Late glacial palaeoceanography of Hinlopen Strait, northern Svalbard

Nalân Koç, Dorthe Klitgaard-Kristensen, Kristine Hasle, Carl Fredrik Forsberg & Anders Solheim

Timing and structure of the Late and post-glacial development of the northern Svalbard margin, together with the initial influx of Atlantic water into the Arctic Ocean are still very poorly constrained. We investigated a sediment core (NP94-51) from a high accumulation area on the continental shelf north of Hinlopen Strait with the purpose of resolving the timing and structure of the last deglaciation. Detailed analyses of ice-rafted detritus, benthic and planktonic foraminiferal fauna, diatom flora, grain size and radiocarbon dates are used to reconstruct the palaeoceanographic evolution of the area. Our results indicate that the disintegration of Hinlopen Strait ice and possibly the northern margin of the Svalbard Ice Sheet commenced between 13.7 and 13.9 ^{14}C Ky BP. Influx of subsurface Atlantic waters into the area (12.6 ^{14}C Ky BP) and the retreat of the sea ice cover, with the accompanying opening of the surface waters (10.8 ^{14}C Ky BP), happened at different times and both much later than the disintegration of the ice sheets. The transition into the Holocene shows a two-step warming.

N. Koç & K. Hasle, Norwegian Polar Institute, Polar Environmental Centre, N-9296 Tromsø, Norway; D. Klitgaard-Kristensen, Dept. of Geology, University of Bergen, Allégaten 41, N-5007 Bergen, Norway; C. F. Forsberg & A. Solheim, Norwegian Geotechnical Institute, Box 3930 Ullevaal Stadion, N-0806 Oslo, Norway.

The Late and post-glacial development of the palaeoceanographic conditions of the Nordic seas are quite well documented (see e.g. Hald & Vorren 1987; Jones & Keigwin 1988; Jansen & Veum 1990; Lehman et al. 1991; Koç Karpuz & Jansen 1992; Koç et al. 1993; Koç & Jansen 1994; Haflidason et al. 1995; Sarnthein et al. 1995; Hald & Aspeli 1997; Klitgaard-Kristensen et al. 1998). The initial signal of deglaciation in the area is recorded between 15 and 13 ^{14}C Ky BP as a widespread meltwater event in the δ^{18}O record of the investigated cores. A corridor free of sea ice opened along Norway at ~13.4 ^{14}C Ky BP as the surface salinities increased and summer insolation values of the northern hemisphere reached half of maximum values. The migration of the oceanographic fronts and sea ice cover, and the accompanying warming of the surface ocean waters, have been time-transgressive both towards the north and to the west. For example, the initial warming of the surface North Atlantic after the Last Glacial Maximum (LGM) happened synchronously between 50° N to 63° N at 13.4 ^{14}C Ky BP, but was delayed by 1000 years at 72° N (Koç et al. 1996).

Today the Norwegian Atlantic Current carries warm and saline waters into the Nordic seas. These waters submerge around 78° N in Fram Strait. In the form of a strong boundary current, the West Spitsbergen Current (WSC) conveys the Atlantic Layer into the Arctic Ocean along the northern continental slope of Svalbard

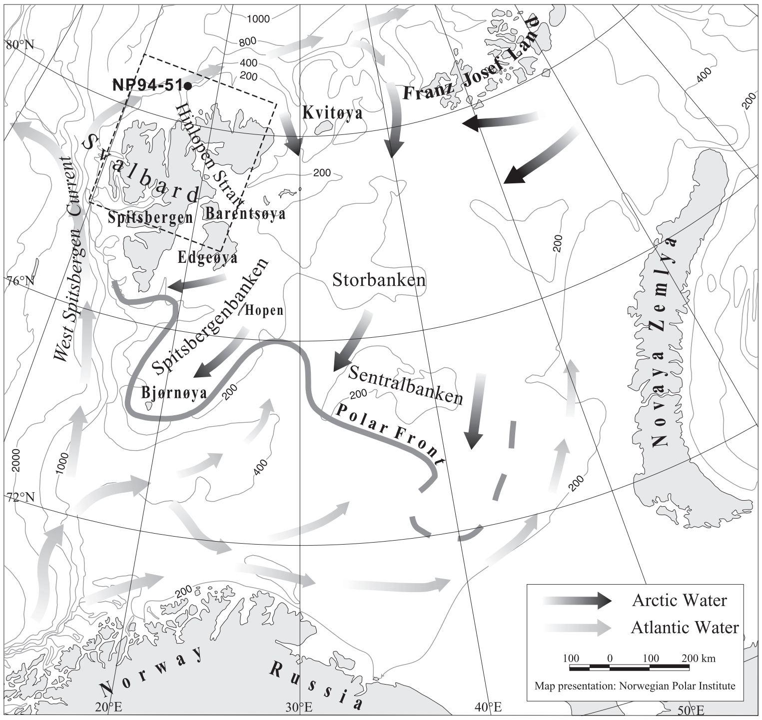

Fig. 1. Regional map showing the location of the studied core NP94-51. The present oceanic surface circulation is also indicated. Dashed rectangle indicates area shown in inset of Fig. 2.

(Fig. 1). The Atlantic Layer is defined as having temperatures above 0 °C, and ranging in depth from about 200 m to between 600 m and 800 m. On the continental shelf north of Hinlopen Strait the Atlantic Layer is observed from 100 m to 800 m water depth with the core of the layer having temperatures 3 - 4.5 °C at 100 - 400 m water depth (Fig. 2). The sensible heat stored in the Atlantic Layer is large and the inflow of Atlantic water through Fram Strait and over the Barents Sea are considered to be the major oceanic heat source for the Arctic Ocean (Pfirman et al. 1994; Rudels et al. 1994).

Timing and structure of the last deglaciation around Svalbard, together with the initial influx of the Atlantic water into the Arctic Ocean are still not well constrained. This is due both to the limited stratigraphic resolution of the investigated cores and to the low abundances of foraminifera off western Svalbard after the meltwater spike at 13 - 15 ^{14}C Ky BP during the deglaciation (Hald et al. 1996). Most knowledge of the palaeoceanographic evolution of the area has been focussed on the Late Quaternary (Dokken & Hald 1996; Hebbeln & Wefer 1997; Knies et al. 1999, 2000; Matthiessen et al. 2001; Wollenburg et al. 2001). Comparatively little is known about the late and post-glacial development of the northern Svalbard margin, with current knowledge based on a few seismic lines and sediment cores (Leirdal 1997; Knies & Stein 1998) and on land-based studies of isostatic sea level changes (Forman et al. 1995; Forman & Ingólfsson 2000).

We investigated a sediment core (NP94-51) from a high accumulation area on the continental shelf north of Hinlopen Strait with the purpose of resolving the timing and structure of the last deglaciation. This is a climatically sensitive part of the Arctic Ocean, which is extremely vulnerable to the transport of Atlantic water via Fram Strait.

Material and methods

Hinlopen Strait and the trough extending northwards from it constitute a depression running from the central part of Svalbard to the shelf edge (Fig. 1). In 1994, the Norwegian Polar Institute carried out an extensive seismic survey and sediment coring programme onboard the RV *Lance*. Several post-glacial accumulations with good potential

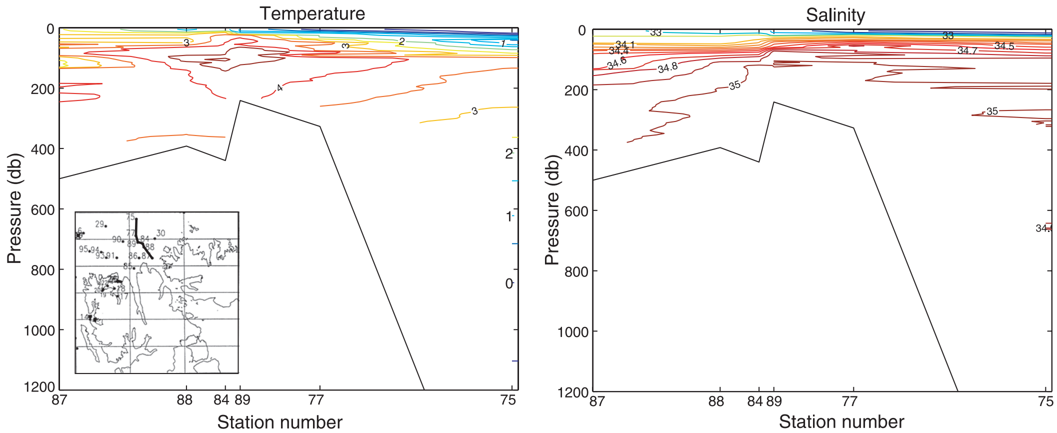

Fig. 2. Hydrography (temperature in °C and salinity in ‰) from the continental shelf north of Hinlopen Strait to the slope along the indicated transect during the summer of 1994 as measured at the CTD stations.

for providing high resolution palaeoceanographic records of both the deglaciation and the Holocene were mapped and cored (Solheim & Forsberg 1996; Leirdal 1997). The sediment core NP94-51SC2 (80° 21.346' N, 16° 17.970' E; 400 m water depth) was retrieved with a Selantic Subsea Ltd. Selcore from Hinlopen Strait on the continental shelf north of Svalbard.

We have dated the 713 cm long core by 6 accelerator mass spectrometry (AMS) radiocarbon dates which were measured at the Radiocarbon Laboratory of Uppsala, Sweden, and at the Beta Analytic Radiocarbon Dating Laboratory, Florida, USA (Table 1). An age model was developed based on linear extrapolation between the dated levels. Based on the AMS ^{14}C dates, the depth interval 514 - 713 cm, corresponding to the time interval ca. 9.7 - 14 ^{14}C Ky BP, was selected for this study.

The working half of the 9.5 cm diameter core was sampled in 1 cm increments, except for a thin rind of sediment adjacent to the core liner. A 1 cc sample from each 1 cm segment was removed for diatom analyses, and the remaining material was used for sedimentological and foraminiferal analyses. Samples were dried and weighed before being wet sieved. The residue was then dried for use in ice-rafted detritus (IRD) and foraminiferal counts. All counts have been made on the 125 - 1000 µm fraction. Due to the low abundances of foraminifera in certain depth intervals we counted all individuals in the whole sample. Treatment of the samples for diatom analyses followed the procedures outlined in Koç et al. (1993).

Table 1. Age model for core NP94-51SC2. AMS ages are corrected for the reservoir effect of 440 years.

Reference no.	Depth (cm)	Corrected age	Material
Beta-92998	32 - 33	1980 ± 60	*Nonionellina labradorica*
Beta-92348	276 - 277	7350 ± 50	*Portlandia arctica*
TUa-3076	525 - 526	9815 ± 95	*N. labradorica*
TUa-3410	569 - 570	10 630 ± 70	*N. labradorica*
TUa-3075	624 - 626	12 970 ± 105	Benthic foraminifera
TUa-3587	690 - 699	13 725 ± 135	Benthic foraminifera

Results

Sedimentation rates

Based on the AMS dates we have obtained for core NP94-51 (Table 1), two periods of enhanced accumulation (100 cm/Ky) are observed. These are the periods between 13 - 14 ^{14}C Ky BP and 8 - 10 ^{14}C Ky BP. The period 13 - 14 ^{14}C Ky BP is related to the increased sedimentation of coarse material due to the disintegration of the northern margin of Svalbard and the period 8 - 10 ^{14}C Ky BP is related to ameliorated ocean conditions (see the discussion below).

Ice-rafted detritus

Contents of terrigenous material >125 µm are commonly interpreted as indicators of increased

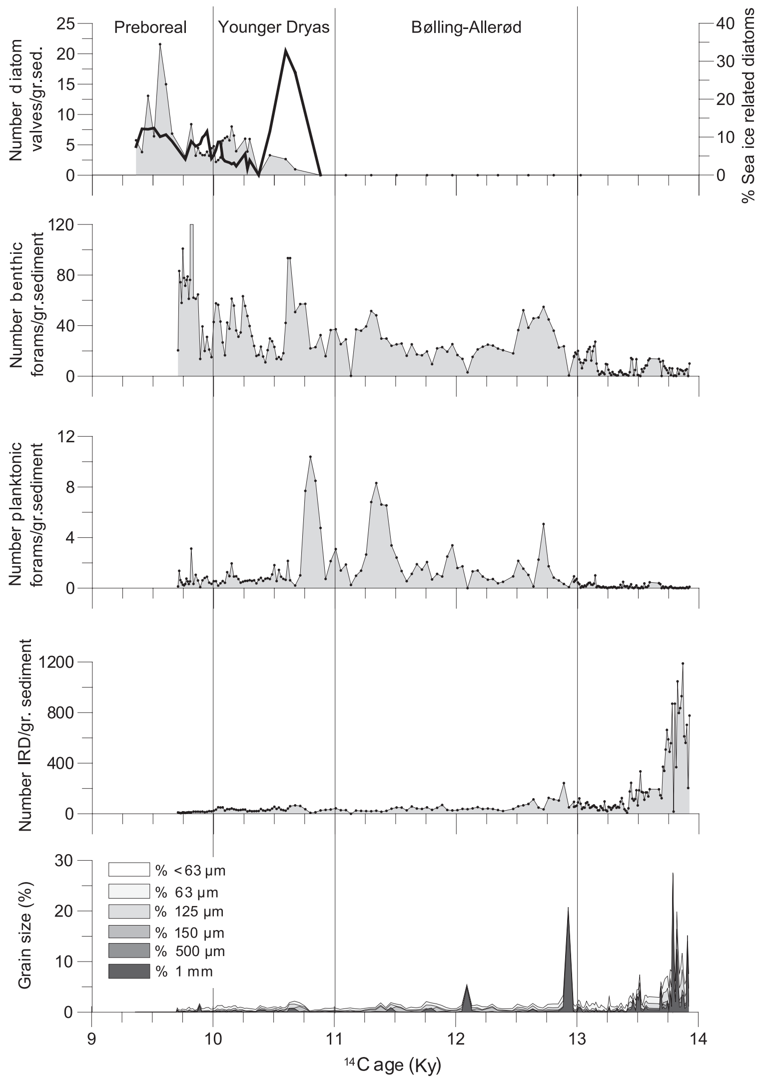

Fig. 3. Grain size distribution data, together with counts of ice-rafted detritus (IRD), planktonic and benthic foraminifers and diatoms plotted against ^{14}C age for the NP94-51 core. Percent abundance of the sea ice assemblage (thick line) consists of diatom species that are related to sea ice or the marginal ice zone, such as *Bacterosira fragilis*, *Detonula confervacea*, *Fragilariopsis oceanica*, *Porosira glacialis* and *Thalassiosira hyalina*.

iceberg drift (e.g. Jansen & Sjøholm 1991; Bischof 1994; Henrich et al. 1995). In core NP94-51, a strong IRD signal is recorded between 13.7 - 13.9 ^{14}C Ky BP (Fig. 3). This interval contains nearly no biogenic components, which indicates unfavourable conditions for biological productivity. Concentration of IRD falls from then on, and there is very little IRD after 13.4 ^{14}C Ky BP. No significant IRD signal is recorded during the Younger Dryas (YD) interval either.

We interpret the IRD peak between 13.7 - 13.9 ^{14}C Ky BP to reflect greatly increased iceberg rafting at Hinlopen Strait resulting from the initial deglaciation of the northern margin of Svalbard.

Planktonic foraminifers

The planktonic species, *Neogloboquadrina pachyderma* (sinistral) dominates in Polar/Arctic surface water masses (Johannessen et al. 1994). In areas with sea surface temperatures below 4 °C this species comprises 95 % or more of the planktonic fauna. Tow samples from Fram Strait, the Greenland Sea and the southern Nansen Basin show that *N. pachyderma* (sin.) dwells predominantly between 200 - 100 m water depth under ice-covered conditions (Carstens & Wefer 1992). Also, core-tops from the Barents and Kara seas are almost exclusively of this species (Lubinski et al. 2001).

Planktonic foraminifers are mostly absent in the sediments until about 12.7 ^{14}C Ky BP (Fig. 3). From then on a slight increase in abundances indicates influx of subsurface waters with slightly higher productivity to the area. The assemblage, which is dominated by more than 95 % *N. pachyderma* (sin.), indicates that the subsurface waters have never been warmer than 4 °C during the investigated time period.

Benthic foraminifers

Extremely low numbers of benthic foraminifers characterize the sediments from core bottom up to about 12.8 ^{14}C Ky BP (Fig. 3). From 13.7 ^{14}C Ky BP to 12.6 ^{14}C Ky BP the benthic foraminiferal species *Elphidium excavatum* and *Cassidulina reniforme* dominate concurrently with low occurrences of a few other species, such as *Nonionellina labradorica*, *Islandiella norcrossi*, *I. helenae* and *Stainforhtia loeblichi* (Fig. 4). This fauna is typical of a glacial marine environment in relatively close proximity to glaciers (e.g. Osterman 1982; Mudie et al. 1984; Hald et al. 1994).

At 12.6 ^{14}C Ky BP, *C. neoteretis* dominates the fauna and exhibits a decreasing relative percentage until 10.7 ^{14}C Ky BP. The peaks of *C. neoteretis* at 12.4, 12, 11.7, 11.5 - 11.3 ^{14}C Ky BP and 10.8 ^{14}C Ky BP are all associated with the slight increases in the number of planktonic foraminifera (Fig. 3). *C. neoteretis* (as *C. teretis*) is currently found in association with chilled Atlantic Water in the Barents Sea along with maximum occurrences of planktonic foraminifera (Mackensen & Hald 1988; Hald & Steinsund 1996), indicating that the bottom-waters at our core site experienced inflow of Atlantic water starting from 12.6 ^{14}C Ky BP. At 13.1 ^{14}C Ky BP, *C. neoteretis* shows a slight increase in relative percentage, which could indicate an initial inflow of Atlantic derived water. During the periods of lower abundance of *C. neoteretis,* species such as *Cibicides lobatulus* and *Melonis barleeanus* occur. *C. lobatulus* is often associated with a stronger current regime (e.g. Steinsund 1994). Its high occurrence from 118 - 11.4 ^{14}C Ky BP suggests change in the current regime, possibly as a response to variations in the inflow of Atlantic water. *M. barleeanus* is currently associated with chilled Atlantic water or fine-grained sediments with high organic carbon content in the Barents Sea and Kara Sea (Steinsund 1994). In our core it does not follow the variations in *C. neoteretis* precisely, hence the Atlantic Water alone cannot be the controlling factor; other factors such as fine-grained sediments and the organic carbon content can be decisive for the occurrences of *M. barleeanus.*

E. excavatum shows a pronounced increase in abundance from 11.2 - 10.9 ^{14}C Ky BP and minor increases at 11.9 ^{14}C Ky BP and 11.6 ^{14}C Ky BP (Fig. 4). This species is known from environments characterized by cold (< 1 °C), seasonally ice-covered waters, high turbidity and lowered salinity (Hald et al. 1994). This suggests a deterioration of the climate during these periods, indicating stronger influence of glaciers, increased sea ice or changes in salinity related to meltwater.

From 10.8 - 10.1 ^{14}C Ky BP the high abundance of *Nonionellina labradorica* is only interrupted from 10.6 - 10.4 ^{14}C Ky BP, when *C. reniforme, E. excavatum* and *Stainforthia loeblichi* show increasing abundances. In the Barents Sea the highest abundances of *N. labradorica* is recorded in connection with the Polar Front, where seasonal biological productivity is high (Steinsund 1994). This indicates that for the major part of the YD the Polar Front was located in the vicinity of the core site. The fauna change from 10.6 to 10.4 ^{14}C Ky BP could indicate more cold water (0 - 1 °C), more sea ice and less influence of meltwater. This interpretation is based on the present occurrence of *C. reniforme* in waters of salinities above 30 ‰ in the Barents Sea and that *S. loeblichi* is found in connection with sea ice (Steinsund 1994).

At 10.1 ^{14}C Ky BP *N. labradorica* decrease in abundance. This could reflect a retreat of the Polar Front from the area of the core site. The increase of *E. excavatum* at 10.1 ^{14}C Ky BP is interpreted as reflecting more meltwater and higher turbidity in the water (Hald et al. 1994) after the Polar Front's retreat. The transition from the YD to the Holocene is also accompanied by increases of *M. barleeanus* and *I. norcrossi/helenae* that point to ameliorated conditions, although the warming is not very significant at the transition to the Holocene.

The return of *N. labradorica* at 9.8 ^{14}C Ky BP could reflect a return of the Polar Front and, hence, deterioration of the climate.

Diatoms

Diatoms first occur around 10.8 ^{14}C Ky BP during the YD (Fig. 3). The initial assemblage consists of

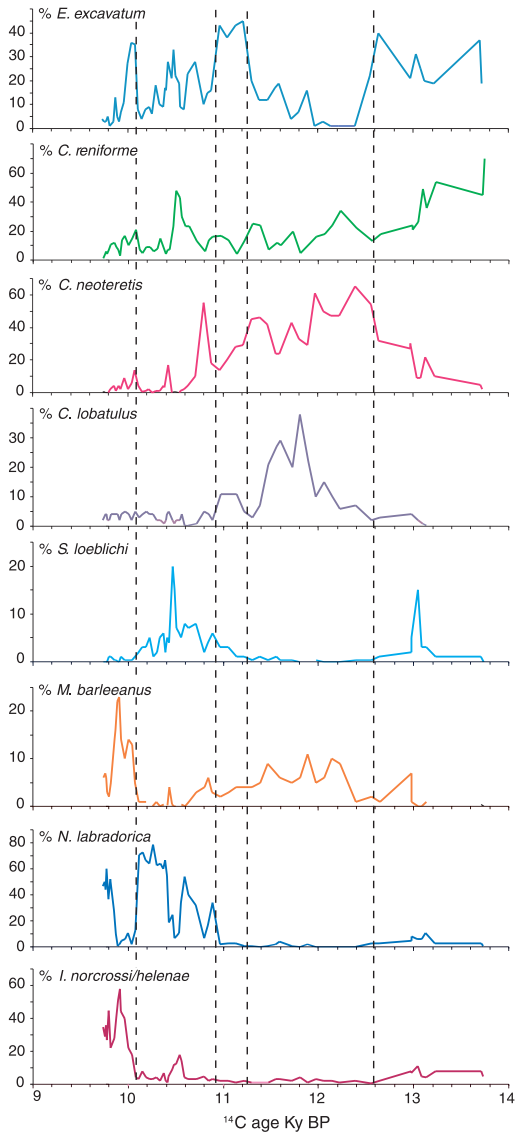

Fig. 4. Benthic foraminifera species distribution in core NP94-51. Dashed lines show boundaries of major assemblage changes.

species that are related to sea ice or the marginal ice zone, such as *Bacterosira fragilis*, *Detonula confervacea*, *Fragilariopsis oceanica*, *Porosira glacialis*, *Thalassiosira hyalina* and—of the Arctic water species—*Thalassiosira gravida* (resting spores).

The absence of diatoms before 10.8 ^{14}C Ky BP indicates that the surface waters in the area were mostly sea ice-covered, including during the Bølling–Allerød period. Surface waters became seasonally open at this site for the first time around 10.8 ^{14}C Ky BP. The peak in the sea ice related species reflects the passing of the Polar Front over the site.

Discussion

Models of ice sheet extent based on uplift data suggest that the Late Weichselian ice sheet extended to the shelf edge to the west and north of Svalbard (Lambeck 1995, 1996). During the LGM sea level was ca. 120 m lower than today (Fairbanks 1989) and Hinlopen Strait was covered by a grounded ice sheet preventing water exchange through the strait. Recent results suggest that the Barents Sea Ice Sheet started to recede at 15 ^{14}C Ky BP (Elverhøi et al. 1995; Landvik et al. 1998; Knies et al. 1999; Kleiber et al. 2000). Cores adjacent to Franz Victoria Trough document the first major pulse of freshwater along the northern margin of the Barents Sea Ice Sheet at about 14 ^{14}C Ky BP (Knies et al. 2000). Our data from NP94-51 indicate that the disintegration of Hinlopen Strait ice and possibly the northern margin of the Svalbard Ice Sheet commenced between 13.9 - 13.7 ^{14}C Ky BP. These results are in accord with the deglaciation of the continental margin adjacent to the Franz Victoria Trough and indicate that the whole northern margin of the Barents Sea Ice Sheet disintegrated around the same time.

Along the western margin of the Barents Sea Ice Sheet a major meltwater event around 13.6 - 14.2 ^{14}C Ky BP has been mapped and interpreted to indicate the disintegration of the western part of the ice sheet (Jones & Keigwin 1988; Koç & Jansen 1994; Sarnthein et al. 1995). These very similar dates point to a possibly synchronous disintegration of the northern and western parts of the ice sheet.

Influx of subsurface Atlantic waters into the area and the retreat of the sea ice cover with the accompanying opening of the surface waters happened at different times and both much later than the disintegration of the ice sheets. A glacial marine environment in relatively close distance to glaciers characterized the site from 13.7 ^{14}C Ky BP to 12.6 ^{14}C Ky BP. Bottom-waters at the core site experienced inflow of chilled Atlantic water from 12.6 ^{14}C Ky BP. This date is close to the initial warming of the surface waters at SW

Barents Sea at 12.5 ^{14}C Ky BP (Koç et al. 1996), and indicates that once the warm surface flow reached 72° N it continued further into the Arctic as a subsurface flow.

While a deterioration in the bottom-water conditions is recorded from 11.2 ^{14}C Ky BP and throughout the YD, the surface waters opened for the first time around 10.8 ^{14}C Ky BP with the Polar Front located in the vicinity of our core site, as indicated by the abundance of sea ice diatoms. After 10.5 ^{14}C Ky BP surface water conditions slightly ameliorated as the Polar Front moved further away from the site. Along both the eastern and western coasts of Edgeøya and Barentsøya contemporaneous deglaciation occurred around 10.3 ^{14}C Ky BP (Landvik et al. 1995). We think the opening of the surface waters of Hinlopen Strait provided the necessary flux of warmth to the area to initiate the deglaciation at Edgeøya and Barentsøya.

The climatic transition from the YD to the Holocene happened at 10.1 ^{14}C Ky BP at this site accompanied by increases of *M. barleeanus* and *I. norcrossi/helenae*. However, the lack of significant increase in *C. neoteretis* implies that significant bottom-water warming is not evident at the transition to the Holocene at the northern Svalbard margin. This is true also for the surface waters. In contrast, in the eastern Nordic seas this transition involves surface water temperature increases between 5 and 9 °C (Koç et al. 1996). This implies the presence of a strong front further south in the Nordic seas during this transition.

The return of *N. labradorica* at 9.8 ^{14}C Ky BP could reflect a return of the Polar Front and, hence, deterioration of the climate during the PB. This would indicate the presence of a possible Preboreal Oscillation at this area and a two-step warming at the start of the Holocene as documented from the Nordic seas (Koç Karpuz & Jansen 1992; Hald & Aspeli 1997).

Acknowledgements.—This work was financed by the Norwegian Research Council through their funding of the Norwegian Ocean Climate (NOClim) project and the Norwegian Polar Institute. We thank J. O´Dwyer, A. Estoppey and A. Igesund for assisting with the figures. We appreciate greatly the cooperation of P. J. Svanem and S. Gulliksen of the Radiometric Dating Laboratory, Trondheim, in providing the AMS ^{14}C ages. We also thank J. Knies and two anonymous referees whose constructive comments improved the paper.

References

Bischof, J. F. 1994: The decay of the Barents ice sheet as documented in the Nordic seas ice-rafted debris. *Mar. Geol. 117*, 35–55.

Carstens, J. & Wefer, G. 1992: Recent distribution of planktonic foraminifera in the Nansen Basin, Arctic Ocean. *Deep-Sea Res. 39*, S507–S524.

Dokken, T. M. & Hald, M. 1996: Rapid climatic shifts during isotope stages 2-4 in the Polar North Atlantic. *Geology 24*, 599–602.

Elverhøi, A., Andersen, E. S., Dokken, T., Hebbeln, D., Spielhagen, R., Svendsen, J.-I., Sørflaten, M., Rørnes, A., Hald, M. & Forsberg, C. F. 1995: The growth and decay of the Late Weichselian ice sheet in western Svalbard and adjacent areas based on provenance studies of marine sediments. *Quat. Res. 44*, 303–316.

Fairbanks, R. G. 1989: A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature 342*, 637–642.

Forman, S. L. & Ingólfsson, Ó. 2000: Late Weichselian glacial history and postglacial emergence of Phippsoya, Sjuøyane, northern Svalbard: a comparison of modelled and empirical estimates of a glacial-rebound hinge line. *Boreas 29*, 16–25.

Forman, S. L., Lubinski, D., Miller, G. H., Snyder, J., Matishov, G., Korsun, S. & Myslivets, V. 1995: Postglacial emergence and distribution of late Weichselian ice-sheet loads in the northern Barents and Kara seas, Russia. *Geol. 23*, 113–116.

Haflidason, H., Sejrup, H. P., Klitgaard-Kristensen, D. & Johnsen, S. 1995: Coupled response of the late glacial climatic shifts of northwest Europe reflected in Greenland ice cores: evidence from the northern North Sea. *Geology 23*, 1059–1062.

Hald, M. & Aspeli, R. 1997: Rapid climatic shifts of the northern Norwegian Sea during the last deglaciation and the Holocene. *Boreas 26*, 15–28.

Hald, M., Dokken, T. & Hagen, S. 1996: Paleoceanography on the European Arctic Margin during the last deglaciation. In J. T. Andrews et al. (eds.): *The Quaternary paleoceanography of the North Atlantic Margins. Spec. Publ. 111.* Pp. 275–287. Geological Society of London.

Hald, M. & Steinsund, P. I. 1996: Benthic foraminifera and carbonate dissolution in the surface sediments of the Barents and Kara seas. *Ber. Polarforsch. 212*, 285–307.

Hald, M., Steinsund, P. I., Dokken, T., Korsun, S., Polyak, L. & Aspeli, R. 1994: Recent and late Quaternary distribution of *Elphidium excavatum f clavatum* in Arctic seas. *Cushman Found. Spec. Publ. 32.* Pp. 141–153. Washington D.C.: Cushman Foundation for Foraminiferal Research.

Hald, M. & Vorren, T. O. 1987: Stable isotope stratigraphy and paleoceanography during the last deglaciation on the continental shelf off Troms, northern Norway. *Paleoceanography 2*, 583-599.

Hebbeln, D. & Wefer, G. 1997: Late Quaternary paleoceanography in the Fram Strait. *Paleoceanography 12*, 65–78.

Henrich, R., Wagner, T., Goldschmidt, P. & Michels, K. 1995: Depositional regimes in the Norwegian–Greenland Sea: the last two glacial to interglacial transitions. *Geol. Rundsch. 84*, 28–48.

Jansen, E. & Sjøholm, J. 1991: Reconstruction of glaciation over the past 6 Myr from ice-born deposits in the Nor-

wegian Sea. *Nature 349*, 600–603.
Jansen, E. & Veum, T. 1990: Evidence for two-step deglaciation and its impact on North Atlantic deep-water circulation. *Nature 343*, 612–616.
Johannessen, T., Jansen, E., Flatøy, A. & Ravelo, A. C. 1994: The relationship between surface water masses, oceanographic fronts and paleoclimatic proxies in surface sediments of Greenland, Iceland, Norwegian seas. *NATO ASI Ser. 1, 17*, 61–85.
Jones, G. A. & Keigwin, L. D. 1988: Evidence from Fram Strait (78° N) for early deglaciation. *Nature 336*, 56–59.
Kleiber, H. P., Knies, J. & Niessen, F. 2000: The Late Weichselian glaciation of the Franz Victoria Trough, northern Barents Sea: ice sheet extent and timing. *Mar. Geol. 168*, 25–44.
Klitgaard-Kristensen, D., Sejrup, H. P., Haflidason, H., Johnsen, S. J. & Spurk, M. A. 1998: A regional 8200 cal. yr BP cooling event in NW Europe. *J. Quat. Sci. 13*, 165–169.
Knies, J., Nowaczyk, N., Müller, C., Vogt, C. & Stein, R. 2000: A multiproxy approach to reconstruct the environmental changes along the Eurasian continental margin over the last 150 000 years. *Mar. Geol. 163*, 317–344.
Knies, J. & Stein, R. 1998: New aspects of organic carbon deposition and its paleoceanographic implications along the northern Barents Sea margin during the last 30,000 years. *Paleoceanography 13*, 384–394.
Knies, J., Vogt, C. & Stein, R. 1999: Late Quaternary growth and decay of the Svalbard/Barents Sea ice sheet and paleoceanographic evolution in the adjacent Arctic Ocean. *Geo-Mar. Lett. 18*, 195–202.
Koç, N. & Jansen, E. 1994: Response of the high latitude Northern Hemisphere to orbital climate forcing: evidence from the GIN-Seas. *Geology 22*, 523–526.
Koç, N., Jansen, E. & Haflidason, H. 1993: Paleoceanographic reconstructions of surface ocean conditions in the Greenland, Iceland and Norwegian seas through the last 14 ka based on diatoms. *Quat. Sci. Rev. 12*, 115–140.
Koç, N., Jansen, E., Hald, M. & Labeyrie, L. 1996: Lateglacial–Holocene sea-surface temperatures and gradients between the North Atlantic and the Norwegian Sea: implications for the Nordic heat pump. In J. T. Andrews et al. (eds.): *The Late glacial paleoceanography of the North Atlantic Margins. Spec. Publ. 111.* Pp. 177–185. Geological Society of London.
Koç Karpuz, N. & Jansen, E. 1992: A high resolution diatom record of the last deglaciation from the SE Norwegian Sea: documentation of rapid climatic changes. *Paleoceanography 7*, 499–520.
Lambeck, K. 1995: Constraints on the Late Weicselian ice sheet over the Barents Sea from observations of raised shorelines. *Quat. Sci. Rev. 14*, 1–16.
Lambeck, K. 1996: Limits on the areal extent of the Barents Sea Ice Sheet in Late Weichselian time. *Glob. Planet. Change 12*, 41–51.
Landvik, J. Y., Bondevik, S., Elverhøi, A., Fjeldskaar, W., Mangerud, J., Siegert, M. J., Salvigsen, O., Svendsen, J.-I. & Vorren, T. O. 1998: The Last Glacial Maximum of Svalbard and the Barents Sea area: ice sheet extent and configuration. *Quat. Sci. Rev. 17*, 43–75.
Landvik, J. Y., Hjort, C., Mangerud, J., Möller, P. & Salvigsen, O. 1995: The Quaternary record of eastern Svalbard—an overview. *Polar Res. 14*, 95–103.
Lehman, S. J., Jones, G. A., Keigwin, L. D., Andersen, E. S., Butenko, G. & Ostmo, S.-R. 1991: Initiation of Fennoscandian ice-sheet retreat during the last deglaciation. *Nature, 349*, 513–516.
Leirdal, G. 1997: *Senkvartær utvikling av kontinentalmarginen nord for Svalbard. (Late Quaternary development of the continental margin north of Svalbard).* Cand. Scient. thesis, Geological Institute, University of Oslo.
Lubinski, D. J., Polyak, L. & Forman, S. L. 2001: Freshwater and Atlantic water inflows to the deep northern Barents and Kara seas since ca 13 ^{14}C ka: foraminifera and stable isotopes. *Quat. Sci. Rev. 20*, 1851–1879.
Mackensen, A. & Hald, M. 1988: *Cassidulina teretis* Tappan and *C. laevigata* d´Orbigny: their modern and late Quaternary distribution in northern seas. *J. Foraminfer. Res. 18*, 16–24.
Matthiessen, J., Knies, J., Nowaczyk, N. R. & Stein, R. 2001: Late Quaternary dinoflagellate cyst stratigraphy at the Eurasian continental margin, Arctic Ocean: indications for Atlantic water inflow in the past 150,000 years. *Glob. Planet. Change 31*, 65–86.
Mudie, P. J., Keen, C. E., Hardy, I. A. & Vilks, G. 1984: Multivariate analysis and quatitative paleoecology of benthic foraminifera in surface and Late Quaternary sediments, northern Canada. *Mar. Micropaleontol. 8*, 283–313.
Osterman, L. E. 1982: Late Quaternary history of southern Baffin Island, Canada: a study of foraminifera and sediments from Frobisher Bay. PhD thesis, University of Colorado.
Pfirman, S. L., Bauch, D. & Gammelsrød, T. 1994: The northern Barents Sea: water mass distribution and modification. In O. M. Johannessen et al. (eds.): *The polar oceans and their role in shaping the global environment. Geophys. Monogr. 85.* Pp. 77–94. Washington, D.C.: American Geophysical Union.
Rudels, B., Jones, E. P., Anderson, L. G. & Kattner, G. 1994: On the intermediate depth waters of the Arctic Ocean. In O. M. Johannessen et al. (eds.): *The polar oceans and their role in shaping the global environment. Geophys. Monogr. 85.* Pp. 33–46. Washington, D.C.: American Geophysical Union.
Sarnthein, M., Jansen, E., Weinelt, M., Arnold, M., Duplessy, J. C., Erlenkeuser, H., Flatøy, A., Johannessen, G., Johannessen, T., Jung, S., Koç, N., Maslin, M., Pflaumann, U. & Schulz, H. 1995: Variations in Atlantic surface ocean paleoceanography, 50°-80° N: a time-slice record of the last 30,000 years. *Paleoceanography 10*, 1063–1094.
Solheim, A. & Forsberg, C. F. 1996: *Norwegian Polar Institute´s cruise to the northern margin of Svalbard and the Barents Sea 25/7-2/9, 1994: marine geology/geophysics and physical oceanography. Nor. Polar Inst. Rep. Ser. 92.* Oslo: Norwegian Polar Institute.
Steinsund, P. I. 1994. *Benthic foraminifera in surface sediments of the Barents and Kara seas: modern and Late Quaternary applications.* PhD thesis, University of Tromsø, Norway.
Wollenburg, J. E., Kuhnt, W. & Mackensen, A. 2001: Changes in Arctic Ocean paleoproductivity and hydrography during the last 145 kyr: the benthic foraminiferal record. *Paleoceanography 16*, 65–77.