Radical past climatic changes in the Arctic Ocean and a geophysical signature of the Lomonosov Ridge north of Greenland

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The Arctic Ocean is a landlocked basin, at present covered by perennial sea ice. During the past few decades a significant thinning and shrinking of the sea ice has been observed, and modelling studies indicate that the Arctic Ocean ice cover could, by the end of this century, almost disappear from most parts of the Arctic Ocean during peak summer seasons. It remains uncertain, however, whether the environmental changes are an enhanced greenhouse-warming signal or a result of natural (long-term) variability, but palaeoceanographic studies can contribute to our understanding of the natural variability of environmental parameters, e.g. sea-ice cover and oceanographic changes on time-scales of centuries to millennia.

As part of the multidisciplinary EU project *Greenland Arctic Shelf Ice and Climate Experiment* (GreenICE), sediment coring and seismic reflection measurements have been undertaken in a hitherto unexplored part of the Arctic Ocean, the margin of the Lomonosov Ridge in the Lincoln Sea (Fig. 1). The aim of the project was to study the structure and dynamics of the sea-ice cover and attempt to relate these to longer-term records of climate variability retrieved from sediment cores. The main field work was carried out in May 2004 from an ice camp established by a Twin Otter aircraft on drifting sea ice at 85°N, 65°W, *c.* 170 km north of Alert, Arctic Canada. The camp was deployed over the shallowest part of the Lomonosov Ridge off the northern Greenland/Canada continental margin (Fig. 1). The sea-ice drift would normally be between east and south, but persistent easterly winds resulted in a fast drift trajectory towards the WSW, such that the camp drifted a distance of approximately 62 km during the two weeks camp period.

At present the study area is heavily ice covered, and forecast models of future shrinking Arctic sea-ice cover suggest that this area is one of the least sensitive to warming in the Arctic. The results obtained from the GreenICE project challenge this view.

An unexplored area

The reduction and thinning of Arctic sea ice in recent decades (e.g. Rothrock *et al.* 1999; ACIA 2004) has drawn attention to whether these environmental changes are an early reaction to global warming, or whether they are part of a long-term variation of the Arctic environment. Modelling studies of global warming effects indicate that the Arctic is

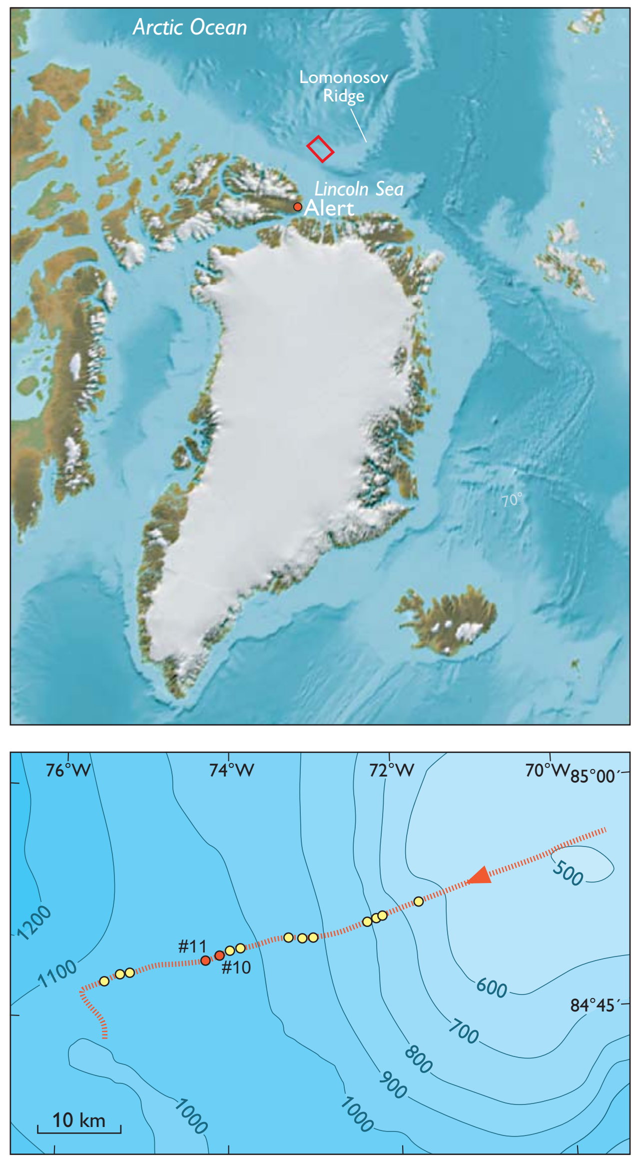

Fig. 1. **Upper**: The GreenICE field camp area (marked by a red square) was deployed north of Arctic Canada and North Greenland at the shallowest part of the submarine Lomonosov Ridge, in a region where no geologic record has hitherto been retrieved. **Lower**: Drift path of the field camp is shown by arrow and **red line** and coring stations by yellow and **red dots**.

likely to show a significant temperature increase, and that sea-ice cover could, by the end of this century, almost disappear during peak summer seasons (Johannessen *et al.* 2004). Such a scenario would not only have a dramatic impact on Arctic ecosystems, navigation and indigenous people, but could also influence the thermohaline circulation and regional climate in the sub-Arctic and North Atlantic region. In a discussion of these scenarios, there is an urgent need for high-latitude Arctic records of variations in climate, oceanography and sea-ice cover representing long time periods and, in particular, records of natural environmental change during earlier warm periods, which can be used to evaluate present-day changes. In spite of its importance, the recent geological record of many parts of the Arctic Ocean, including the Lincoln Sea, are still poorly known and hampered by difficult access.

Reduced ice cover during interglacial periods

Seismic data and sediment cores were collected from the drifting GreenICE station in this normally inaccessible area of the Lincoln Sea. During the camp period, 15 gravity core stations were established (Figs 1, 2), and the retrieved cores were subsequently subjected to a wide array of investigations including AMS-^{14}C dating, faunal analysis of nannofossils and benthic and planktonic foraminifers, and stable isotope and geochemical analysis. The two longest cores, GreenICE Core 10 (176 cm) and GreenICE Core 11 (64 cm), show several characteristic colour cycles previously recorded in other parts of the Arctic Ocean (Fig. 3; Phillips & Grantz 1997; Nørgaard-Pedersen *et al.* 1998; Jakobsson *et al.* 2000; Polyak *et al.* 2004; Spielhagen *et al.* 2004). The stratigraphy of Core 11 is based on nannoplankton, benthic foraminiferal assemblages and AMS-^{14}C dates and provides a record of the last *c.* 130 000 years, including the last interglacial period (Eemian). Preliminary investigations indicate that the longer Core 10 contains a record of the last *c.* 200 000 years.

Planktonic foraminiferal assemblages are used as a key palaeoceanographic proxy, and a surprisingly large variability of these foraminifers was observed for an interior Arctic Ocean site. The discovery of abundant numbers of the small subpolar foraminifers *Turborotalita quinqueloba* in two core sections, corresponding to the last interglacial and a younger warm interstadial (Fig. 3), is an enigma, as this species indicates fairly strong subsurface Atlantic water advection and possibly a much reduced summer sea-ice cover in the area compared to present-day conditions. The youngest part of the retrieved sediment record is condensed, but samples taken from close to the surface, representing Holocene and Recent conditions, lack the subpolar foraminifer species and thus indicate a consistent thick perennial sea-ice cover in accordance with present-day conditions (Nørgaard-Pedersen *et al.* in press)

The results support the concept that interglacial conditions in the interior Arctic Ocean can vary considerably. At present, however, it is not known whether the influx of subpolar foraminifers was related to an ice-margin or polynya-type setting, or whether it reflects a generally reduced sea-ice cover of the interior Arctic Ocean. Ongoing work aims to explore whether the observed trends can be traced to other key sites in the Arctic Ocean.

Seismic investigations and active faulting

A 62 km long seismic reflection profile was collected during the drift of the GreenICE field camp (Figs 1, 4). Seismic reflection data were obtained from the shallowest part of the

Fig. 2. **A**: Lightweight gravity coring equipment (constructed by J. Boserup, GEUS) used during the drift of the GreenICE camp. **B**: Sediment cores were retrieved through a hole drilled in the ice.

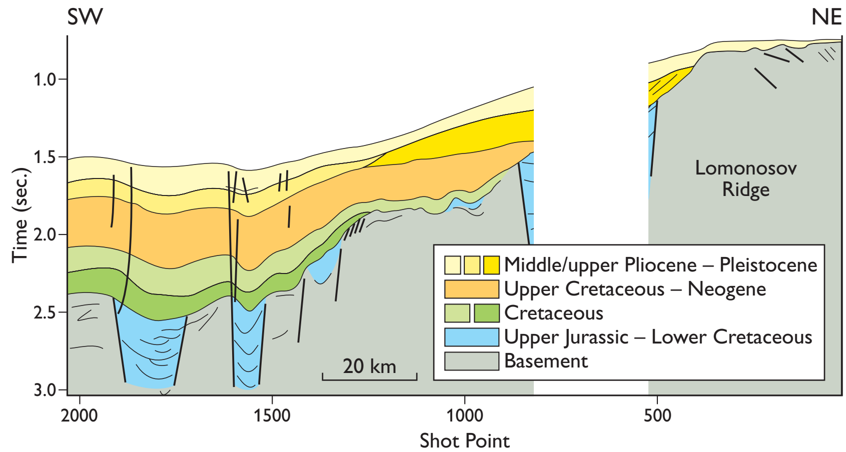

Fig. 4. Seismic line retrieved during the ice drift over the Lomonosow Ridge north of Canada and Greenland (adapted from Kristoffersen & Mikkelsen 2006).

submarine Lomonosov Ridge facing the Canadian/Greenlandic continental margin, and comprise two parallel single channel lines (Kristoffersen & Mikkelsen 2006). The data reveal that the top of Lomonosov Ridge is bevelled at a water depth of 550 m and that only a thin sediment cover (less that 50 m) overlies the acoustic basement. Pre-Pleistocene sediments were probably eroded by a grounded marine ice sheet extending north from Ellesmere Island, and/or by deep draft icebergs. In the deep passage between the Lomonosov Ridge and the Lincoln Sea continental margin, more than 1 km of sediment is present. The uppermost 300 m of this succession reflects a significant sediment drift possibly related to

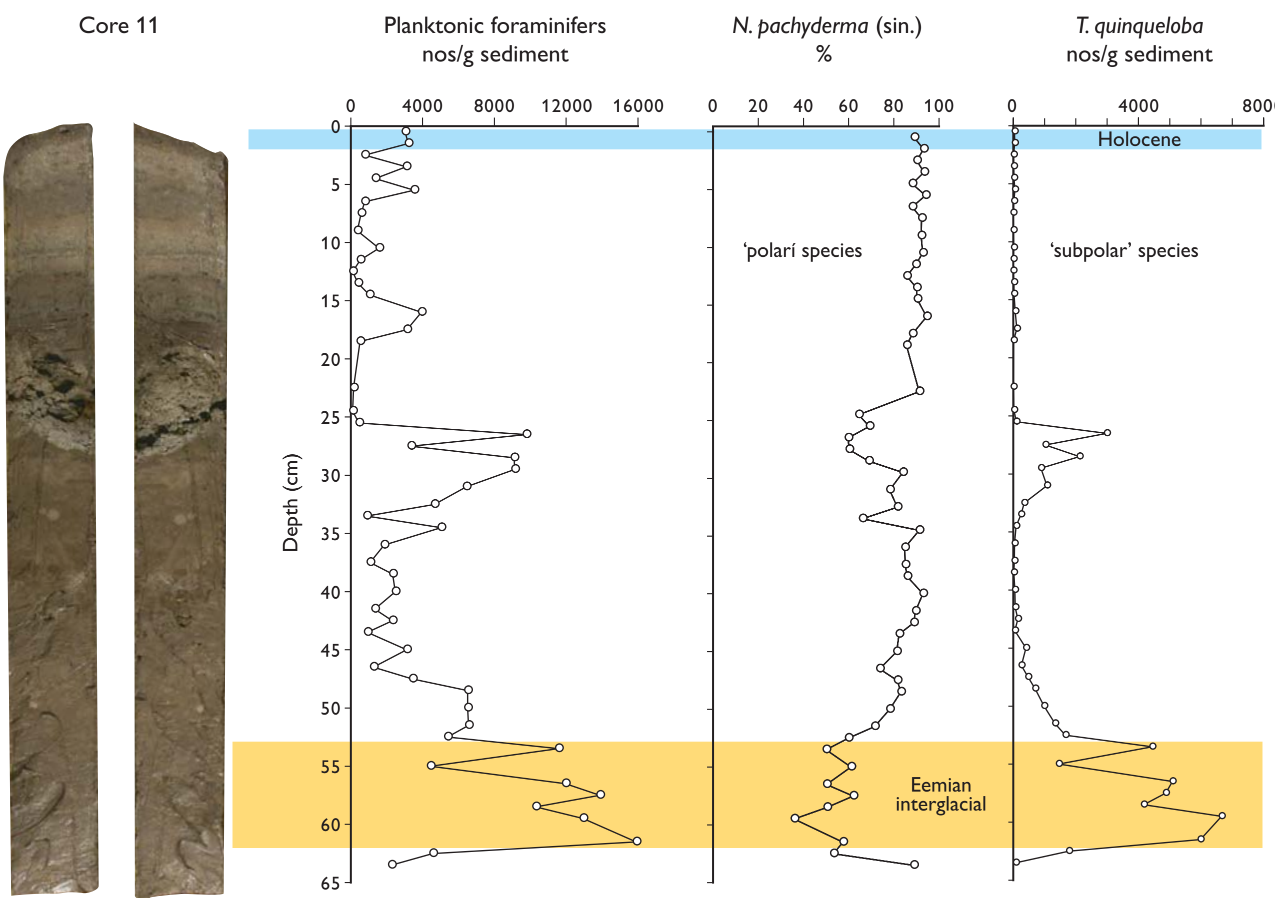

Fig. 3. The GreenICE sediment cores show marked colour cycles. GreenICE Core 11 covers a time span of *c.* 130 000 years and includes the Eemian interglacial marine isotope stage 5e. Abundant subpolar foraminifers (*Turborotalita quinqueloba*) in Eemian deposits indicate open water conditions not far from the GreenICE site. This is in contrast to Holocene sediments that show a total dominance of polar species (*Neogloboquadrina pachydermal*).

increased Plio-Pleistocene sediment input, and the underlying 700 m of sediment onlap a subsiding ridge slope. Blocks of older margin sediments may represent the acoustic basement in the area. A basal unconformity, which may correspond to the Hauterivian break-up unconformity of Embry & Dixon (1994), caps a series of NW–SE-trending grabens, and several of the main graben faults extend to the sea bed and appear to have been active until recent times.

Acknowledgements

The Greenland Arctic Shelf Ice and Climate Experiment (GreenICE) was supported by EU-grant EVK2-2001-00280.

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