Last Interglacial and Early Glacial Circulation in the Northern North Atlantic Ocean

Karen-Luise Knudsen,1 Marit-Solveig Seidenkrantz, and Peter Kristensen

Department of Earth Sciences, University of Aarhus DK-8000 Aarhus C, Denmark

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The present review of northern North Atlantic temperatures and oceanographic circulation during the last interglacial and the early glacial intervals is based partly on studies of northwestern European shelf records and partly on cores from the northern North Atlantic. There is a general lack of direct land/shelf–ocean correlation in this area, and the discussion is therefore based exclusively on a comparison of the climatic events in the different records. Similar reconstructions of the northern North Atlantic circulation have previously been attempted by Kellogg (1980), Sejrup et al. (1995), Seidenkrantz and Knudsen (1997), Fronval et al. (1998), Bauch et al. (1999), and Seidenkrantz et al. (2000).

THE LAST INTERGLACIATION

Marine shelf records from northern Denmark comprise deposits from the late Saalian, the Eemian, and the early Weichselian. An overview of the results from one of these records (Nørre Lyngby, Fig. 1) is shown in Fig. 2. At the Saalian–Eemian transition there is a benthic foraminiferal change from a high-arctic to a boreal–lusitanian fauna within a time span of 700–1000 yr (based on assumed constant sedimentation rate) (Fig. 2). The foraminiferal faunas show a number of significant changes through the Eemian (Kristensen et al., 1998); among these are two major inter-Eemian cooling episodes when the foraminiferal faunas revert to subarctic assemblages, indicating decreased water temperatures and changes in the ocean circulation. The longest of these cooling episodes (NL-1, Fig. 2) had an apparent duration of 2000–3000 yr, assuming a constant sedimentation rate. The main reason for including this entire succession, comprising three separate warm periods, in the Eemian Interglaciation is that the warm intervals all reflect temperatures higher than at present in the area (Seidenkrantz et al., 1998), and Seidenkrantz (1998). Environmental proxy data from Ocean Drilling Project
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FIG. 1. Maps showing surface-water circulation and faunal provinces in the northern North Atlantic region (also see Seidenkrantz et al., 2000, and references therein). (A) Modern circulation. (B) Eemian climatic optima. (C) Eemian cold events. NAC = North Atlantic Current; EGC = East Greenland Current; DK = Denmark. The Nørre Lyngby (NL) and the ODP 644 core sites are shown on map A.

(ODP) site 644 have been chosen for the comparison with the Nørre Lyngby shelf record because of its relative proximity in the easternmost part of the Nordic seas and, thus, the potential of similarity in environmental development. The temporal variation in arctic benthic foraminifera at Nørre Lyngby is shown on a timescale instead of a depth scale in Fig. 2B.

The upper boundary of the interglacial interval (MIS 5e) in core ODP 644 was determined by an increase in oxygen isotope values (benthic and planktonic foraminifera), and it was placed at ca. 113,000 yr B.P. by Fronval and Jansen (1996, 1997). A major sea-surface temperature drop at the site is, however, indicated by a faunal change to more than 90%–95% *N. pachyderma* (s.) by about 116,000 yr B.P. This is close to the time of seasonal expansion of sea ice in the area, as indicated by an initial increase in ice-rafted debris (IRD) (Fig. 2), and it corresponds to the MIS 5e–5d boundary of the SPECMAP timescale (Martinson et al., 1987). The climatic shift from interglacial to glacial conditions in northwestern Europe is presumably related to this significant drop in sea-surface temperatures at ca. 116,000 yr B.P. in the eastern Nordic seas.

Two alternative correlations of the ODP 644 record and the Nørre Lyngby record are shown in Fig. 2. There appears to be no simple way of matching the interglacial climatic fluctuations patterns in the two areas. This may be due to changes in sedimentation rates at one or both sites. Hiatuses in the records also cannot be ruled out.

The heat flux to the Nordic seas was significantly greater and more variable during the last interglaciation than at any time during the early glacial interval (Fronval and Jansen, 1996, 1997). A strong east–west gradient between the high temperatures in the Norwegian Sea and low temperatures in the Iceland Sea existed in the early part of MIS 5e (Fronval and Jansen, 1997). During the later warm interval, the gradient was reduced, leading to more latitudinally uniform sea-surface temperatures. Warm Atlantic waters may have reached farther west in the Nordic seas than during the Holocene (Fig. 1).

Fronval and Jansen (1996, 1997) and Fronval et al. (1998) concluded that during warm periods of the last interglaciation, the Arctic Front was located far west of its present location in the Iceland Sea region. In the early part of MIS 5e (126,000–125,000 yr B.P.; Fronval et al., 1998), this was probably due to a stronger or more westerly located North Atlantic Current or a weaker East Greenland Current. Within the later warm intervals, however, a higher heat flux to the western part of the basin was presumed to reflect a combination of a stronger Irminger Current and/or a weaker East Greenland Current (Fronval et al., 1998).

Cooler last interglacial condition than in the Holocene are indicated in the northernmost Nordic seas. Bauch et al. (1999) concluded that the main mass of inflowing warm Atlantic water remained in the southern part of the Nordic seas during the last interglaciation. This would have resulted in a much steeper meridional temperature gradient than in the Holocene, and may have been caused by the reduced northward flow of Atlantic waters towards the Fram Strait and the Arctic Ocean (Bauch...
FIG. 2. (A) Foraminifera in the late Saalian–Eemian and early Weichselian at Norre Lyngby, Denmark (cf. location Fig. 1). Arctic, transitional, (Trans.) and boreal (including Lusitanian) benthic species are grouped according to Seidenkrantz and Knudsen (1997) and shown as percentages of the total benthic foraminifera. Cosmopolitan species and taxa with uncertain environmental requirements are not included. Planktonic percentages are calculated of the total (benthic + planktonic) foraminiferal contents. (B) Data from ODP site 644 in the Nordic seas (Fig. 1). N. pachyderma sin. (reversed scale, i.e., warm to the right, cold to the left) and ice-rafted debris (IRD) after Fronval and Jansen (1997). Two alternative correlations of the ODP record with Norre Lyngby are proposed (reversed scale, i.e., warm to the right, cold to the left). Alternative 1 places the marine isotope stage (MIS) 5e–5d boundary at 116,000 yr B.P. in accordance with Martinson et al. (1987). Alternative 2 places the interglacial–glacial transition at 113,000 B.P. (marked with a broken line) according to Fronval and Jansen (1997). The age models for Norre Lyngby assume a continuous constant sedimentation rate between substage boundaries. A tentative correlation with the stratigraphies of northwestern Europe (Müller, 1974) and La Grande Pile (Woillard, 1978) is shown.

et al., 1999). However, high interglacial water temperatures in North Russian coastal areas indicate enhanced influx of warm water in a corridor along the Norwegian coast, at least during a part of the last interglaciation (Funder et al., in press).

Although the hydrography in the eastern North Atlantic was generally similar to today, the northward flow of warm surface waters must have been more pronounced. This conclusion is based on the higher water temperatures in the warm intervals.
and on the high amount of planktonic foraminifera on the Danish shelf. However, these planktonic foraminifera consist almost entirely of sinistrally coiled *N. pachyderma*, which reach a maximum during the cold episode NL-1 (Fig. 2A). In contrast, few planktonic foraminifera are found in deposits of the Holocene climatic optimum, and today planktonic species only occur in more open waters about 100 km to the northwest, off southwestern Norway.

About 124,000 yr B.P., according to the timescale of Fronval et al. (1998), the Arctic Front had a more southerly location than it does today. This is compatible with the results from Danish shelf cores, which indicate that cold water penetrated far south during the two last interglacial cool intervals (Seidenkrantz and Knudsen, 1997). However, the exact timing and correlation of these cool events is uncertain.

Studies from the Baltic (e.g., Zans, 1936; Kristensen et al., 2000; Funder et al., in press) show an open connection of the Nordic seas through the Baltic to the White Sea in the early part of the Eemian (Fig. 1). This was facilitated by the deep trough that remained after disappearance of Saalian ice. This situation may have contributed to the maritime climate of the early Eemian (e.g., Zagwijn, 1996).

The faunal province maps (Fig. 1) illustrate the faunal distribution of the different oceanographic situations during the last interglacial compared to the present (see also Seidenkrantz et al., 2000). A high influx of warm Atlantic water during the last interglacial warm intervals is clearly reflected by a shift of the faunal province boundaries toward the northwest and the northeast compared to the present situation. A resulting strong meridional temperature gradient is reflected by the faunal province boundaries (Fig. 1B). A reconstruction of the faunal provinces during cool events is illustrated in Fig. 1C. An influx of cold water masses far south in the easternmost part of the Nordic seas and the northwestern European shelf region is indicated. However, few records are currently known to support this reconstruction.

**THE EARLY GLACIAL INTERVAL**

The shift from interglacial to glacial conditions in northwestern Europe may be related to the decrease in sea-surface temperatures in the eastern Nordic seas. At Norre Lyngby this is reflected by a change from a boreal–lusitanian assemblage to a high arctic one within 500–700 yr, assuming a constant sedimentation rate (Fig. 2). The faunal composition fluctuates in the initial part of the Weichselian with a significant temperature drop just prior to the interstadial zone (Brørup, MIS 5c), during which high-arctic species increase and transitional taxa decrease (Fig. 2). This cold event may correlate with the C24 expansion of polar water in the central North Atlantic (McManus et al., 1994; Fronval and Jansen, 1997). The Brørup Interstadial assemblages differ from interglacial faunas by having high percentages of the species *Elphidium excavatum* (40%–80%, not included in the transitional species of Fig. 2A). The cold peaks after the Brørup Interstadial may correlate with cold periods C22 and C21.

At ODP site 644, the MIS 5e/5d boundary (116,000 yr B.P.) is marked by a drop in sea-surface temperature and an initial increase in IRD (Fig. 2). These shifts indicate a southward movement of the Arctic Front, at least in the eastern part of the Nordic seas. Continuous high percentages of *N. pachyderma* (s.) through the entire early glacial interval indicate low sea-surface temperatures. Ice rafting increases during MIS 5d, although it remains at a low level until it peaks in the late MIS 5d, corresponding to cold event C24 (Fig. 2). The IRD record appears to provide a detailed account of the ice-sheet variability during the early glacial period in the Nordic seas, and the temperature variations are recognized even in the midlatitude North Atlantic (Fronval and Jansen, 1997).

**CONCLUSIONS**

A comparison of previous studies of last interglacial records from the Nordic seas and the northwestern European shelf suggests that this region has experienced a less stable climate than the midlatitudinal North Atlantic. In general, the influx of warm Atlantic water to the region was higher during the last interglacial substage MIS 5e than during the Holocene (MIS 1), indicating a strengthening of the North Atlantic Current. The Atlantic water masses, however, appear to have been deflected more to the west in the southern part of the Nordic seas during MIS 5e than during the Holocene, resulting in a much steeper meridional gradient.

The interglacial climatic fluctuations in the Nordic seas may be a result of occasional reduction of the thermohaline circulation. Although the northern North Atlantic was significantly colder during the early glacial interval than during the last interglacial, high percentages of foraminifera and light δ18O values indicate that the Nordic seas were seasonally free of ice (Fronval and Jansen, 1997). The heat flux was also significantly lower during the early glacial interstadial intervals than during MIS 5e and the early glacial sea-surface temperatures fluctuated much less in the Nordic seas than in the central North Atlantic (Sejrup and Larsen, 1991; Fronval and Jansen, 1997). Thus, in the northern North Atlantic, the influx of warm Atlantic waters was substantially reduced during the whole of MIS 5d–5a.

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**REFERENCES**


