Foraminiferal stratigraphy of raised marine deposits, representing isotope stage 5, Prins Karls Forland, western Svalbard

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Bergsten, H., Andersson, T. & Ingólfsson, Ó. 1998: Foraminiferal stratigraphy of raised marine deposits, representing isotope stage 5, Prins Karls Forland, western Svalbard. *Polar Research 17(1)*, 81–91.

Two raised marine sequences from Prins Karls Forland, western Svalbard, interpreted to have been deposited during part of isotope substage 5e (Eemian) and substage 5a, were studied for foraminifera content. Time constraints are given by ^{14}C ages, infrared stimulated luminescence age estimates and amino acid ratios in subfossil marine molluscs. A diamicton (unit B) separates the two marine sequences and reflects an advancement of local glaciers sometime late in isotope stage 5. The two marine sequences contain diverse benthic foraminiferal faunas, indicating periods of a relatively warm and seasonally ice-free marine shelf environment. Compared to the lowermost sequence (unit A), the upper marine sequence (unit C) seems to reflect a more shallow environment that could have resulted from the global lowering of the sea level towards the end of isotope stage 5. Our results further emphasise the problem of biostratigraphic distinction between interglacial and interstadial deposits at high latitudes, with temperature conditions for substage 5a close to those of substage 5e and present conditions.

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Introduction

The Poolepynten site is situated on Prins Karls Forland, western Svalbard at N78°27′/E11°40′ (Fig. 1). It is one of few sites from the Svalbard area that displays well-preserved marine biostratigraphic sequences of late Quaternary sediments. Previous investigations of Spitsbergen foraminiferal faunas, interpreted to represent this time-interval, have been presented by Feyling-Hanssen & Ulleberg (1984), Miller et al. (1989) and Lycke et al. (1992). The aim of this study is to present the foraminiferal stratigraphy and the inferred palaeoenvironmental conditions of the Poolepynten site in order to address the question of biostratigraphic distinction between interglacial and interstadial deposits at high latitudes (e.g. Sejrup & Larsen 1991). The results are compared with documented modern and Holocene data, and an effort is made to correlate our data to other Svalbard localities with documented foraminiferal stratigraphies from uplifted pre-Holocene sediments. In addition, open-water conditions and the advection of Atlantic water into the Svalbard area during the late Quaternary (Gard 1988; Dokken & Hald 1996; Hebbeln & Wefer 1997) are discussed.

Chronology and glacial history

Sediments in the Poolepynten sections are exposed in up to 10 metre high coastal cliffs over a distance of approximately 800 metres. The deposits were previously identified and described by Miller (1982) and Forman (1986). More recently Andersson et al. (unpubl.) identified and described four main lithostratigraphic units (A–D) and corresponding depositional events (Fig. 2). Units A and C comprise horizontal to subhorizontal planar parallel beds of fine to medium sand, deposited from sediment gravity flows in a near-shore, shallow marine/sublittoral environment. In situ marine molluscs, beds with marine kelp and dropstones frequently occur in both units. Unit B is divided into two subunits. Subunit B1 is a massive, silty/clayey diamicton and is interpreted as a subglacial till. A clast fabric analysis indicates that it was deposited by a local glacier advancing from Prins Karls Forland into the Forlandsundet basin. Subunit B2 is a coarse grained deposit of sub-angular to sub-rounded gravel and cobbles, interpreted as an ice-proximal outwash deposit related to the glacial event that deposited the subunit B1 till. Unit D unconform-

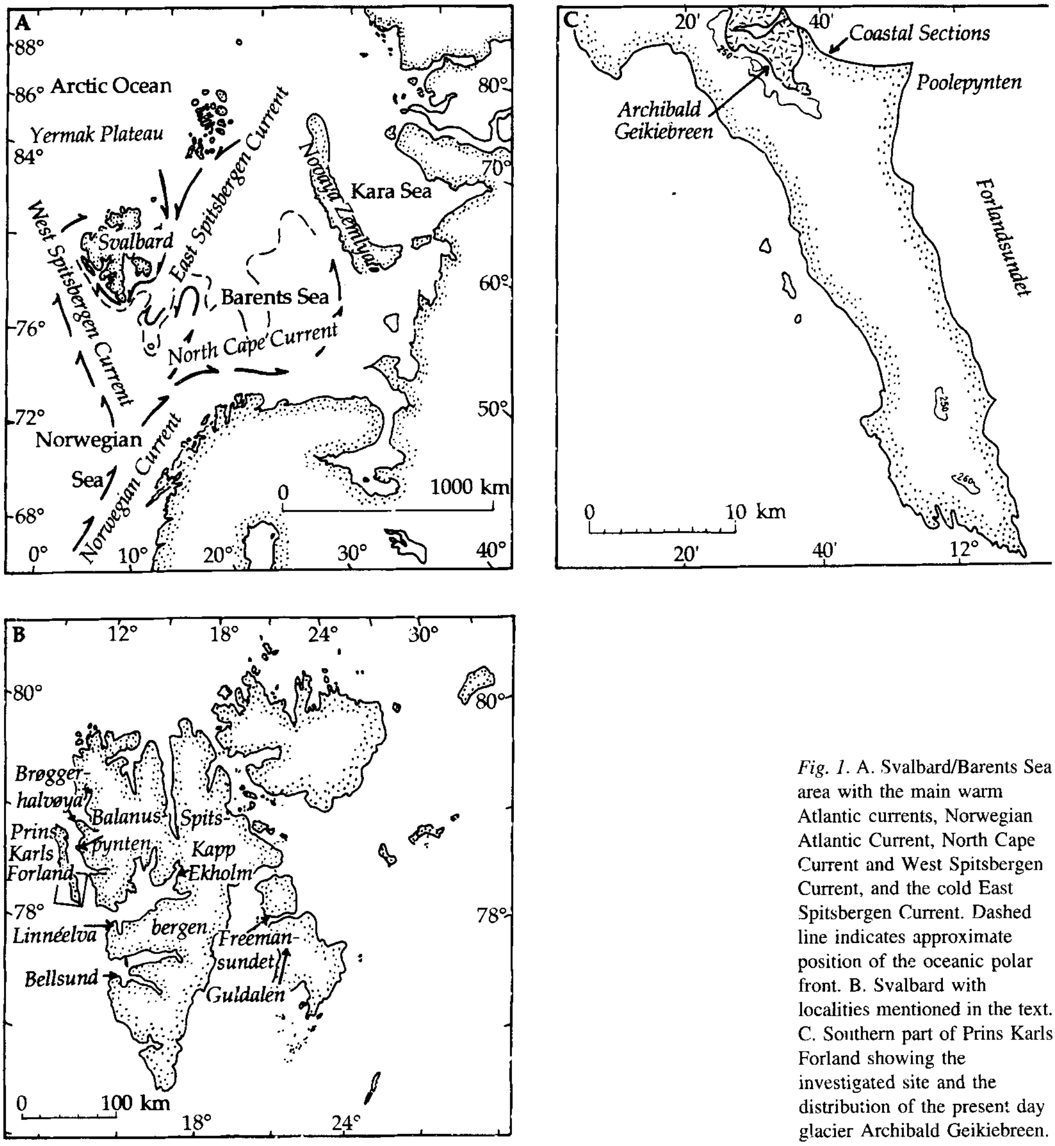


Fig. 1. A. Svalbard/Barents Sea area with the main warm Atlantic currents, Norwegian Atlantic Current, North Cape Current and West Spitsbergen Current, and the cold East Spitsbergen Current. Dashed line indicates approximate position of the oceanic polar front. B. Svalbard with localities mentioned in the text. C. Southern part of Prins Karls Forland showing the investigated site and the distribution of the present day glacier Archibald Geikiebreen.

ably overlies units A and C. It comprises clast- and matrix-supported gravel, interpreted as a littoral beach deposit.

AMS ^{14}C ages from units A and C show infinite ages of >49 ka BP (Fig. 2). Two infrared stimulated luminescence age estimates from units A and C provide broad temporal constraint, with age envelopes between 130 and 80 ka and 70 to 40 ka, respectively. Correlation of the Poolepynten stratigraphic data to other west Spitsbergen sites, in combination with the broad temporal constraints, led Andersson et al. (unpubl.) to infer a shallow marine/sublittoral deposition during part of the history from the Eemian (substage 5e; 130 to 117 ka) to the Holocene. (All isotope stages refer to marine isotope stages; the chronology is according to Martinson et al. 1987). ^{14}C dated whalebone and mollusc shells from unit D,

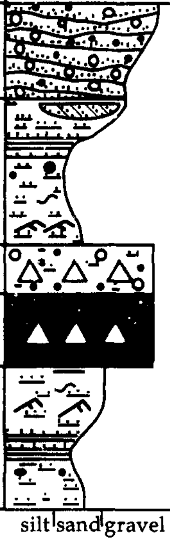
Local unit	Composite lithological log	Depositional event	^{14}C years BP	IRSL age (ka) estimate	Mean Tot D/L ratio	Chrono-stratigraphy	Inferred age (ka)
D		Littoral deposition	8810 ±135 11 340 ±150		0.020 ± 0.002	Holocene/ Late Weichselian	8 - 11
		(Erosion)					(Hiatus)
C		Sublittoral/ shallow-marine deposition	>49 000	40 - 70	0.021 ± 0.003	Early Weichselian	70 ± 10
B2		Ice-proximal deposition				Early Weichselian	80 ± 10
B1		Subglacial deposition					
A		Sublittoral/ shallow-marine deposition	>49 000	80 - 150	0.025 ± 0.001	Early Weichselian	80 ± 10
							(Hiatus)
					0.045 ± 0.001	Eemian	ca 130

Fig. 2. Composite log of the Poolepynten stratigraphy. Unit thicknesses are arbitrary (from Andersson et al. unpubl.). Reported Late Weichselian/early Holocene ^{14}C ages have been corrected for a marine reservoir effect of 470 years (Stuvier & Braziunas 1993).

indicate that this unit was deposited in the interval between 8 and 11 ka BP.

Climate and oceanography; the last interglacial–glacial cycle

The stratigraphic record for western Svalbard displays at least three deglacial events during the last interglacial–glacial cycle, i.e. the last 130 ka years (Miller et al. 1989; Larsen et al. 1991). Four emergence cycles, interpreted to represent deglacial events during the last interglacial–glacial cycle, are recognised in the Kapp Ekholm stratigraphy, central Spitsbergen (Mangerud & Svendsen 1992). However, beyond the range of the ^{14}C method, the precision in the dating methods is still too low to resolve these events satisfactory. A recent geochronologic study using the infrared and red stimulated luminescence dating techniques, indicates deglaciation and retreat of the Barents Sea ice sheet at ca 140 ± 20 ka and 70 ± 10 ka (Forman unpubl.). A high concentration of ice-rafted debris (IRD) around 50–60 ka BP, attributed to glacier advances on Svalbard, is recorded by Hebbeln (1992) from deep-sea sediment in the Fram strait, and by Andersen et al. (1996) from shallow cores from the western Svalbard continental slope.

Present-day sea surface and air temperatures, as well as the overall climatic setting in the Svalbard area, are determined by the prevailing ocean circulation pattern. Today warm North Atlantic Surface Water is advected northwards by the Norwegian Current (Fig. 1). The detailed pattern of the advection of North Atlantic water northwards during stage 5 onwards is not known for the Polar North Atlantic, but it can be stated that for the last ca. 130 ka there has been an advection of North Atlantic waters towards the Svalbard area during several occasions. However, there are highly different opinions on whether isotope substage 5e (Eemian) in this area was warmer or colder than present day temperatures. In studies of late Quaternary nannofossils from the surrounding seas, Gard (1988) argues that the warmest sea surface temperatures and a strong West Spitsbergen Current system are recorded during substage 5e (130 to 117 ka) with similar but slightly colder conditions during substage 5a (85 to 74 ka). Gard argues for some open waters and an intermediate climatic regime in the Svalbard area during stage 3 (59 to 24 ka) and then again an interglacial regime in the Holocene. Hebbeln & Wefer (1997) report seasonally ice-free conditions and advection of Atlantic water into the Fram Strait during isotope substages 5e (Eemian), 5a and the Holocene with the strongest advection and warmest conditions during the Holocene. Furthermore, they present data indicating a weaker advection of Atlantic water during substage 5e than in substage 5a. This also contrasts to data from the Nordic Seas that indicates a stronger heat flux during interglacial times than at any time during the Early Weichselian (Fronval & Jansen 1997). Dokken & Hald (1996) recorded six periods of sea-ice break-up and a high production of foraminifera in the Polar North Atlantic during stages 4, 3 and 2 (74 to 12 ka), attributed to inflow of North Atlantic Surface Water. The oldest of their high productive periods is dated to ca >60–54 ka. Fronval & Jansen (1996, 1997) show that the climate during substage 5e, at least within the Norwegian–Iceland Sea, was less stable than that of the Holocene and that the transition from the Eemian to the cold substage 5d was characterised by fluctuating climatic conditions.

A direct connection between glacier expansion and cold climate, as can be made for north-west Europe, seems not to be applicable for Svalbard (cf. Larsen et al. 1991). Glacier expansion in the Svalbard area seems to be more closely connected to short-distance open waters as precipitation source for the build-up of on-shore ice (Hebbeln et al. 1994).

Results

A total of 16 samples from the shallow marine/sublittoral sequences (units A and C) were analysed for their content of foraminifera. The samples were freeze-dried and washed over a 125 μm sieve, and then density separated. Between 300 and 900 specimens were counted in each sample. A total of 42 benthic taxa were identified (Table 1); four samples contained single planktonic specimens. The fauna consists almost exclusively of calcareous species. The frequency of selected species and a composite log of the stratigraphy are presented in Fig. 3.

Unit A is characterised by a high diversity of species; the total number of species varies between 16 and 32, with the highest number in the lowermost sample. The unit is dominated by *Cassidulina reniforme* (50–72%) together with *Astrononion gallowayi* (3–31%) and *Elphidium excavatum* (3–15%). A number of common accessory species include *Buccella frigida*, *Guttulina* spp, *Haynesina orbiculare*, *Elphidium incertum* and *Islandiella helenae*. Some species are present in unit A only, e.g. *Bolivina pseudopunctata*, *Dentalina* sp., *Gavelinopsis praegeri*, *Glabratella wrightii*, *Glandulina* spp, *Quinqueloculina seminulum* and *Trifarina fluens*. The fauna contains mainly arctic species but a number of boreal-arctic species occur as well e.g. *B. pseudopunctata*, *Elphidium albiumbilicatum*, *E. incertum*, *Epistominella vitrea*, *G. praegeri* and *Rosalina* spp. The concentration of benthic foraminifera in unit A varies between 480 and 2020 specimens per 100 g dried sediment, which is generally higher than the values for unit C.

The common denominator of unit C is the high abundance of different *Elphidium* taxa (19–73%), with the highest percentages in samples no. 24–25 (69–73%) compared to 6–17% for unit A. Many of the specimens in unit C are worn and difficult to differentiate (especially in samples 24 and 25) and many *Elphidium* species have been grouped as *Elphidium* spp. This group contains foremost *E. excavatum*, *E. albiumbilicatum*, *E. magellanicum* and *E. incertum*. Samples no. 20–22 and no. 26–27 contain a high abundance of *C. reniforme* (34–44%) while samples no. 24–25 show a much lower abundance (5–13%) of this species. Both *Buccella frigida* and *Buccella frigida* v. *calida* are relatively common in this unit. Three of the taxa registered are present in unit C only: *Elphidium groenlandicum*, *Elphidium hallandense* and *Lagena* spp. The diversity in unit C is lower than in unit A and the total number of species per sample ranges between 10 and 15 with the exception of sample no. 22 where it is 22.

Discussion

Foraminiferal ecology and distribution

Faunas dominated by *E. excavatum* are common

Table 1. Percentages of foraminifera from the Poolepynten site.

	Unit C							Unit A								
Species Sample no.	20	21	22	24	25	26	27	40	42	30	31	32	47	48	49	50
Astrononion gallowayi	8.3	13.7	13.7	5.4	8.3	12.4	6.8	3.4	16.2	10.9	12.5	8.1	12.7	16.7	30.6	18.1
Astrononion stelligerum																0.1
Bolivina pseudopunctata									0.3	0.5	0.2	0.2	3.3	0.3	0.7	0.2
Buccella frigida	2.9	5.0	7.0	11.9	7.6	7.9	7.4	4.2	3.5	2.8	3.5	2.0	1.1	1.1	1.5	3.6
Buccella frigida var. *calida*	0.3	3.7			0.7	4.1	6.5	0.6	0.8	1.3	1.1	0.4	0.6	0.8	0.5	0.4
Cassidulina reniforme	39.3	27.2	50.0	5.0	13.0	33.5	44.2	69.5	50.7	68.2	70.5	72.4	63.0	63.3	50.0	61.9
Cibicides lobatulus		3.0	0.6	0.4	0.3	0.4	0.9	0.3	0.5	0.8	0.4	0.2	0.3	0.8	0.2	1.1
Dentalina sp.															0.2	0.1
Elphidium albiumbilicatum	5.4		7.8	5.4	2.0	7.3	3.6	0.3	0.5	0.8	1.6	1.8	0.3	0.6		1.1
Elphidium asklundi			0.3		1.0	0.2	0.9	0.6	0.2	0.3		1.0	0.6			0.2
Elphidium excavatum	14.6	17.0	7.2	3.1	12.6	11.8	13.4	15.1	12.0	6.8	4.4	5.6	10.2	6.2	7.8	3.1
Elphidium groenlandicum			0.1													
Elphidium hallandense		4.7		0.4	0.7	1.5										
Elphidium incertum			0.1			0.6	1.5		1.8	0.5		1.0	0.3	1.4	0.5	0.6
Elphidium magellanicum	0.6		0.7			0.4	2.7							0.3		0.6
Elphidium spp	26.4	25.2	2.4	64.2	52.2	18.8	9.8	0.8		1.0			0.3			0.2
Epistominella vitrea		0.2	0.1					0.8	0.7	0.3	1.2	0.8	0.3	1.4	1.0	0.9
Fissurina spp.		0.2	0.1			0.6	0.6	0.3		0.5		0.2	0.3		0.2	
Gavelinopsis praegeri												0.2				
Glabratella wrightii																0.1
Glandulina sp.									1.2	0.3	0.2	1.6		0.3		
Guttulina spp.			0.4					1.1	5.2	1.3	1.8	1.4	1.7	2.5	2.2	3.8
Haynesina orbiculare	0.3		1.5	2.7	0.7		1.2	1.4	3.7	1.0	1.2	0.6	2.2	2.8	0.2	0.1
Islandiella helenae			2.4						0.5	0.3	0.4	0.6	0.3	0.3	1.5	1.3
Islandiella islandica			0.6												0.2	0.3
Islandiella norcrossi			0.4						0.3	0.8	0.2	0.2		0.6	1.0	
Jadammina spp	1.1			1.2	0.3	0.4		0.3				0.2	0.3		0.5	0.1
Lagena spp.				0.4												
Miliolinella subrotunda										0.5						
Miliolids			1.8					0.3	0.5	0.8	0.5	0.4	0.3		0.2	0.1
Nonionellina labradorica			2.2					0.3	0.3			0.2	0.6			0.1
Oolina spp.			0.1		0.3				0.2	0.3		0.2		0.3		0.1
Patellina corrugata							0.3								0.2	0.3
Quinqueloculina agglutinata									0.2						0.2	0.1
Quinqueloculina seminulum								0.6	0.5	0.3	0.4		0.6			0.1
Quinqueloculina sp.														0.3		
Rosalina bradyi							0.3									0.2
Rosalina spp.	0.3								0.3			0.6				0.3
Stainforthia loeblichi			0.1					0.3								
Stainforthia schreibersiana																0.2
Trifarina fluens													0.3		0.2	0.1
Triloculina sp.													0.3			
Varia; agglutinated species													0.6			
Varia; calcareous species	0.6				0.3					0.3						0.1
No. of counted benthic foram.	349	401	670	260	301	468	337	357	600	396	567	496	362	354	408	896
Benthic foram./100 g sediment	1400	630	1910	320	150	550	380	480	2010	890	2020	1430	820	800	960	700
Total % of *Elphidium* species	47.0	46.9	18.6	73.1	68.5	40.6	31.9	16.8	14.5	9.4	6.0	9.4	11.7	8.5	8.3	5.8
Total % of calcareous species	98.9	100	100	98.8	99.7	99.6	100	99.7	99.8	100	100	99.8	99.1	100	99.3	99.8
No. of species	12	10	22	11	14	14	15	18	22	23	16	23	23	18	21	32
No. of planktonic foram.			4						1	1				1		

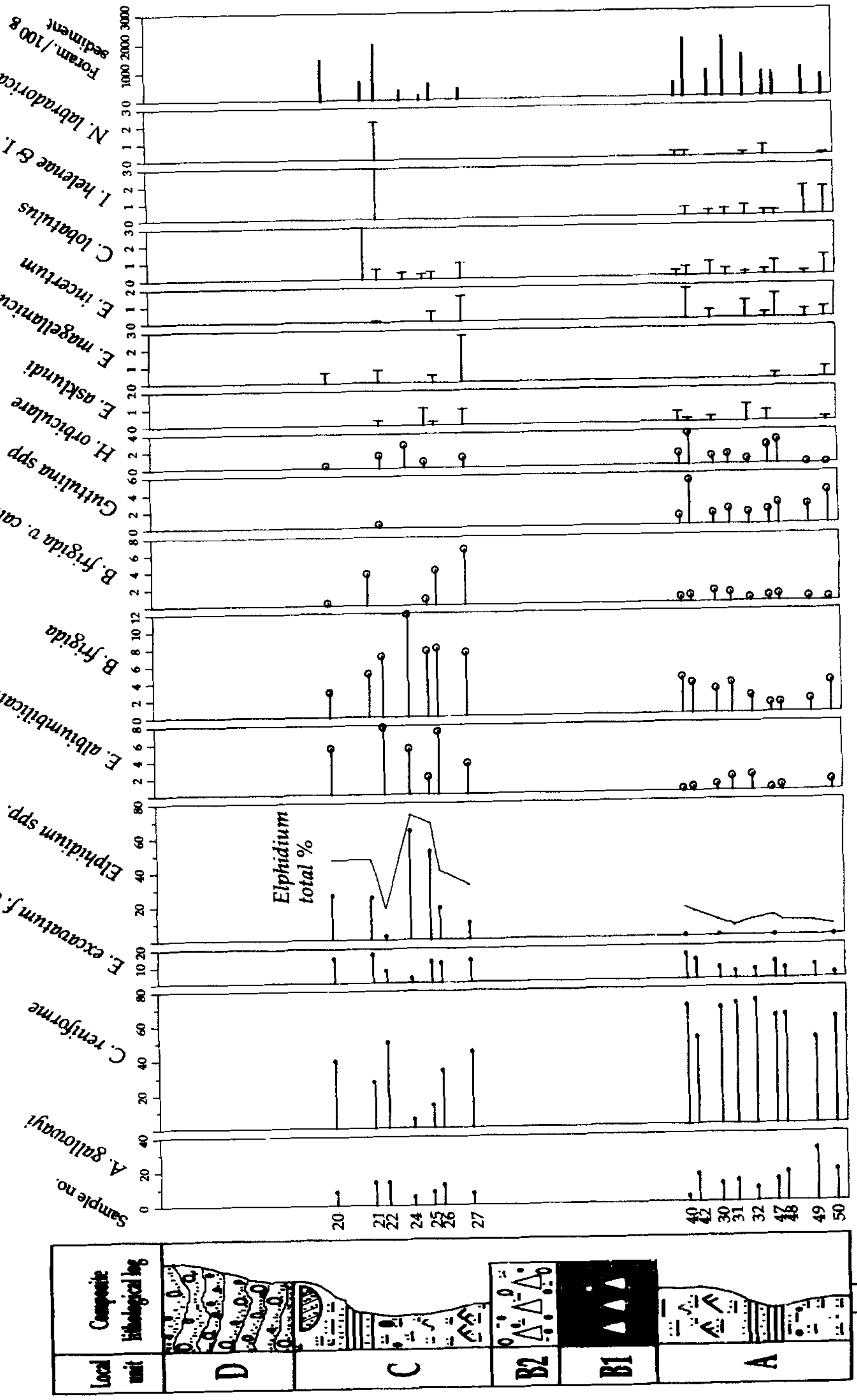


Fig. 3. Selected benthic foraminifera from the Poolepynten site combined with a composite log from the section. Unit thicknesses of the log are arbitrary. Please note the three different percentage scales for the foraminifera. Lithological legend in Fig. 2.

in late Quaternary shallow, near-glacial sediments in both north-western Europe and North America as well as Svalbard. In the Barents Sea, its modern distribution is related to temperatures of ≤1°C in turbid, shallow (<100 m water depth) and low saline waters (Hald et al. 1994; Steinsund et al. 1994). Also, in studies of recent foraminiferal assemblages from Spitsbergen fjords (Hansen & Knudsen 1995; Korsun et al. 1995; Hald & Korsun 1997) it can be seen that *E. excavatum* assemblages dominate the foraminiferal faunas near a glacier termini. In the Barents and Kara seas this species is related to low and fluctuating temperatures and salinity, high turbidity and sedimentation rates, and the presence of sea-ice (Steinsund et al. 1994). In addition many other *Elphidium* taxa are related to shallow, often brackish waters, in glacially influenced areas, i.e. *E. albiumbilicatum*, *E. magellanicum* and *E. incertum*.

E. excavatum is often accompanied by C. *reniforme*, both in modern faunas of the arctic shelves and in stratigraphic records of late glacial sediments of north-western Europe. It is also related to near-glacial conditions, although somewhat more distal to a meltwater source. In recent foraminifera of Spitsbergen fjords, faunas dominated by C. *reniforme* are correlative with winter-cooled waters in the inner part of the fjords; distally following the *E. excavatum* dominated area (Korsun et al. 1995; Hald & Korsun 1997). In the Barents and Kara seas Steinsund et al. (1994) found this species to occur with highest abundance at <1°C to freezing point where it also seems to tolerate low salinity, although preferring a salinity of >30‰. It generally occupies areas of larger depths than *E. excavatum*. Nevertheless, although the abundance of C. *reniforme* decreases with increasing water depth, it is still a common species at greater depths at places like the Yermak Plateau, Arctic Ocean, where it is recorded as a living species at water depths down to 2000 m (Bergsten 1994).

Astrononion gallowayi is a common secondary species of the arctic shelves today, although generally not reaching as high abundance as in the Poolepynten sediments. In the Barents and Kara seas, Steinsund et al. (1994) present the highest abundance close to the coast of Novaja Zemlja in temperatures between −1°C and +1.5°C and a salinity >31‰. *A. gallowayi* is also common in some surface samples from Freemansundet and in early Holocene sediments of Guldalen, Spitsbergen (zone B faunas; Hansen & Knudsen 1995) and is also a major living species in the fauna of Bellsund, Spitsbergen (Lycke et al. 1992).

Buccella frigida and *B. frigida* v. *calida* (often listed as *B. frigida*) are widely distributed secondary species in the area. *B. frigida* is a common living species in Bellsund (Lycke et al. 1992) and Hald & Steinsund (1996) relate these species to areas of seasonal ice with ice-edge algae blooms. Also, *I. norcrossi* and *I. helenae* seem to be linked to these conditions. *Haynesina orbiculare* and *E. incertum* show strong correlation to brackish environments (Steinsund et al. 1994). *Cibicides lobatulus* is favoured by coarse substrates due to its attached mode of life. *Bolivina pseudopunctata* is abundant in the living fauna of Bellsund, Spitsbergen (Lycke et al. 1992), as well as many other species that are characteristic of the Poolepynten site.

Inferred palaeoenvironmental conditions

Almost all the foraminifera species of the Poolepynten site are represented in recent to Holocene sediments of the Spitsbergen fjords and surrounding shelves although not always in the same combinations or abundance. Only single species occurring in low abundance, such as *Elphidium groenlandicum*, are not reported from modern or Holocene faunas of the surrounding area. Within the different foraminiferal zones the grain-size distribution of the investigated samples is comparatively homogeneous and differences within the foraminiferal faunas are therefore mainly related to other environmental factors.

During the deposition of the unit A and unit C sediments, glacio-marine conditions prevailed, indicated by relatively uniform and high values of C. *reniforme* in the sediments. In unit A C. *reniforme* dominates and accounts for ≥50% while *Elphidium* taxa dominate over C. *reniforme* in all but two samples in unit C. *Elphidium* taxa and C. *reniforme* together account for 58–86% in unit A and 64–86% in unit C. The glacial environment is, however, seasonally open towards the sea and the influence of North Atlantic water is seen through the diversity of other species. The dominance of *Elphidium* taxa in unit C in combination with the presence of species as *B. frigida*, *B. frigida* v. *calida* and *H. orbiculare* display a highly variable environment with presence of sea-ice and primary production blooms along the ice-edge and in seasonally open waters.

When comparing the absolute abundance of foraminifera in the Poolepynten site with those of modern Spitsbergen areas, the Poolepynten site shows values (median value; 812 specimens/100 g sediment) slightly higher than those of Freemansundet (Hansen & Knudsen 1995; median value, 247 specimens/100 g sediment). The total median value (6400 specimens/100 g sediment) for the seven Svalbard fjords presented by Hald & Korsun (1997) show higher numbers than those presented for the Poolepynten site. At least partly, the difference between Poolepynten and recent Svalbard fjords is explained by the preservation of a much higher amount of agglutinating taxa in recent faunas. Generally today, the most productive areas are associated with the Polar Front. Nutrient-rich water is also generated due to algae production along the ice-edge and in open channels in the ice during spring and summer.

The foraminiferal fauna of Poolepynten consists almost exclusively of calcareous benthic species (Table 1). This type of fauna is typical of the late-glacial shelf of north-western Europe as well as the modern and late Quaternary of Svalbard, and the Kara and Barents Seas. However, the absolute dominance (≥99%) of benthic calcareous species at the Poolepynten site is seldom seen in the modern environments of the area and disintegration of agglutinated specimens cannot be excluded. In the Poolepynten samples signs of carbonate dissolution are evident in unit C, especially in samples no. 24–25. Whether this is an effect of dense bottom water affecting the site occasionally or a secondary effect after burial of the shells is difficult to determine. However, juvenile gastropods in combination with the many juvenile individuals of *Macoma calcarea* in unit C indicate that carbonate dissolution has been of minor importance since deposition (Andersson et al. unpubl.).

When comparing the fauna of unit A with that of the present interglacial, i.e. the living and Holocene fauna of the Svalbard area (Elverhøi et al. 1980; Østby & Nagy 1982; Lycke et al. 1992; Hansen & Knudsen 1995; Hald & Korsun 1997), it can be seen that most of the species recur in both. However, the Holocene fauna in the area generally displays a higher abundance of *Elphidium* taxa than what is seen in unit A. *Elphidium*-dominated assemblages are common in the shallow fjord environments of Svalbard and other parts of the arctic region. It is therefore likely that unit A represents a slightly different environment than the present. The environment of zone A might have been more open than what is seen in the present Spitsbergen fjords and less influenced by near-glacial conditions although still close to glaciated areas. However, with regards to the calcareous fauna, there are similarities between unit A and the modern living Bellsund fauna (Lycke et al. 1992), although the Bellsund fauna show a prominent contribution of agglutinated species. The difference in the foraminiferal fauna of unit A compared to the Holocene might also be an indication of a more prominent influence of North Atlantic water and warmer conditions than today. This conclusion is supported by the high diversity fauna and the comparatively large number of species, which is especially evident in the lowermost sample (no. 50). Unit A can be concluded to have been deposited in a climatic setting similar to that of today, or possibly slightly warmer or more open to the sea.

Unit C displays a foraminiferal fauna reminiscent of modern and Holocene faunas of the area, and is interpreted to reflect a near-glacial, highly variable, seasonally open-water environment close to a glacier termini. Compared to unit A, the fauna in unit C seems to reflect a more shallow and enclosed environment, as seen in the increase of *Elphidium* taxa and a decreased diversity. Some of the change registered in the foraminiferal fauna could be due to shallowing of the area.

Palaeoclimatic setting of the Poolepynten section

On the basis of its stratigraphic position, lithology, foraminiferal content, reported ages and amino acid results (Figs. 2 and 3), the lower part of unit A of Poolepynten is interpreted to represent a relatively warm and seasonally ice-free period during isotope substage 5e (Eem; 130–117 ka). The lowermost sample of unit A (no. 50) contains a more diversified and North Atlantic-influenced fauna than the remaining samples and it is possible that this sample represents the end of a slightly warmer phase. This interpretation is supported by amino acid ratios on paired shells of *Hiatella arctica* from the same level in the stratigraphy, showing a mean Total value of 0.045 ± 0.001 (Fig. 2) that is correlative with the mean Total value of 0.044 ± 0.004 on shells from the purported Eemian (substage 5e) age deposit on Brøggerhalvøya (Miller et al. 1989). The picture of substage 5e in the North Atlantic region has lately been shown to be complex, with large fluctuations between warm and cool intervals (Seidenkrantz et al. 1995; Fronval & Jansen 1997). On the basis of the foraminiferal fauna, it is not possible to further distinguish if unit A reflects these climatic fluctuations or if the upper part of unit A is younger than substage 5e. However, amino acid ratios and reported luminescence age estimates indicate that the upper part of unit A is significantly younger than the lower part. On the basis of reported ages, and by correlation of stratigraphic data to other sites in western Spitsbergen, Andersson et al. (unpubl.) inferred a late stage 5 age (ca 80 ± 10 ka BP) for the upper part of unit A (Fig. 2). This implies that there may be a hiatus in unit A, separating the lower and upper part, and that the unit displays parts of two emergence cycles of different ages.

Unit C, deposited after a local ice-advance on Prins Karls Forland that deposited unit B, shows many similarities with unit A although the foraminiferal faunas are somewhat different. Both faunas represent glacio-marine conditions with seasonally open waters and influence of advected North Atlantic water. However, when compared to unit A, unit C reflects a more enclosed, near-glacial and fluctuating fjord-environment. The fauna of unit C is fairly similar to the Holocene and modern faunas, indicating accumulation during conditions similar to those of today. On the basis of the reported time-constraints and relation to Gard (1988) coccolith data, we suggest that unit C was deposited during the latter part of stage 5a (70 ± 10 ka BP; Fig. 2). The increase in *Elphidium* spp., coupled with a decrease in diversity that can be observed in the upper parts of unit C, Episode B and Formation C deposits at Poolepynten, Brøggerhalvøya and Linnédalen respectively, might be a regional signal of falling sea level and increased environmental stress at the latter part of stage 5a. For the Svalbard area, the shore-level displacement during this time interval is not known in any detail. However, documented global eustatic sea-level changes show sea-levels rising up to −30 to −20 m during the latter part of stage 5 (ca 80 ka), followed by rapidly falling levels during the latter part of substage 5a and successively lower levels during stage 4 (Bard et al. 1996; Chappel et al. 1996).

Climatic conditions in northwest Europe during substage 5a seem to have been slightly cooler than at present (cf. Sejrup & Larsen 1991). In contrast, warm conditions similar to, or warmer than today, are registered in Svalbard and circumpolar regions around the North Atlantic (Gard 1988; Miller et al. 1989; Hebbeln & Wefer 1997). It has been pointed out that correlation of temperate periods based on environmental data at high latitudes is difficult because temperature conditions during Early Weichselian interstadials were similar to present day values and to conditions prevailing during the Eemian interglacial (Sejrup & Larsen 1991; Ingólfsson et al. 1995). Our study is another example of the difficulties in distinction between interglacial and interstadial deposits at these high latitudes.

Ocean temperature and climate are not directly related to glacials or interglacials/interstadials at high latitudes in the same way as can be seen for northwestern Europe. North–south palaeotemperature gradients for the Eemian and the Early Weichselian show large discrepancies between different latitudes of the circum-North Atlantic (Sejrup & Larsen 1991; Fronval & Jansen 1997). Also, ice sheet build-up and decay differ both in time and magnitude at different latitudes of the North Atlantic probably due to availability of precipitation which, in turn, is linked to surface circulation of the sea.

Correlation with other on-shore Svalbard stratigraphies

Nearby on-shore biostratigraphies that are possible to correlate with foraminiferal zone A of Poolepynten are foraminiferal zone QB of Balanuspynten across Forlandsundet (Feyling-Hanssen & Ulleberg 1984), foraminiferal zone FL-I and FL-III of Linnéelva and FS-I of Skilvika (Lycke et al. 1992) and foraminiferal zone F15 V and F15 II of Brøggerhalvøya (Miller et al. 1989). Zone QB of Balanuspynten is interpreted to be of Eemian age (Feyling-Hanssen & Ulleberg 1984). Zone FL-I of Linnéelva and FS-I of Skilvika have been interpreted to represent ice-free periods between 40 and 120 ka, probably >90 ka for the two foraminiferal zones mentioned here. They were assigned ages on basis of their foraminiferal composition in combination with thermoluminescence dates and amino acid results (Lønne & Mangerud 1991; Lycke et al. 1992). A recent geochronologic study, using infrared and red stimulated luminescence dating techniques, provide a close limiting age estimate of 80 ± 10 ka

BP for the enclosing sediments of zone FL-III at Linnéelva (Forman unpubl.). Miller et al. (1989) concluded that the high diversity and high abundance of foraminifera and the occurrence of southern species in their assemblage zone F15 V at Brøggerhalvøya reflect more favourable marine climatic conditions than those prevailing in the area today, and consequently correlated zone F15 V with substage 5e and the last interglacial (Eemian) of western Europe. The age of zone F15 II is constrained by limiting ^{14}C and U-Th ages of 70 ± 10 ka BP from enclosing Episode B sediments (Miller et al. 1989).

A biostratigraphic correlation of unit C of Poolepynten with any of the old marine sequences nearby is difficult. It rather seems more similar to the modern and Holocene fjord-faunas of the area. However, it is noteworthy that foraminiferal zones F15 I and FL-IV at Brøggerhalvøya and Linnéelva respectively, show a gradual increase in the abundance of *Elphidium* spp. and a lower diversity when compared to underlying zones F15 II and FL-I respectively. The same relation can be observed for unit C at Poolepynten when compared with the underlying unit A.

Conclusions

The present investigation documents seasonally ice free conditions and an influence of advected North Atlantic water on the western coast of Svalbard during two different periods of stage 5.

The lower part of unit A, which is the lower marine sequence of the Poolepynten site contains a relatively more diverse and North Atlantic-influenced fauna and is interpreted as deposited during substage 5e (Eemian). The upper part of unit A as well as unit C is interpreted as deposited during substage 5a.

Unit C seems to reflect a shallower environment compared to unit A, which in turn could reflect the global lowering of sea level towards the end of substage 5a.

The marine sequences of the Poolepynten site emphasise the problem of biostratigraphic distinction between interglacial and interstadial deposits at high latitudes due to low temperature gradients.

Acknowledgements. – This work is a part of The Swedish Arctic Research Programme (SWEDARCTIC). Generous support has been provided by the Swedish Natural Science Research Council, the Norwegian Polar Institute, the Swedish Polar Secretariat, and the Earth Sciences Centre, University of Göteborg. Thanks are also due to the Norwegian authorities on Svalbard for permission to carry out fieldwork in the Forlandet Nasjonalpark. The paper benefited from the reviews by M. Hald and one anonymous referee.

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