Labrador Sea circulation and climate variability over decade to millennial time scales

Jonathan T. Overpeck, Ole Bennike and Alex Robertson

The Labrador Sea is one of the primary areas of deep water formation in the North Atlantic Ocean, and is therefore a key region for regional- and global-scale ocean thermohaline circulation and climate variability studies (e.g. Sy *et al.* 1997). Since high resolution records are difficult to obtain due to low sedimentation rates and bioturbation in the Labrador Sea itself high resolution proxy records must come from regions surrounding the Labrador Sea. Here we report on reconnaissance work carried out on coastal lakes in Greenland. The primary objective of this study is to generate annually-dated lake sediment records of climate variability for the last 2000 years. A second objective is to generate century-resolved, quantified, radiocarbon dated records that extend back to the last deglaciation. Finally, we will also attempt to retrieve lake sediments from ice-free time periods of the last glacial stage or the last interglacial stage; such pre-Holocene lake sediments have already been successfully recovered from lakes on Baffin Island, in Canada (Wolfe & Härtling 1996; Miller *et al.* in press). This work will improve the understanding of how the Labrador Sea modulates ocean circulation as well as North Atlantic, Arctic, and global climate.

Reconnaissance field work was carried out in West Greenland in the summer of 1996 (Anderson & Bennike 1997); in the summer of 1997 further reconnaissance studies were undertaken in the area between Kap Farvel and Søndre Strømfjord (Fig. 1). The objectives of these studies were to locate basins with annually laminated (varved) sediments, as such sediments allow a dating uncertainty of only a few years (Hughen *et al.* 1996). We concentrated our initial efforts on low-elevation isolated basins which can contain salt water below a freshwater cap as a result of recent isostatic uplift or tidal interaction with the modern ocean. These basins can become density stratified and meromictic, resulting in anoxic bottom water and the preservation of laminated sediment (Fig. 2). Similar basins are well known from arctic Canada where they have provided high resolution proxy climate records for periods of up to 500 years (Hughen *et al.* 1996). The lake Sælsøen in North-East Greenland, at latitude 77°N, is the only such isolated basin previously identified in Greenland (Trolle 1913). In addition to the work in Greenland, similar work

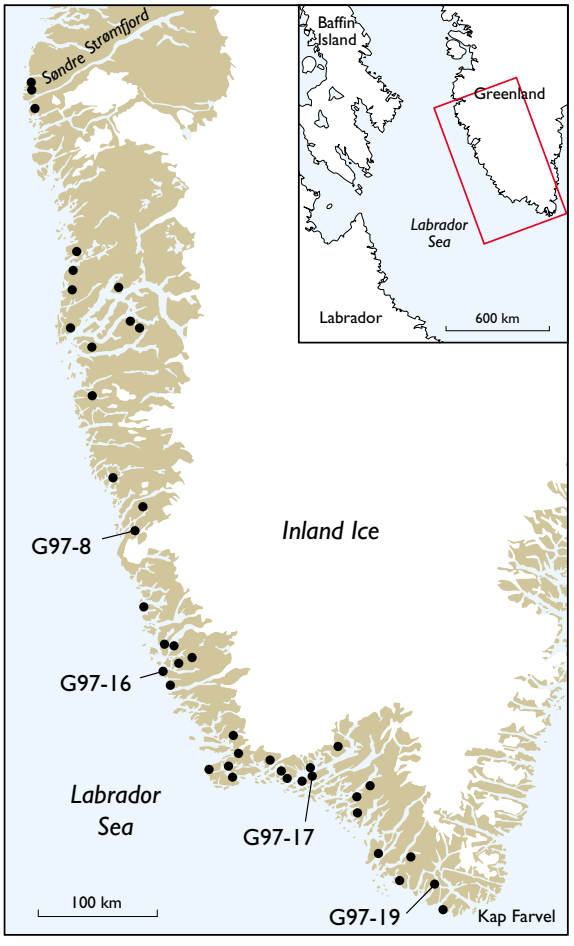


Fig. 1. Map of south-western Greenland showing the locations of the basins sampled during the 1996 and 1997 field seasons.

Geology of Greenland Survey Bulletin 180, 168–171 (1998)

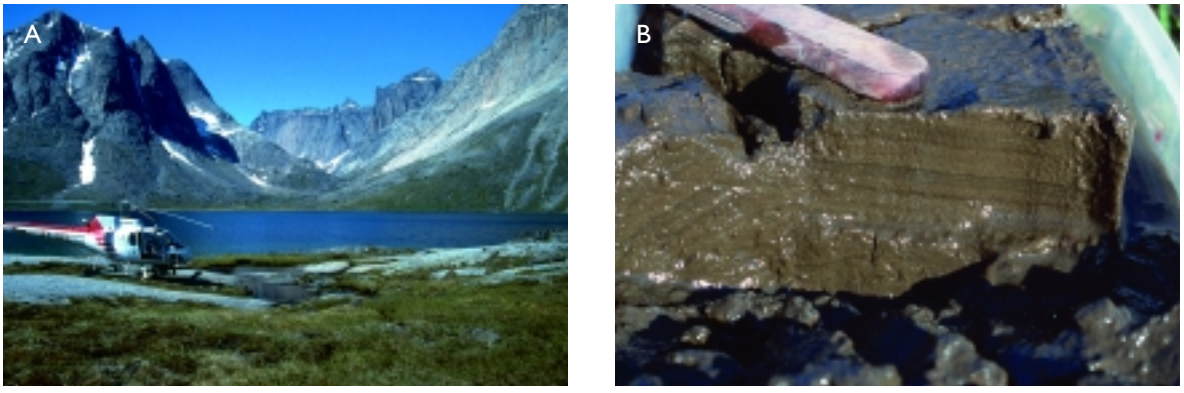


Fig. 2. **A**: Lake G97-19 (60°04.9′N, 44°16.0′W) in the Kap Farvel area, South Greenland. The lake measures about 800 × 1000 m, and the cliff faces next to it are more than 1000 m high. **B**: Laminated sediments collected at a water depth of *c.* 50 m in lake G97-17 (60°51.2´N, 46°28.1´W). For locations see Fig. 1.

is also in progress on coastal Labrador, on the south-western side of the Labrador Sea.

Methods

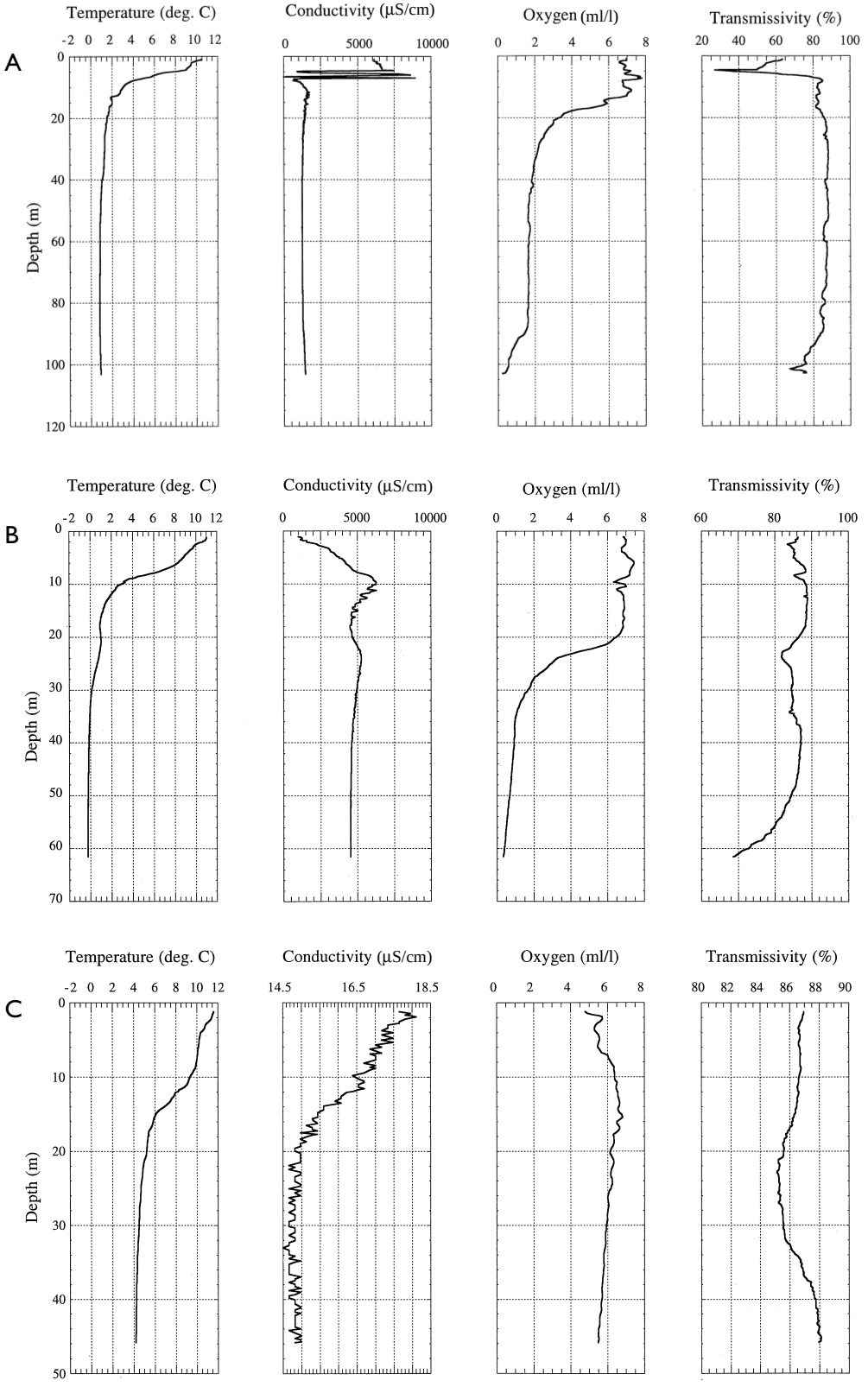
Helicopters from Greenlandair Charter were used for transport to 14 lakes in 1996 and 31 lakes in 1997 (Fig. 1); an inflatable boat was used on the lakes. We collected small surface sediment samples (0–2 cm) with an Ekman dredge and checked the sediment for laminations. Larger sediment samples for macrofossil and submerged bryophyte samples were collected from some of the basins. Surface water samples were collected for stable isotope and water chemistry analyses; moss polsters were collected for pollen analysis. The vegetation around the lakes was also briefly described. Data provided from these samples will mainly be used for calibration studies. In 1997 we measured temperature, conductivity, dissolved oxygen content, light transmission, density, and pH of the water column, using a Seabird CTD profiler.

Results

During the two summers 43 basins in Greenland were visited, and the eastern North America network of sediment-climate proxy calibration sites was expanded into low arctic and subarctic regions. Some of the basins were marine throughout, a few appeared to be meromictic, while the majority were fresh water basins (Fig. 3). Surface area varied from less than 10 to *c.* 1500 ha but most basins had areas around 50 ha. The deepest basin sampled was slightly more than 100 m deep, but 20–50 m was a more normal water depth. The most promising sites that are likely to contain varved sediments were fresh, dilute lakes that are deep in relation to surface area, and surrounded by sheltering mountains. Apparently the shelter in combination with the long period of ice cover, hinders mixing of the water masses so that bottom waters become anoxic. No basins were found containing isolated salt water at depth.

Macrofossil analyses

Sediment samples from 22 lakes were analysed for macroscopic plant and animal remains. Sample size varied from 100 cm^3 to 3400 cm^3, and the samples were collected from *c.* 2 cm to *c.* 20 cm below the sediment surface. Remnants of land plants were found to be fairly frequent even though many of the samples were collected in rather deep water, quite far from the shore. Thus it should be possible to extract enough material from cores of terrestrial plants for accelerator mass spectrometry (AMS) radiocarbon dating. Most common were leaves and fruit stones of *Empetrum nigrum*, leaves of *Vaccinium uliginosum* and nutlets, female catkin scales and leaves of *Betula* sect. *Nanae*. Remains of *Juniperus communis* and *Betula pubescens* were found in sediments from a few of the most southerly lakes. *Salix herbacea* leaves were found to be quite common, although this tiny willow was only noted at a few of the lakes. In contrast to land plants, remains of macrolimnophytes were only found in a few lakes; and were only represented by the bryophyte *Drepanocladus (=Warnstorfia) exannulatus*. Marine basins with black,


A
Temperature (deg. C)
-2 0 2 4 6 8 10 12
Conductivity (µS/cm)
0 5000 10000
Oxygen (ml/l)
0 2 4 6 8
Transmissivity (%)
20 40 60 80 100
Depth (m)
0 20 40 60 80 100 120
B
Temperature (deg. C)
-2 0 2 4 6 8 10 12
Conductivity (µS/cm)
0 5000 10000
Oxygen (ml/l)
0 2 4 6 8
Transmissivity (%)
60 80 100
Depth (m)
0 10 20 30 40 50 60 70
C
Temperature (deg. C)
-2 0 2 4 6 8 10 12
Conductivity (µS/cm)
14.5 16.5 18.5
Oxygen (ml/l)
0 2 4 6 8
Transmissivity (%)
80 82 84 86 88 90
Depth (m)
0 10 20 30 40 50

Facing page

Fig. 3. Limnological measurements from basin G97-8, G97-16 and G97-17. For locations see Fig. 1. **A**: G97-8 (62°43.8′N, 49°59.7′W) shows an anomalous situation with fresh water overlain by *c*. 5 m of denser salt water. The top-sediments are glacial clay/silt. **B**: G97-16 (61°33.8′N, 49°06.5′W) is a salt water basin with brackish and fresh water in the upper 10 m. The top-sediments are marine, homogeneous gyttja, even though the bottom waters are almost anoxic. **C**: G97-17 (60°51.2′N, 46°28.1′W) is a fresh water basin. The top-sediments are laminated algal gyttja, in spite of the apparent presence of oxygen in the waters near the bottom.

sulphide-rich but bioturbated, non-laminated sediments contained the highest concentration of macroscopic remains of land plants. Iron-stained sediment which was found in some lakes contained few, poorly preserved macrofossils. It was also evident that it was easy to distinguish between marine-brackish and freshwater sediments on the basis of macrofossil analysis.

Acknowledgements

The US National Science Foundation funded the field work. Ole Bennike's participation in 1997 was financed by the Carlsberg Foundation.

References

Anderson, N.J. & Bennike, O. 1997: Holocene lake sediments in West Greenland and their palaeoclimatic and palaeoecological implications. Geology of Greenland Survey Bulletin **176**, 89–94.

Hughen, K.A., Overpeck, J.T., Anderson, R.F. & Williams, K.M. 1996: The potential for palaeoclimatic records from varved arctic lake sediments: Baffin Island, eastern Canadian Arctic. In: Kemp, A.E.S. (ed.): Palaeoclimatology and palaeoceanography from laminated sediments. Geological Society Special Publication (London) **116**, 51–71.

Miller, G.H., Mode, W.N., Wolfe, A.P., Bennike, O., Forman, S.L., Short, S.K., Stafford, T.W., Jr. & Williams, K.M. in press: Stratified interglacial lacustrine sediments from Baffin Island, arctic Canada: chronology and paleoenvironmental implications. Quaternary Science Reviews.

Sy, A., Rhein, M., Lazier, J.R.N., Koltermann, K.P., Meincke, J., Putzka, A. & Bersch, M. 1997: Surprisingly rapid spreading of newly formed intermediate waters across the North Atlantic Ocean. Nature **386**, 675–679.

Trolle, A. 1913: Hydrographical observations from the Danmark Expedition. Meddelelser om Grønland **41**, 271–426.

Wolfe, A.P. & Härtling, J.W. 1996: The late Quaternary development of three ancient tarns on southwestern Cumberland Peninsula, Baffin Island, Arctic Canada: paleolimnological evidence from diatoms and sediment chemistry. Journal of Paleolimnology **15**, 1–18.

Authors' addresses:

J.T.O., *NOAA Paleoclimatology Program, National Geophysical Data Centre, 325 Broadway, Boulder, CO 80303, USA* and *Institute of Arctic and Alpine Research, Department of Geological Sciences, University of Colorado, Boulder, CO 80309-0450, USA.*

O.B., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark.*

A.R., *Institute of Arctic and Alpine Research, Department of Geological Sciences, University of Colorado, Boulder, CO 80309-0450, USA.*