast, the biomass in the middle of Nordensheld Bay (0.03 mg/10 cm^3) is two orders of magnitude less than the biomass in adjacent areas of the sea (Fig. 12). The larger (>1 mm) arenaceous foraminifera such as *Rhabdammina abyssorum* (Sars, 1868), *Hyperammina subnodosa*, *Pelosina variabilis* are common in muddy Barents Sea sediments and constitute the majority, ca. 90%, of the foraminiferal biomass (Korsun et al. 1994). Such larger species or any foraminifera >0.250 mm in diameter are not found in Nordensheld Bay. Due to the smaller test size, the foraminiferal biomass is significantly lower in Nordensheld Bay than in the open Barents Sea though the number of live specimens is similar (Fig. 12).

Macrofauna biomass is low (<1 g/m^2) in glacier-proximal sediments with seasonal laminations in Hornsund (Görlich et al. 1987). The laminations indicate the absence of bioturbation and hence, an inhibited macrobenthos (Görlich et al. 1987). We infer that foraminiferal biomass shows a similar decrease in Nordensheld Bay, Novaja Zemlja.

Foraminiferal test size

The analysis of foraminifera from Novaja Zemlja and Svalbard fjords shows test size diminishing in the glaciomarine sediments compared to marine sediments from the open Barents Sea. In the glaciomarine sediments of Nordensheld Bay, foraminiferal tests are absent in sieve fractions >0.25 mm. In contrast, all of thirty-six foraminiferal samples from the open Barents Sea have a number of specimens larger than 1 mm (Korsun 1991). The studied cores show smaller test size from glaciomarine sediments, indicative of juvenile specimens. A high occurrence (up to 50%) of these small foraminifera has not been observed in Holocene sequences from the open Barents Sea (Østby & Nagy 1982; Korsun et al. 1994; among others). The high frequency of juvenile tests indicates a high mortality in the fossil populations. Feyling-Hanssen (1982) noted that

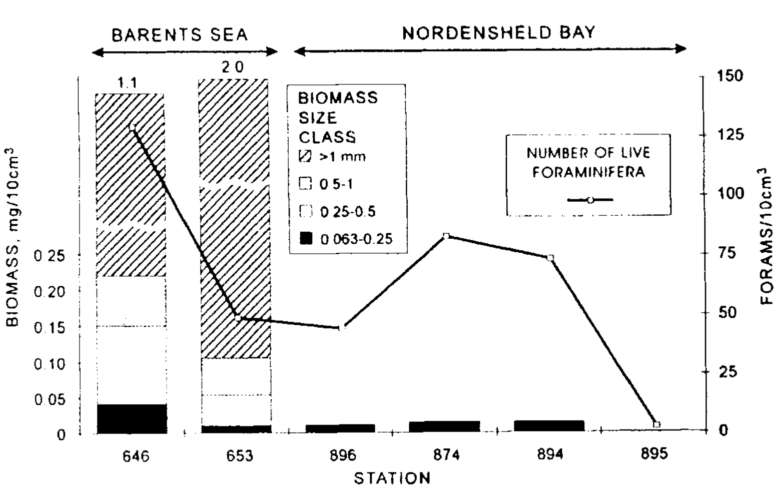

Fig. 12. Size distribution of foraminiferal biomass (cytoplasmic volume) and number of live foraminifera in Nordensheld Bay, Novaja Zemlja. Two samples from the northeastern Barents Sea are shown for comparison.

E. clavatum specimens from glacial deposits are smaller in comparison to tests from full marine environments. Our results show that the other foraminifera, typical of glaciomarine settings, *C. reniforme* (Osterman & Nelson 1989), demonstrate a similar tendency and the difference is highly significant. The linear size of *C. reniforme* tests in glaciomarine sediments of Nordensheld Bay (Novaja Zemlja) and Hornsund (Spitsbergen) is 20% smaller than in marine sediments of the open Barents Sea.

We presume that the smaller size of foraminifera in the glaciomarine sediments is an example of the opportunistic response to an environmental stress. In fjords influenced by glacier discharge, the inferred environmental parameters affecting benthic populations are meltwater discharge and high sedimentation rates (Appolonio 1973; Pierson 1980; Görlich et al. 1987). Intrusion of particulate rich meltwater into the bottom part of the water column is uncommon in glaciomarine environments (Gilbert 1983). Meltwater usually occupies the upper part of the water column and indirectly effects benthos communities via diminishing the primary production in the plankton community, that reduces organic flux to the bottom (Görlich et al. 1987). We favour high sedimentation rates as the dominant controlling factor for diminishing foraminiferal test size. Rapid settling of sediment and turbidite deposition may continuously disturb benthos communities burying the fauna and maintain the benthos community at an early stage of the succession. Such pioneer communities are characterised by high mortality of immature specimens and typically consist of opportunistic species which have a small size and a short life cycle (Odum 1971).

The foraminiferal test size decreasing in the studied glaciomarine sediments versus the full marine sediments in the open Barents Sea is expressed in the absence of larger species, paucity of large specimens, and high occurrence for juvenile foraminifera. This difference may be useful as another indicator of glaciomarine settings in paleoreconstructions.

Rare species

The foraminiferal fauna in the studied glaciomarine sediments (Table 2) is represented mostly by taxa characteristic of the Arctic zoogeographic province of the Barents Sea (Digas 1970). There are two species whose presence is quite unusual for the Barents Sea region, *P. niveum* and *Q. stalkeri*.

We found the first species, *P. niveum*, in both cores from Nordensheld Bay but not in the modern samples. This species has not been registered in the surface sediments of the open Barents Sea (Digas 1970; Steinsund et al. in press). Several tests (unstained) have been observed in the inner part of Yarnyshnaya Bay, Kola Peninsula, 69°07′N, 36°03′E (Korsun 1986). Live specimens of this foraminifera are only found in two shallow water sites at 4 and 12 m on Franz Josef Land (Korsun unpubl. data). The limited occurrence of this species precludes an environmental interpretation.

Q. stalkeri is present in the modern samples and in all the cores except for Ho-2. It is a subdominant or dominant species in several samples (Figs. 7, 9, and 10). This species is quite rare in the open Barents Sea. In the total calcareous foraminiferal data set for the Barents and Kara Seas (598 samples; Steinsund et al. in press), *Q. stalkeri* occurs (about 1%) only in 10 samples from the open Sea. No live specimen of this species is found in sixty samples from the open Barents Sea (Korsun et al. 1994). *Q. stalkeri* has been registered neither in the Kola Peninsula Bays (Schedrina 1958; Korsun 1986, 1992) nor in Franz Josef Land (Basov 1961; Lukina 1977).

In contrast, *Q. stalkeri* is common in surface sediments from Svalbard fjords (Nagy 1965; Elverhøi et al. 1980). This species, including live specimens, was identified in six fjords on western and northern Spitsbergen and composed up to 14% of the total fauna (Hald & Korsun, unpubl.).

Although, *Q. stalkeri* has been supposedly found in a variety of near-shore environments (Feyling-Hanssen et al. 1971), the occurrence of the species in the Barents Sea region seems to have some connection to modern fjord environments of Novaja Zemlja and Svalbard. *Q. stalkeri* is possibly an indicator of glaciomarine depositional environments.

Conclusion

N. labradorica and *I. norcrossi* reach peak abundance in the outer fjord samples.

C. reniforme and Allogromiina spp. dominate foraminifera in the middle and inner fjord, closer to the glacier outlet. The foraminiferal distribution and changing dominance of species in Nordensheld Bay is similar to Svalbard fjords that are affected by glacial discharge. Ecological stress is probably caused by the high and changeable sedimentation rate and meltwater flux (c.f. Görlich et al. 1987).

Q. stalkeri is frequent in Novaja Zemlja and Svalbard fjords compared to the other areas of the Barents Sea region as a possible indicator of glaciomarine settings.

In Nordensheld Bay, the number of live foraminifera in the outer and middle fjord (24–122 spec./10 cm^3) is similar to the values from the open Barents Sea, whereas the biomass (0.03 mg/10 cm^3) is two orders of magnitude less due to a smaller test size.

Tests of *C. reniforme* are significantly smaller in glaciomarine sediments than in marine sediments in the Barents Sea. Glaciomarine sediments have in general a noticeable lack of large tests and species and an abundance of juveniles. The smaller test size is an opportunistic response of the foraminiferal populations to the environmental stress of glacier proximity.

Acknowledgements. – G. A. Tarasov supplied cores from Bellsund and Hornsund fjords. Early reviews by G. G. Matishov, P.-I. Steinsund, M. Hald, J. Snyder, P. N. Webb, A. Reed and D. Rodbell were helpful in focusing the discussion. C. Hart and J. Snyder assisted with translation. We gratefully acknowledge the captains and crews of the R/V DALNIE ZELENTSY and R/V POMOR for providing a reliable sampling platform. This research was partially supported by the U.S. National Science Foundation Grant DPP-9001471 and the Office of Naval Research Contract N00014-92-1908. We appreciate the draftmanship of J. Nagy and word-processing assistance of S. J. Harris. This is BPRC contribution #948.

References

Aksyonov, A. A. (ed.) 1987: *The Arctic shelf of Eurasia during the Late Quaternary.* Nauka, Moscow. 278 pp. (In Russian).

Appolonio, S. 1973: Glaciers and nutrients in Arctic seas. *Science 180.* 491–493.

Basov, V. A. 1961: Composition and distribution of foraminifera in sediments from Franz Josef Land. *Trudy NIIGA 124,* 61–65. (In Russian).

Boulton, G. S. 1990: Sedimentary and sea level changes during glacial cycles and their control on glaciomarine facies architecture. Pp. 15–52 in Dowdeswell, J. J. & Scourse, J. D. (eds.): *Glaciomarine Environments: Process and Sediments.* Geological Society, Avon, United Kingdom.

Chinarina, A. D. (ed.) 1992: *Complex international expedition of the Murmansk Marine Biological Institute into areas of high-latitude archipelagoes of the Barents Sea (Franz Josef Land and Novaya Zemlya.* Apatity. 54 pp. (In Russian with English Abstract).

Digas, L. 1970: Zoogeographic zonation of the Barents Sea on foraminifera [Zoogeograficheskoe rajonirovanie Barentseva morja po foraminiferam. Pp. 127–142 in *Voprosy geologii Juzhnogo Urala i Povolzh'ja.* Saratov University, Saratov, Russia. (In Russian).

Elverhøi, A., Liestol, O. & Nagy, J. 1980: Glacial erosion, sedimentation and microfauna in the inner part of Kongsfjorden, Spitsbergen. *Norsk Polarinst. Skrifter 172,* 33–61.

Elverhøi, A., Lønne, Ø. & Seland, R. 1983: Glaciomarine sedimentation in a modern fjord environment, Spitsbergen. *Polar Res. 1,* 127–149.

Feyling-Hanssen, R. W., 1964: Foraminifera in Late Quaternary deposits in the Oslofjord area. *Norges Geol. Unders. 225,* 383 pp.

Feyling-Hanssen, R. W. 1982: Foraminiferal zonation of a boring in Quaternary deposits of the northern North Sea. *Bull. Geol. Soc. Denmark 31,* 29–47.

Feyling-Hanssen, R. W., Jørgensen, J. A., Knudsen, K. L. & Andersen, A-L. L. 1971: Late Quaternary Foraminifera from Vendsyssel, Denmark and Sandnes, Norway. *Bull. Geol. Soc. Denmark 21(2–3),* 67–317.

Gataullin, V. N., Polyak, L. V., Epstein, O. G. & Romanyuk, B. F. 1993: Glacigenic deposits of the Central Deep: A key to the Late Quaternary evolution of the eastern Barents Sea. *Boreas 22,* 47–58.

Gilbert, R. 1983: Sedimentary processes of Canadian Arctic fjords. *Sedimen. Geol. 36,* 147–175.

Goës, A., 1892: Rhizopodia reticulata insamlade vid Spitsbergen 1890. Pp. 77–78 in Nordenskiold, G. (ed.): Redögorelse for den svenska expedisjonen till Spitsbergen. *Svenska Vetens.-Akad. Handl. Bihanga 17,* 77–78. (In Swedish).

Goës, A., 1894: A synopsis of the Arctic and Scandinavian recent marine foraminifera hitherto discovered. *Svenska Vetens.-Akad. Handl. 25,* 1–127.

Görlich, K., Weslawski, J. M. & Zajaczkowski, M. 1987: Suspension settling effect on macrobenthos biomass distribution in the Hornsbund fjord, Spitsbergen. *Polar Res. 5 n.s.,* 175–192.

Hald, M., Danielsen, T. K. & Lorentzen, S. 1989: Late Pleistocene-Holocene foraminiferal distribution in the southwestern Barents Sea: Paleoenvironmental implications. *Boreas 18,* 367–388.

Hansen, A. & Knudsen, K. L. 1992: Recent foraminifera in Freemansundet, eastern Svalbard. Pp. 177–189 in Møller, P., Hjort, C. & Ingolfsson, Q. (eds.): *Weichselian & Holocene glacial and marine history of east Svalbard: Preliminary report on the PONAM fieldwork in 1991.* LUNDQUA Report 35.

Kirienko, E. A. 1984: Holocene foraminiferal assemblages from the Isfjorden, Spitsbergen. *Proceedings of Leningrad University, Series 6 Geology and Geography 1,* 56–69. (In Russian).

Kiær, H. 1899 Talamophora. Den norske nordhavs-eksedition, 1876–1878. *Zoologi 7(25),* 1–13.

Korsun, S. A. 1986: Modern foraminiferal assemblages of an open fjord-like inlet, Eastern Murman. Pp. 176–184 in: *Quaternary Paleoecology and Paleogeography of northern seas.* Nauka, Moscow. (In Russian with English abstract).

Korsun, S. A. 1991: Foraminiferal biomass evaluation: determination of average test volume in different sieve fractions. Pp. 81–93 in: *Information Science and Statistics in Hydrobiological Studies of the Barents Sea.* Kola Science Center Publishers, Apatity, Russia (In Russian with English abstract).

Korsun, S. A. 1992: Foraminiferal distribution in the estuary of Rynda river, Eastern Murman, Barents Sea. Pp. 150–170 in: *Problems of Cenozoic Paleoecology and Paleogeography of seas of the Polar Ocean.* Nauka, Moscow. (In Russian with English abstract).

Korsun, S. A., Pogodina, I. A., Tarasov, G. A. & Matishov, G. G. 1994: *Foraminifera of the Barents Sea (Hydrobiology and Quaternary Paleoecology).* Kola Science Center Publishers, Apatity, Russia. 250 pp. (In Russian with English abstract).

Luczkowska, E. 1975: Middle Holocene Foraminifera from Hornsund, Spitsbergen. *Studia Geologica Polonica 44*, 93–114.

Lukina, T. G. 1977: Foraminifera of the upper parts of the shelf near Franz Josef Land. Pp. 72–105 In: *Biocoenoses of Franz Josef Land and fauna of adjacent shelf. Studies of fauna of seas 14.* Zool. Inst., Leningrad, Russia. (In Russian with English abstract).

Murmansk Hydrometeorological Survey, 1988: *Information on water temperature of the Barents Sea.* Murmansk, Russia 100 pp. (In Russian).

Nagy, J. 1965: Foraminifera in some bottom samples from shallow waters in Vestspitsbergen. *Norsk Polarisnt. Årbok 1963*, 109–128.

Norman, U. 1987: Hydrografiske Observations fra Svalbard, 1984, 1985. *Tromura 53*, 129 pp.

Odum, E. P. 1971: *Fundamentals of Ecology.* 3rd ed., W. B. Saunders Co., Philadelphia. p. 740.

Østby K. L. & Nagy J. 1982: Foraminiferal distribution in the western Barents Sea, Recent and Quaternary. *Polar Res. 1*, 53–95.

Osterman, L. E. & Nelson, A. R. 1989: Latest Quaternary and Holocene paleoceanography of the eastern Baffin Island continental shelf, Canada: benthic foraminiferal evidence. *Can. J. Earth Sci. 26*, 2236–2248.

Pierson, T. H. 1980: Macrobenthos of fjords. *Fjord Oceanography, NATO Publ. Series.*

Potekhina E. M., Khusid, T. A., & Belyaeva N. V. 1991. Foraminifera and mineral particles in sea ice from bays of Northern Island of Novaya Zemlya. *Bull. MOIP. Geol. 66(2)*, 126–127.

Rouvillois, A., 1966 Contribution a l'étude micropaléontologique de la Bai du Roi, au Sptizberg. *Revue des Micropaleonolgie 9*, 169–176.

Sakharova, I. A. & Korsun, S. A. 1989: Productivity oscillations and biostratigraphy of northern seas. Foraminiferal analysis. Pp. 65–82: *In: Quaternary Paleoecology and Geology of the Northern European Seas.* Kola Science Center Publishers, Apatity, Russia. (In Russian with English abstract).

Schedrina Z. G. 1958: Foraminifera of eastern Murman. *Publ. Murmansk Biol. Station 4*, 118–129.

Spiridonov, M. A., Rybalko, A. Y. & Polyak, L. V. 1992: Late Quaternary stratigraphy and paleogeography of the eastern Barents Sea off central Novaya Zemlya. Pp. 47–68 in Spiridonov, M. A. & Rybalko, A. Y. (eds.): Sedimentary cover of glaciated shelf, North-Western seas of Russia. (In Russian).

Steinsund, P. I., Polyak, L., Hald, M., Mikhailov V., & Korsun, S.: Recent distribution of calcareous benthic foraminifera in the Barents and Kara Sea. *J. Foram. Res.* in press.

Tantsiura, A. I. 1973: On the currents of the Barents Sea, *Transactions of the Polar Scientific Research Institution of Marine Fisheries and Oceanography – N. M. Knipoui (PINRO).* In Russian, translated to English by the Norwegian Polar Institute, Oslo.

Tarasov G., Nurenberg D., Grot E., & Khasankaev N. 1993: The bottom sediments. Pp. 22–26 in: *Reports on the international multi-disciplinary cruise to high-latitude archipelagoes of the Barents Sea (Franz Josef Land and Novaya Zemlya).* Kola Science Center Publishers, Apatity, Russia.

Vinje, T. & Kvambekk, Å. S. 1991: Barents Sea drift ice characteristics. Pp. 59–68 in Sakshaug, E., Hopkins, C. C. E. & Øritsland, N. A. (eds.): Proceedings of the Pro Mare Symposium on Polar Marine Ecology, Trondheim, 12–16 May 1990. *Polar Res. 10(1).*

Vorren T. O., Hald, M., & Thomsen, E. 1984: Quaternary sediments and environments on the continental shelf off northern Norway. *Mar. Geol. 57*, 229–257.

Weslawski, J. M., Jankowski, A., Kvasniewski, S., Swerpel, S. & Ryg, M. 1991: Summer hydrology and zooplankton in two Svalbard fiords. *Polish Polar Res. 12*, 445–460.