Lake sediment coring in South Greenland in 1999

Ole Bennike and *Svante Björck*

The transition from the last ice age to the Holocene was a period of extremely rapid and large climatic changes (Björck *et al.* 1998). Because of this, the period has attracted much attention by Quaternary workers since these fluctuations were first demonstrated by Danish scientists (Hartz & Milthers 1901; Iversen 1934, 1954). In the ice-free parts of Greenland, many attempts have been made over the past few decades to find sediments from this transitional period. Some radiocarbon dates on marine molluscs from the late-glacial have been published, but most are based on conventional dating of several shells that might represent a mixture of Holocene and interglacial material. Conventional radiocarbon dating of lake sediments has also produced a number of 'late-glacial' dates, but where checked by accelerator mass spectrometry (AMS) radiocarbon dating, the sediments have proved to be Holocene (Björck *et al.* 1994a, b). These sediments contain 'old carbon' in the form of coal fragments and reworked interglacial organic detritus.

In 1999 we tried a new approach to locate late-glacial lake sediments in Greenland. In southernmost Greenland, the shelf is narrow and the land area relatively

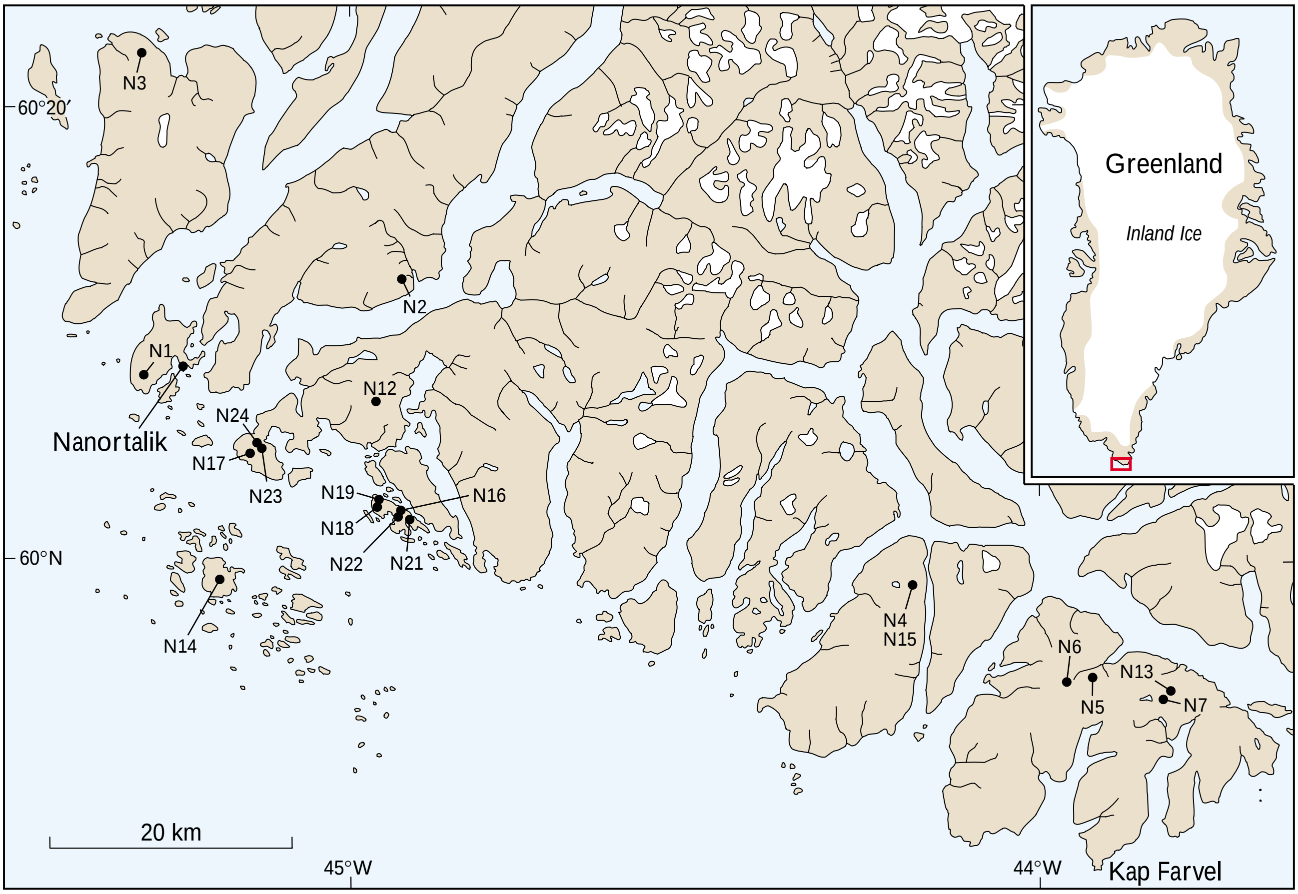

Fig. 1. Map of South Greenland showing the locations of the studied lake basins. Glacier ice is shown **white** and lakes in **blue**.

small. Therefore the amount of glacierization during the Quaternary glacial stages must have been limited. In addition, this region is situated so far south in the North Atlantic that it must have been much influenced by the warming at 14,700 GRIP years BP (Björck *et al.* 1998). The southern location also means that the temperature conditions would allow a fairly rich plant and animal life to have become established rather early after recession of the ice. Sediment records from lakes located near sea-level at some distance from the outer coast extend back to the earliest Holocene (Fredskild 1973). Lakes situated at higher elevations might have become deglaciated earlier, when the Inland Ice thinned over the coast towards the end of the last ice age. Thus, in the 1999 programme we have sampled high-elevation basins, situated at 350–720 m above sea level (see Table 1). Basins situated in cirque valleys were avoided because it is possible that glaciers would have been present in such basins during the Little Ice Age. However, it turned out that most of the high-elevation basins investigated were devoid of sediments. Even at water depths over several tens of metres, the bottom consisted of stones and boulders and a good sedimentary sequence was only found in a single lake. For this reason, low-elevation basins as far away as possible from the present ice margin were also cored.

In addition, it was decided to core a series of isolation basins at different elevations below the marine limit in order to establish a securely constrained curve for the relative shore-level change after the last deglaciation. Many such curves have been published from different parts of Greenland, but they are mainly based on mollusc shell dates which are much more uncertain than dates from isolation basins. The dated molluscs lived at various depths below sea-level and their relationship to the former sea-level is always uncertain. The locations of the cored basins are shown in Fig. 1 and short notes on the lakes are given in Table 1.

This work is a continuation of the studies of recent years on lake sediments in South and West Greenland by the Geological Survey of Denmark and Greenland (Anderson & Bennike 1997; Overpeck *et al.* 1998; Anderson *et al.* 1999; 2000, this volume; Bennike 2000; Brodersen & Anderson 2000, this volume).

Material and methods

From a base in Nanortalik a helicopter was used for transport of coring equipment and personnel (Figs 1, 2A). The field work was carried out between 9 and 20 April 1999. The Kap Farvel area is renowned for unstable weather conditions and coring work was cancelled for several days due to strong winds and rain. Temperatures were around 0°C and the thickness of the lake ice varied between 80 and 220 cm. A power-driven 25 cm diameter ice auger was used for drilling through the ice (Fig. 2B). Water depths were usually measured at several sites. Lake sediment coring was undertaken using a Russian corer and a Nesje corer. The elevations of the

Table 1. Lakes investigated in 1999

Lake no.	N. lat.	W. long.	Elevation (m)	Water depth (m)	Notes
N1	60°08.20´	45°18.27´	*c.* 300	Max. 3	Deglaciation sequence
N2	60°12.43´	44°56.44´	*c.* 660	Max. 10	Boulders and some mosses
N3	60°21.89´	45°18.72´	*c.* 600	32.8	Soft sediments, ?diatomite
N4	59°59.16´	44°10.68´	*c.* 600	5–10	Stones and boulders
N5	59°54.69´	43°55.30´	*c.* 510	4.5–18.5	Gyttja clay and silt
N6	59°54.59´	43°58.12´	*c.* 450	12–36	Boulders and some ?diatomite
N7	59°53.88´	43°48.46´	450–500	3.8	Stones and boulders
N12	60°07.16´	44°57.96´	*c.* 465	4.5–10.8	Some gyttja
N13	59°54.32´	43°58.15´	*c.* 300	9–18	Boulders and some ?diatomite
N14	59°58.84´	44°58.79´	33	3.3–8	Late glacial isolation sequence
N15	*c.* 59°58´	*c.* 44°12´	*c.* 720	9	Stones and boulders
N16	60°02.20´	44°55.37´	11	4.5–8.3	Isolation sequence
N17	60°04.46´	45°08.99´	57	5.4–6.8	Clay and gyttja, ?slumping
N18	60°02.16´	44°57.56´	30	1.2	Isolation sequence
N19	60°02.54´	44°57.20´	24	2.1	Isolation sequence
N21	60°01.85´	44°54.82´	3	1.8	Isolation sequence in at least 7 m sediment
N22	60°01.98´	44°55.89´	4	2.65	Isolation sequence in at least 10 m sediment
N23	60°04.57´	45°07.77´	47	2.2	Deglaciation sequence
N24	60°04.87´	45°07.75´	26	0.7–0.8	Isolation sequence

alpine lakes were measured using a digital altimeter whereas the elevations of the basins in the lowland areas were determined photogrammetrically using the computer-supported Kern PG 2 stereo-plotter at the Geological Survey of Denmark and Greenland. The accuracy of these measurements is around ± 1 m. The sediment cores were wrapped and sent back to the laboratory in Copenhagen where they are stored at 4°C. In the laboratory, the cores have been visually described and subsampled. Magnetic susceptibility and loss on ignition have been determined on closely-spaced samples. Some samples have been analysed for macrofossils and diatoms. Selected macrofossils have been used for AMS radiocarbon dating. A high-resolution record of biogenic silica is being worked out for a selected sequence.

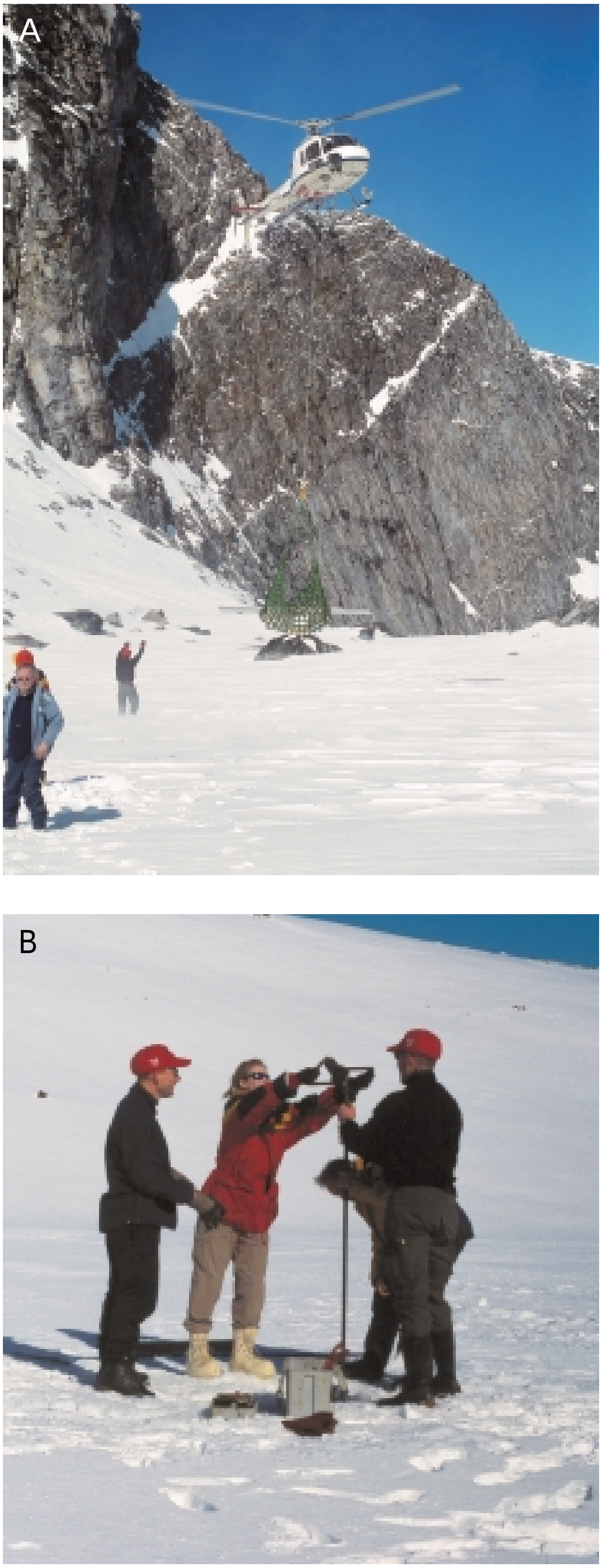

Fig. 2. **A**: The helicopter about to release a sling-load of equipment on the lake ice at basin N5. Photo: Jakob Qvortrup Christensen. **B**: Drilling through the lake ice with a power-driven ice auger, April 1999.

Late-glacial sediments

Late-glacial sediments were encountered in basins N14, N18 and N23 (Fig. 1). Closely-spaced AMS dates from N14 situated at 33 m above sea level (Table 1) indicate continuous sedimentation from *c.* 14 to 11.5 cal. ka BP. Marine sediments are overlain by *c.* 35 cm of late-glacial lacustrine sediments. The Younger Dryas macrofossil assemblages from basin N14 show extremely low diversity consisting of *Warnstorfia exannulata* (water moss), *Daphnia* sp. and *Chydorus arcticus* (water fleas) and Chironomidae indet. (non-biting midges). This low diversity points to extremely harsh conditions, but this shallow lake must have been ice-free for a short period during the summer to allow water mosses to grow on the lake bottom.

Basin N18, which is also an isolation basin, contains at least 50 cm of marine sediments that pre-date the isolation at around 12 cal. ka BP. Again, the Younger Dryas assemblages show low diversity but some seeds of grasses and *Minuartia* sp. are found. Basin N23 is situated above the marine limit but so far only a few samples of Younger Dryas age have been analysed.

Shore-level changes

Two cores showing isolation contacts are shown in Fig. 3. The emergence curve based on isolation contacts shows relative sea-level changes after the last deglaciation (Fig. 4). This is the third Greenland curve to be based on dating of basal lacustrine sediments from isolation basins (Kelly & Funder 1974; Long *et al.* 1999) and the first based on AMS dating of macrofossils.

Because of the early deglaciation of the Kap Farvel area, the curve extends further back in time than any previous sea-level curve from Greenland. The marine limit is rather poorly constrained but is probably at around 30–40 m above sea level (Kelly 1985). The emergence curve shows that a rapid fall in the relative sea-level occurred from *c.* 11.5 cal. ka BP to *c.* 10 cal. ka BP, at which time the present relative sea-level was attained (Fig. 4). This rapid fall of around 20 m per 1000 years was preceded by a period of slower sea-level fall. However, lake N14 is situated 10–15 km from the other isolation basins, at a right angle to the isobases (Fig. 1). This basin thus experienced a somewhat different sea-level history than the other basins and the early rate of relative sea-level fall cannot be quantified.

The curve of Fig. 4 reflects the local deglaciation history. The low initial uplift rate shows that deglaciation proceeded slowly during the Younger Dryas. After the abrupt warming that occurred at the end of the last ice age at 11.5 ka BP, the rate of deglaciation commenced at a much faster rate, giving rise to the fast relative sea-level fall. The present sea-level was attained earlier than reported from any other part of Greenland. In West Greenland the present-day sea-level was attained 2–5 cal. ka BP (Kelly 1985; Long *et al.* 1999), and in North Greenland as late as around 1 cal. ka BP (Bennike 1987; Kelly & Bennike 1992). Thus in North Greenland, palaeo-Eskimo ruins are often situated on raised beaches.

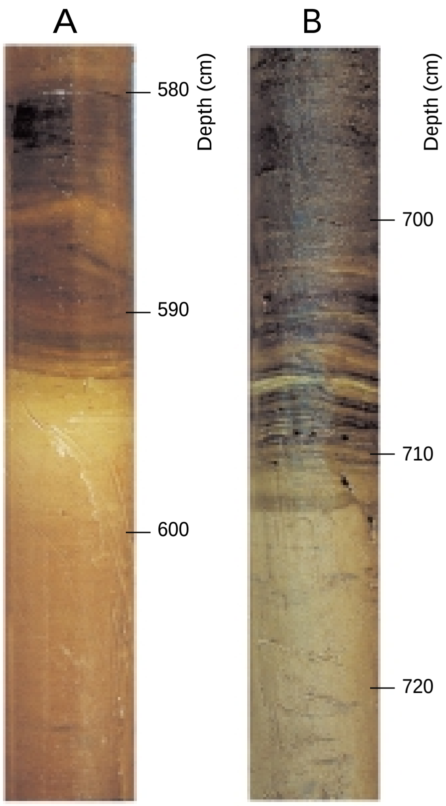

Fig. 3. Sediment cores with isolation contacts from lake N16 (**A**) and lake N21 (**B**). Marine minerogenic sediments are overlain by laminated gyttja that are followed by homogenous lake gyttja. The scales refer to depth below the lake surface level.

Biotic response to climate changes

The temporal ranges of different terrestrial and lacustrine plants and animals are shown in Fig. 5. The known Late Quaternary history of these taxa in Greenland has been extended backwards in time. It is interesting to note that two cladoceran taxa, *Acroperus harpae* and *Alona* sp., were present prior to and after the Younger Dryas period. Although this is based on only one record (N14), it may apply to other basins and to other taxa.

Only three taxa of cladocerans have been encountered in Younger Dryas sediments and only two other groups of freshwater animals are recorded. The freshwater bryozoan *Plumatella repens* arrived early in the Holocene and the oldest remains of the small fish *Gasterosteus aculeatus* (stickleback) were found in sediments dated to *c.* 10.5 cal. ka BP. Among the plants, several taxa of bryophytes were found in the late-glacial sediments, but rare remains of *Minuartia* sp. and Poaceae are the only representatives of seed plants found. The range of several macro-limnophytes, herbs and the dwarf shrub *Empetrum nigrum* have been pushed back in time but no remains of these taxa were found in late-glacial sediments. We consider them Holocene immigrants rather than ice age survivors, in accordance with previous conclusions (Bennike 1999).

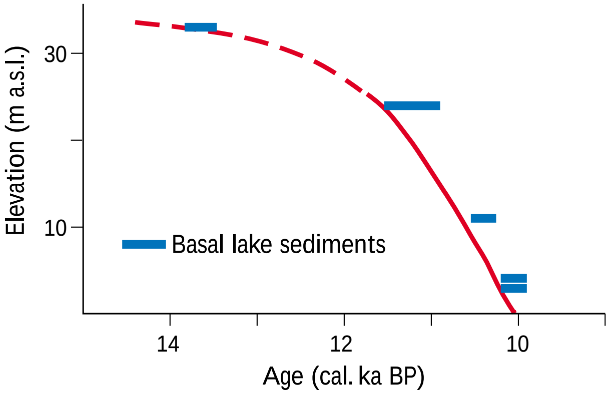

Fig. 4. Preliminary emergence curve based on dates on basal lacustrine sediments from lake basins N14, N16, N19, N21 and N22.

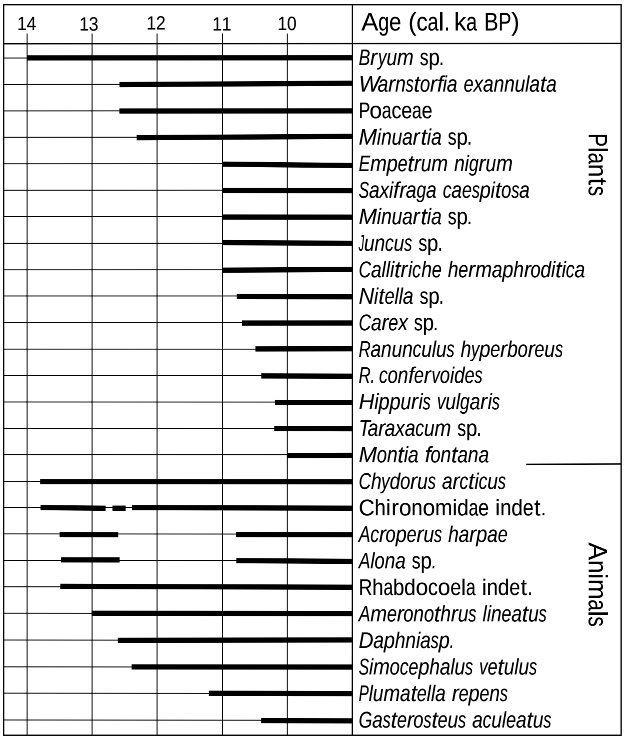

Fig. 5. Late-glacial and early Holocene temporal range of different non-marine plants and animals based on this study.

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Authors' addresses

O.B., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark.* E-mail: *obe@geus.dk*

S.B., *Geological Institute, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.*