

Holocene lake sediments in West Greenland and their palaeoclimatic and palaeoecological implications

N. John Anderson and Ole Bennike

There is considerable interest both from social and environmental perspectives as to the possible effects of future climate changes. This interest, which focuses on the time scales and rates of change of future climatic variability, has led to an increased recognition of the importance of studies of palaeoclimates and their ecological impacts (Street-Perrot & Roberts, 1994). General circulation models (GCMs) suggest that the Arctic will be especially sensitive to increased atmospheric temperatures (the 'greenhouse effect'). Such predictions or forecasts of future climatic scenarios are the primary role for GCMs in the debate about future global climate change (Henderson-Sellers, 1994), but it is also possible to use GCMs to model past-climate changes (Henderson-Sellers, 1990; Street-Perrot & Roberts, 1994).

GCM hindcasts of past climate have the advantage that the predictions can be independently validated against palaeoclimate data derived from a variety of proxy sources, e.g. ice cores, peats, marine and lake sediments (Street-Perrot & Roberts, 1994; Anderson, 1995). Arctic lake sediments are an important natural archive of past changes in climate, but they also record the impact of these climatic changes on the local biota and environment (Smol *et al.*, 1991). Lake sediment records can be used to provide the necessary baseline information against which future anthropogenic changes can be evaluated (Anderson, 1993). Such baseline conditions are often difficult to determine from contemporary data as the monitoring programmes are initiated after change has already occurred.

Arctic lakes and their catchment areas have two other important aspects which make them ideally suited to detailed, quantitative palaeoecological and palaeoclimatic approaches: they have a relatively simple biological structure, and anthropogenic impacts on the catchment areas are so small they can be effectively discounted. Because the shallow lakes are often fishless, the effects of higher trophic levels (the trophic cascade) on the lower trophic levels (primary producers,

e.g. algae and phototrophic bacteria) can also be discounted. This has the implication that the majority of the limnological changes recorded in the lake sediments represent climate-driven catchment-lake interactions. It is possible therefore, to evaluate the effect of past-climate changes, such as the Holocene thermal maximum, on the lake biota. Importantly, independent estimates of past-climate can be derived from GCMs or from the ice-core records (Johnsen *et al.*, 1995).

In contrast to most other regions of the globe that are experiencing increasing temperatures, West Greenland and the Baffin Bay region have seen decreasing temperatures during recent decades. Studies of lake sediments that are widespread in West Greenland can provide information about the temporal and spatial climatic variability since the last ice age.

Field work in 1996

Given the importance of West Greenland lakes for climate change research, a number of projects have been initiated with the aim of addressing some of the points discussed above. In the summer of 1996, lake sediments were collected from a number of lakes in West Greenland. The work comprised three different but complementary efforts.

1. Long-term environmental change

Cores (2–3 m in length) that span the time since the local deglaciation were collected from four lakes: two salt lakes near the airport at Kangerlussuaq (Søndre Strømfjord), one near the tip of Nuussuaq and one on Svartenhuk Halvø (Fig. 1). The purpose of this study is to elucidate the long-term environmental and climatic changes since the last ice age. The sediment cores were collected using Russian and Livingstone samplers. In the laboratory, the cores were split lengthwise and

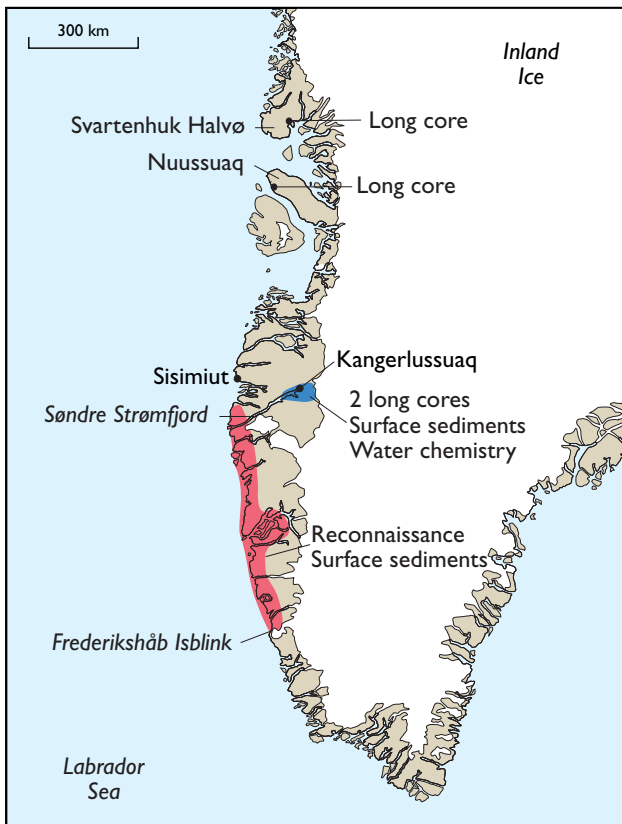


Fig. 1. Map of West Greenland showing the locations of the areas where lake sediment sampling was conducted in 1996.

subsampled for analyses of pollen, microfossils and organic matter content. The chronology of the cores will be established by accelerator mass spectrometry (AMS) radiocarbon dating, mainly on remains of terrestrial plants.

Preliminary analyses of the lake sediments reveal the presence of statoblasts of the freshwater bryozoan *Plumatella repens* in all four long sequences collected. This species has only been recorded alive from a single lake in southernmost Greenland, but its statoblasts are reported from Holocene lake sediments from geographically widespread parts of Greenland (Björck *et al.*, 1994; Bennike, 1995; Bennike & Funder, 1997).

The fresh water ostracod *Ilyocypris bradyi* (Fig. 2) is present in sediments from Store Saltsø, Søndre Strømfjord. This is the first report of this species from Greenland, and it is possible that this apparently thermophilous ostracod died out in Greenland after the end of the Holocene thermal maximum. This was the case with several marine invertebrates (Funder & Weidick, 1991), but it has so far not been documented among any freshwater animals. Several other species of ostracods and molluscs that are found in the lake

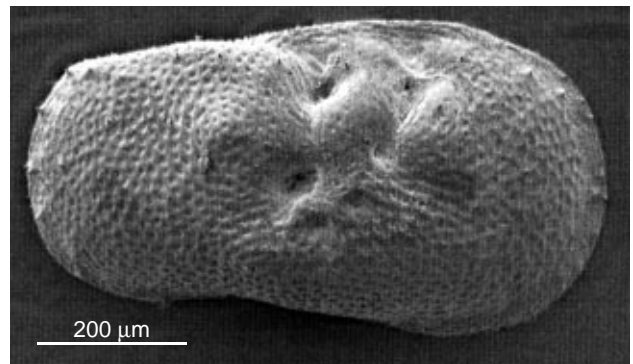


Fig. 2. A fossil right valve of the ostracod *Ilyocypris bradyi* Sars, 1890 from Store Saltsø, Søndre Strømfjord, southern West Greenland.

sediments are new to the fossil fauna of Greenland. When dated, these records will throw light on the timing of their arrival in Greenland.

2. Diatom-conductivity transfer functions in saline lakes

Links between climate, lake levels and lake water salinity have been the subject of intense research activity in other areas (e.g. North American Great Plains; Fritz *et al.*, 1991). There are numerous lakes in the Søndre Strømfjord area but of particular interest are the several 'salt lakes' (Fig. 3) that are unique in an Arctic context (Böcher, 1949; Hansen, 1970). These lakes have hitherto been almost uninvestigated. The 'salt lakes' of Søndre Strømfjord are not typical saline lakes, in that they do not contain a regional halophilic flora and fauna (Williams, 1991), but they are interesting nonetheless, if only because the causal mechanisms are unclear. These saline lakes are situated well above the local marine limit and are, therefore, not isolation basins, the normal cause of saline lakes in the Arctic (e.g. Ouellet *et al.*, 1984). The area at the head of Søndre Strømfjord is more than 100 km from the open sea and as a result has an extreme continental climate compared to the more maritime coastal regions. The continental climate of the area around Søndre Strømfjord results in a high negative ratio of precipitation to evaporation (P/E balance) during the summer, which together with local catchment hydrological factors (e.g. lack of a surface outflow at some of the lakes) are the primary causal mechanisms.

Diatoms are unicellular algae with a siliceous cell wall that generally preserves well in lake sediments. They are widely distributed and ecologically very sensitive.



Fig. 3. A saline lake (a bay of Hundesø; 20 km west of Kangerlussuaq airport) in West Greenland showing the characteristic blue colour of saline lakes in this area. The strait at the top of the photo is c. 200 m across.

The range and abundance of the species composition changes dramatically as the conductivity (as well as pH, nutrients) of the lake water changes. These species changes are recorded in the diatom assemblages deposited in the lake sediments. There is thus a possibility of developing a diatom-conductivity transfer function as has been done for other areas (Fritz *et al.*, 1991, 1994). This would permit local climate reconstructions for the West Greenland area, which would be important for palaeoclimate studies, because of the sensitivity of this area to changes in global climate and their proximity to the ice core records (Johnsen *et al.*, 1995).

Surface sediment samples (0.5–1 cm) were collected with a HON-Kajak sampler from 35 lakes in the area around the head of Søndre Strømfjord (Fig. 4). A range of lake environments including both higher conductivity lakes and normal, dilute lakes was sampled; measured conductivity varied between 40 and 5500 $\mu\text{mS cm}^{-1}$. The sediment samples will be analysed for diatoms. In addition, surface water samples were collected for chemical analysis, and the conductivity of the surface water of the lakes was measured. The aim of this study is to

develop a transfer function that will allow quantitative estimates of former lake water conductivity from diatom frustules preserved in post-glacial lake sediments.

The sensitivity of the lakes at the head of Søndre Strømfjord to changes in precipitation and evaporation is indicated by a rim of drowned willows that was observed near the shore of several of the saline lakes. The water level of these lakes has clearly risen, probably as a response to the West Greenland temperature drop of recent decades that presumably has led to decreased evaporation. Old shorelines and peat deposits above the present water level of these lakes show that water level was once higher than today. If the lake levels have fluctuated as a result of interactions between local hydrology and regional climate (P/E balance) then the lake water conductivity should reflect these changes: lower lake levels will result in higher solute concentrations (i.e. higher conductivity). It is hoped to use the diatom-conductivity transfer function to reconstruct lake water conductivity throughout the Holocene. By comparing the diatom-inferred conductivity, which is primarily a record of local changing hydrology (Laird *et al.*, 1996), with more regional climatic signals (e.g.



Fig. 4. **A:** Typical Kajak core with unlaminated sediments from a freshwater lake. **B:** Extruding a Kajak core in the field.

GCMs; ice-core climate reconstructions) it may be possible to identify the complex interactions between local hydrology (P/E balance, lake water levels) and more long-term regional changes.

Laminated sediments were also observed at some of the lakes, and it is possible that these are annual laminations or varves. If the laminations characterise the whole of the Holocene, a high-resolution record of past lake water conductivity may be obtained. At one site, laminations were observed together with purple sulphur bacteria at the sediment surface. While it is unlikely that these lakes are meromictic, i.e. have a permanently stratified water column, the causal mechanism causing the laminations is not immediately apparent. The long period of ice cover and hypolimnetic anoxia, however, are probably important factors. Future co-operative work with the Freshwater Biological Laboratory of Copenhagen University is planned to assess the thermal regime, basic limnology and the influence of the thermal structure and the biogeochemistry of the hypolimnion on the sediment stratig-

raphy. Freeze-coring of some of these lakes is planned for the spring of 1997.

3. Identification of isolation basins containing seawater

A reconnaissance of lakes and estuaries in coastal West Greenland was conducted by J. Overpeck from the Institute of Arctic and Alpine Research, University of Colorado, Boulder, USA, and one of the authors (O.B.) was invited to participate in the field work. In 1996, the area between Frederikshåb Isblink and the mouth of Søndre Strømfjord was covered. The main purpose was to locate isolation basins that retain seawater in their lower part. Similar basins on Baffin Island and elsewhere in Arctic Canada are meromictic (see above) and contain annually-laminated (varved) sediments (Hardy *et al.*, 1996; Hughen *et al.*, 1996). Numerous lakes in West Greenland have been isolated from the sea due to uplift following the last deglaciation, but lakes with trapped seawater appear to be rare. However, a few potential basins were located, and further reconnaissance work

is planned for 1997. The reason for this attempt to locate study sites in southern West Greenland is its proximity to the Labrador Sea, which is presently one of the main areas for deep-water formation in the North Atlantic Ocean. The main aim is to study the variability of deep-water formation over the past millenia.

Biogeographical notes

In the course of extensive sediment coring of poorly known or totally unstudied lakes, interesting ecological observations are made. A few observations are reported here concerning the macrophytes occurring in the lakes so far studied in West Greenland.

Fruit stones of the pondweed *Potamogeton praelongus* were reported from Holocene lake sediments in the Søndre Strømfjord area by Eisner *et al.* (1995); in the course of field work in 1996, live specimens were found in a single lake in the same area. This is the first record of this non-Arctic species in West Greenland. Extant populations of the charophyte *Chara baltica* were also recorded in a single, small lake in the Søndre Strømfjord area. Although there is one previous record of the species from West Greenland, the precise location in West Greenland is unknown, and there is no preserved specimen to support the report of this species that is otherwise only known from NW Europe (Langangen *et al.*, 1996).

On Svartenhuk Halvø, the charophyte *Nitella opaca* vel *flexilis* was collected from several lakes; the molluscs *Lymnaea vablii* and *Pisidium steenbuchi* were also present. These taxa have not previously been recorded so far north.

Future work

The large number of diverse and relatively unstudied lakes in West Greenland provides considerable scope for integrated studies of limnological and climate change during the Holocene. Future work will include extending the diatom surface sediment sampling survey westwards towards the more maritime area around Sisimiut/Holsteinsborg, and undertaking a combined limnological survey of a representative subsample of both dilute (i.e. freshwater) and saline lakes in the area around the head of Søndre Strømfjord.

Acknowledgements

We are grateful to the Commission for Scientific Research in Greenland for funding the field work. Peter (Samsø) Rasmussen is thanked for his help in retrieving the long cores. A. Langangen, Oslo, identified the charophytes specimens.

References

- Anderson, N. J. 1993: Natural versus anthropogenic change in lakes: the role of the sediment record. *Trends in Ecology & Evolution* **8**, 356–361.
- Anderson, N. J. 1995: Using the past to predict the future: lake sediments and the modelling of limnological disturbance. *Ecological Modelling* **78**, 149–172.
- Bennike, O. 1995: Palaeoecology of two lake basins from Disko, West Greenland. *Journal of Quaternary Science* **10**, 149–155.
- Bennike, O. & Funder, S. 1997: Macrofossil studies of Holocene lake sediments from Jameson Land, East Greenland. *Geology of Greenland Survey Bulletin* **176** (this volume).
- Björck, S., Bennike, O., Ingólfsson, Ó., Barnekow, L. & Penney, D. N. 1994: Lake Boksehandsken's earliest postglacial sediments and their palaeoenvironmental implications, Jameson Land, East Greenland. *Boreas* **23**, 459–472.
- Böcher, T. W. 1949: Climate, soil and lakes in continental West Greenland. *Meddelelser om Grønland* **147**(2), 63 pp.
- Eisner, W. E., Törnqvist, T. E., Koster, E. A., Bennike, O. & van Leeuwen, J. F. N. 1995: Paleocological studies of a Holocene lacustrine record from the Kangerlussuaq (Søndre Strømfjord) region of West Greenland. *Quaternary Research* **43**, 55–66.
- Fritz, S. C., Juggins, S., Battarbee, R. W. & Engstrom, D. R. 1991: Reconstruction of past changes in salinity and climate using a diatom-based transfer function. *Nature* **352**, 706–708.
- Fritz, S. C., Engstrom, S. C. & Haskell, B. J. 1994: 'Little Ice Age' aridity in the North American Great Plains: a high resolution reconstruction of salinity fluctuations from Devils Lake, North Dakota, USA. *The Holocene* **4**, 69–73.
- Funder, S. & Weidick, A. 1991: Holocene boreal molluscs in Greenland – palaeoceanographic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* **85**, 123–135.
- Hansen, K. 1970: Geological and geographical investigations in Kong Frederik IX's Land. Morphology, sediments, periglacial processes and salt lakes. *Meddelelser om Grønland* **188**(4), 77 pp.
- Hardy, D. R., Bradley, R. S. & Zolitschka, B. 1996: The climatic signal in varved sediments from Lake C2, northern Ellesmere Island, Canada. *Journal of Paleolimnology* **16**, 227–238.
- Henderson-Sellers, A. 1990: Modelling and monitoring 'greenhouse' warming. *Trends in Ecology & Evolution* **5**, 270–275.
- Henderson-Sellers, A. 1994: Numerical modelling of global climates. In Roberts, N. (ed.) *The changing global environment*, 99–124. Oxford: Blackwell.
- 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**, 57–71.
- Johnsen, S. J., Dahl-Jensen, D., Dansgaard, W. & Gundestrup, N. 1995: Greenland palaeotemperatures derived from GRIP bore hole temperatures and ice core isotope profiles. *Tellus* **47B**, 624–629.
- Laird, K. R., Fritz, S. C., Grimm, E. C. & Mueller, P. G. 1996: Century-scale reconstruction from Moon Lake, a closed-basin lake in the northern Great Plains. *Limnology & Oceanography* **41**, 890–902.
- Langangen, A., Hansen, J. B. & Mann, H. 1996: The charophytes of Greenland. *Cryptogamie, Algologie* **17**, 239–257.
- Ouellet, M., Dickman, M., Bisson, M. & Page, P. 1989: Physico-chemical characteristics and origin of hypersaline meromictic Lake Garrow in the Canadian High Arctic. *Hydrobiologia* **172**, 215–234.
- Smol, J. P. Walker, I. R. & Leavitt, P. R. 1991: Paleolimnology and hindcasting climatic trends. *Verhandlungen internationale Vereinigung für theoretische und angewandte Limnologie* **24**, 1240–1246.
- Street-Perrot, F. A. & Roberts, N. 1994: Past climates and future greenhouse warming. In Roberts, N. (ed.) *The changing global environment*, 47–68. Oxford: Blackwell
- Williams, W.D. 1991: Comments on the so-called salt lakes of Greenland. *Hydrobiologia* **210**, 67–74.

Authors' address:

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