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Paleoecological Studies of a Holocene Lacustrine Record from the Kangerlussuaq (Søndre Strømfjord) Region of West Greenland

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A lacustrine sediment record from the Kangerlussuaq region, West Greenland, has resulted in a pollen, macrofossil, and sediment stratigraphy that encompasses the last 5000 ^{14}C yr. Deglaciation of the area and subsequent development of a nearby floodplain occurred before 5000 yr B.P. Since that time eolian sand and silt deposition appear to have been continuous, with a significant increase ca. 1000 ^{14}C yr B.P. Pollen analysis shows little change in the character of the vegetation throughout the record. Fluctuations in herb pollen taxa indicate changes in the extent and development of eolian sand sheets. The oldest pollen zone records relatively little pollen accumulation and low taxa diversity. This is followed by a zone of high pollen accumulation, presumably a phase of highest vegetation density, from 4400 to 3400 ^{14}C yr B.P. Thereafter, declining pollen accumulation rates reveal a gradual environmental deterioration. Macrofossil analyses record significant limnological changes, with an early eutrophic phase followed by a mesotrophic phase and a reversal to more eutrophic conditions in the final phase. The preserved record illustrates the interactions of deglaciation, eolian activity, regional vegetation, and limnological change. ©1995 University of Washington.

INTRODUCTION

The unglaciated land at the ice sheet margin of West Greenland offers a unique opportunity to study a landscape that may approximate the environment of the late-glacial period at lower latitudes (e.g., northwestern Europe). Past environmental changes at sites in southern, western, and northwestern Greenland have been reviewed by Fredskild (1985) and Funder and Fredskild (1989). Investigators note that many paleoclimatic changes are asynchronous and that regional vegetation patterns have been slow to emerge. This paper presents the pollen, macrofossil, and sediment analysis of the first lacustrine core from a lake in the Kangerlussuaq (Søndre Strømfjord) region (Fig. 1). This sequence helps to link palynological studies from the Nuuk region (Godthåbsfjord; 64–65° N) with those from northwest Greenland (75–78° N). Results of the analysis are interpreted within the framework of ongoing investigations into modern eolian periglacial deposition (Koster, 1988).

STUDY AREA

Kangerlussuaq is a 175-km-long, WSW–ENE-oriented fjord. The airport of the same name lies at the head of the fjord, about 25 km west of the margin of the Greenland ice sheet. Sandflugtdalen, an elevated fluvioglacial valley, lies between the ice margin and the headwaters of the fjord (Fig. 1). The Sandflugtdalen floodplain decreases in altitude from approximately 120 m at the ice margin to 60 m just west of Mount Keglen. The surrounding hills only occasionally exceed 400–600 m.

Quaternary mapping of the ice-free region in west Greenland has identified a complex of five major stages during the oscillatory Holocene deglaciation, characterized by the presence of large moraine systems (Ten Brink and Weidick, 1974; Ten Brink, 1975). The two youngest, Keglen and Ørkendalen, are located within the study area and have been dated at 6000–6500 ^{14}C yr B.P. and 300–700 ^{14}C yr B.P., respectively (Ten Brink, 1975).

Detailed geomorphic mapping of the study area has identified several former glacial meltwater systems, which are now dry valleys. Lake 31 is located in one of

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The loss on ignition (LOI) curve shows that eolian input continued throughout the period of lake infilling, but with variable intensity (Fig. 4). Relatively low LOI values are found in the lowermost part of the core, increasing to >20% above 70 cm. A significant increase in silt occurs above 10 cm depth.

The radiocarbon dates from Lake 31 are given in Table 1. Sandgren and Fredskild (1991) observed aging of bulk samples by some 300 ^{14}C years in a few small Greenland lakes due to recycling of old humus. Reservoir effects in Lake 31 are not likely to be large because of the shallow water depth and the absence of calcium carbonate in the bedrock.

Calibration of the ^{14}C ages was carried out with the Groningen calibration program (Van der Plicht, 1993) using a strongly smoothed calibration curve (smoothing parameter of 200; Törnqvist and Bierkens, 1994). The median of the probability distribution of the calibrated ages was used for further calculations (Table 1). Linear interpolation between data points (Fig. 6) indicates an average sediment accumulation rate of almost 2 cm per 100 calendar yr (not corrected for compaction), within the range of accumulation rates for Greenland lakes (Fredskild, 1977, 1985). Because the uppermost ^{14}C sample is not located at the top of the sediment core, the age of the uppermost deposits was obtained by extrapolation of the line connecting samples 1 and 2. Apparently the top of the lake sediments, the water–gyttja interface, was lost during coring. Hereafter, we express our calibrated dates as "cal yr B.P." (calendar years before present) to differentiate them from the uncalibrated ^{14}C dates, expressed as "^{14}C yr B.P." Uncalibrated dates are used when comparing our results with other published data.

The basal date, 5030 ± 60 ^{14}C yr B.P., is notably younger than the age of the Keglen moraine system. The investigated core is underlain by approximately 1 m of sand that was not sampled. Because of the low accumulation rate of the lowermost sediments in the core, the underlying sand probably represents a significant time interval. The glacial meltwater system in which Lake 31 developed may have been active for a considerable time after local deglaciation.

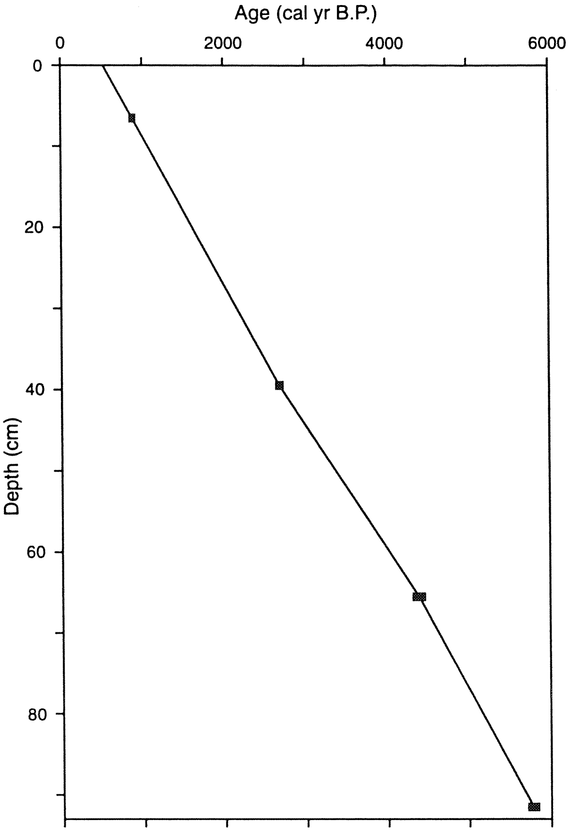

FIG. 6. Time–depth plot of the core from Lake 31.

The minerogenic sediment influx per unit time (Fig. 7) confirms that there were large fluctuations in eolian sediment transport. Organic accumulation is constant throughout the time interval covered by the core, indicating that lithologic changes are the result of fluctuations in minerogenic input.

Pollen Zones and Vegetation Sequence

The pollen percentage diagram (Fig. 8) is based on the sum of all terrestrial pollen types, with pteriodophytes and aquatic pollen expressed as percentages of the sum. The pollen accumulation rate (PAR) diagram (Fig. 9) uses calibrated ages. Zonation is based on the PAR diagram, using stratigraphically constrained cluster analysis (Grimm, 1987). Overrepresentation of *Betula* (from 40 to

TABLE 1
List of ^{14}C Ages

Laboratory No.	^{14}C age (yr B.P.)	Calibrated age (cal yr B.P.)[a]	Geographic coordinates	Sample depth (cm)	Sample name	Material
UtC-1583	960 ± 40	840–920 (880)	67°03′ N 50°28′ W	6–7	Sandflugtdalen 31-1-1	Organic silt
UtC-1584	2590 ± 40	2630–2730 (2690)	67°03′ N 50°28′ W	39–40	Sandflugtdalen 31-1-2	Organic silt
UtC-1585	3950 ± 50	4310–4470 (4390)	67°03′ N 50°28′ W	65–66	Sandflugtdalen 31-1-3	Organic silt
UtC-1586	5030 ± 60	5710–5850 (5790)	67°03′ N 50°28′ W	91–92	Sandflugtdalen 31-1-4	Sandy silt

[a] Confidence interval, median in parentheses (calibration according to Van der Plicht, 1993).

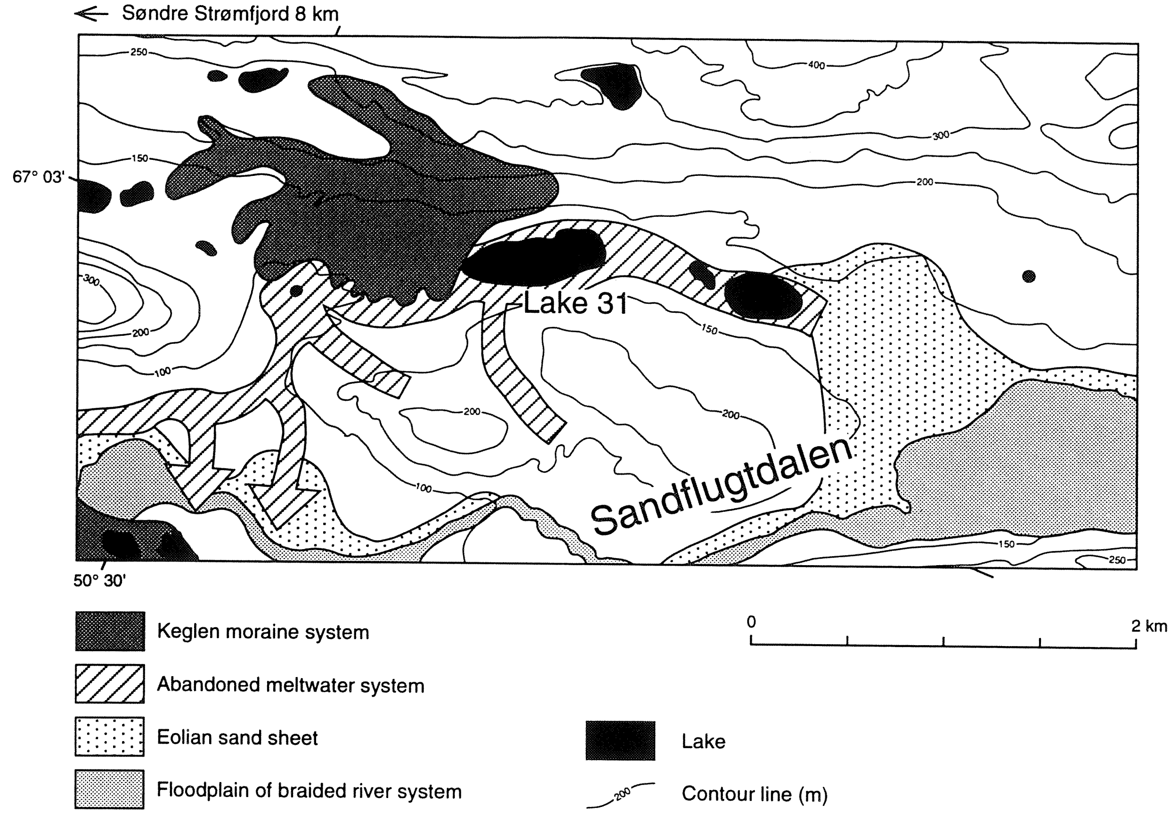

FIG. 2. Topography of the area surrounding Lake 31 in Sandflugtdalen. Geomorphology simplified from De Graaf *et al.* (1991).

Rumex acetosella, and *Artemisia borealis*). Grasses and willow (*Salix glauca*) are the most important plants for the formation of phytogenic dunes (Dijkmans and Törnqvist, 1991).

FIELD AND LABORATORY METHODS

Lake 31 was cored in 1985 by researchers from the Department of Physical Geography, Stockholm University. The 93-cm-long core was taken in 2.65 m of water using a Livingstone piston sampler. The core was transported to Utrecht University, where loss on ignition, grain size, and pollen analyses were carried out. Radiocarbon ages of four 1-cm-thick bulk samples were obtained by accelerator mass spectrometry.

Subsamples of 0.56 cc were taken at 1.5- to 3-cm intervals and prepared using standard pollen procedures, including treatment with hydrofluoric acid and acetolysis. *Lycopodium clavatum* tablets were added to each sample to determine pollen concentrations. The pollen was mounted in silicon oil and identified at ×400.

Macrofossil analysis was performed at the Geological

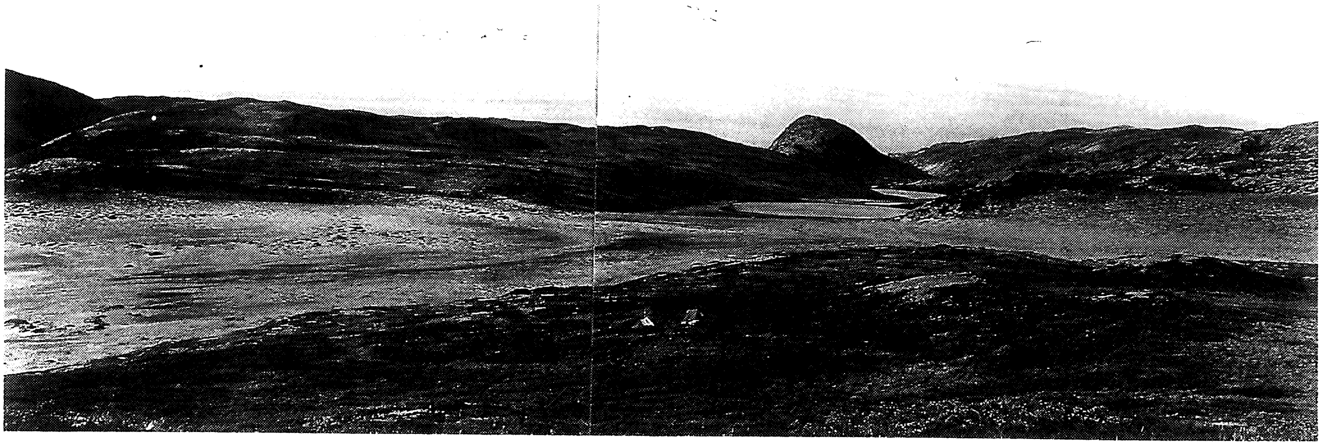

FIG. 3. Ground photo of sand sheet. Lake 31 is in the background in front of Mount Keglen.

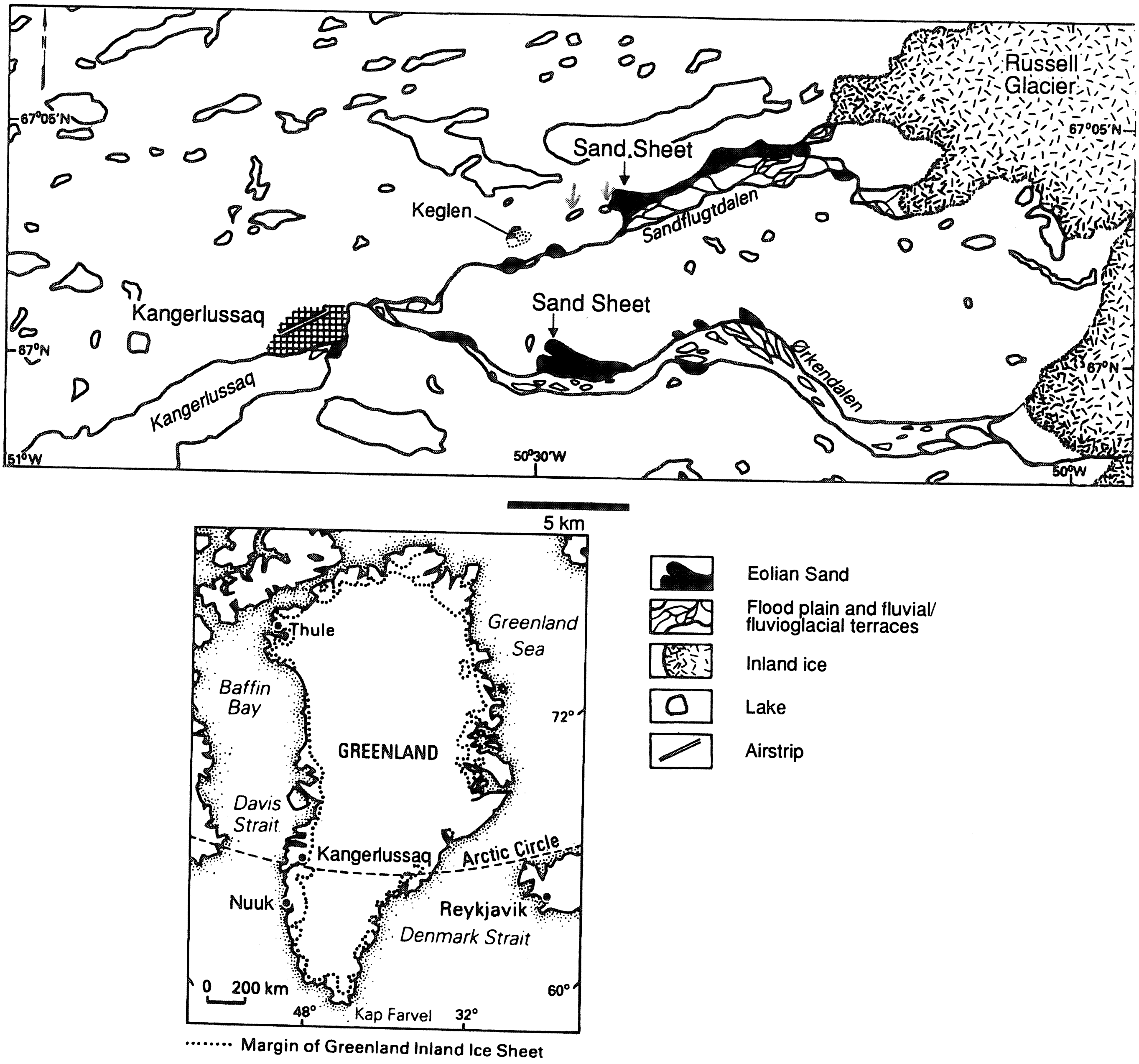

FIG. 1. Map showing location of the study area, with inset map of Greenland.

these valleys (Fig. 2). The lake, at 115 m altitude, measures 750 m by 225 m. The braided river system in Sandflugtdalen is the source area of eolian deposits that cover most of the study area, either as sand sheets or as widespread silt (Fig. 3) (Hansen, 1970; Dijkmans and Törnqvist, 1991).

The region has an arid, continental low-arctic climate. The Kangerlussuaq weather station records a mean annual temperature of −6°C. The average temperature is −26°C for the coldest month and 11°C for the warmest month. Annual precipitation is low (average from 1982–1991, 152 mm), with the greatest amount falling as rain in the summer. The low precipitation has led to the presence of lakes with high salt content (Böcher, 1949; Hansen, 1970). Wind speeds are strong, and catabatic winds decrease in strength with distance from the ice margin. Winter observations revealed that in areas of thin snow cover, wind-transported snow and sand are important factors in deflation and redistribution of sediments (Dijkmans, 1990). Permafrost is continuous in the Sandflugtdalen area.

The vegetation of the region is highly dependent on topography and eolian activity. The vegetation is dominated by the deciduous shrub *Salix glauca* and dwarf-shrub vegetation (*Betula nana* and *Vaccinium uliginosum*). The sparse sand sheet vegetation is predominantly a xerophilous grassland (*Calamagrostis purpurascens, Elymus arenarius* ssp. *mollis, Chamaenerion latifolium,*

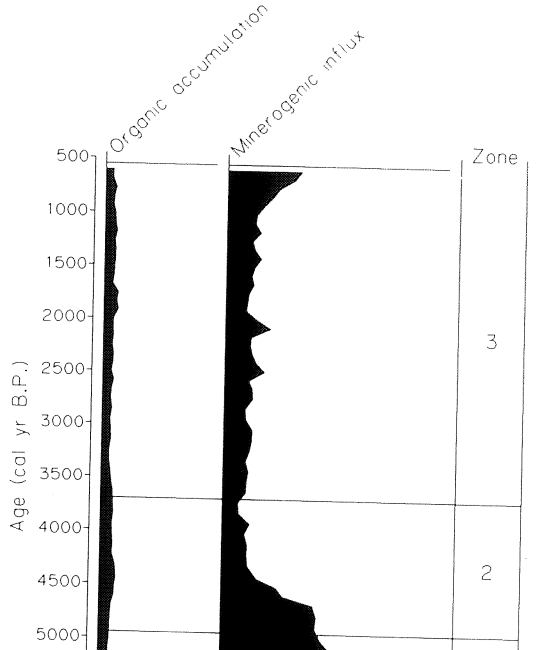

FIG. 7. Minerogenic influx and organic accumulation, expressed as mg · cm^{-2} yr^{-1}.

60% of the pollen sum) has largely obscured the signal of the percentage diagram, while the PAR diagram shows greater variability through time, indicating that vegetational change did occur.

Zone 1 (92 to 76 cm, 5000–4400 ^{14}C yr B.P. or 5800–5000 cal yr B.P.) is dominated by *Betula,* with Cyperaceae being a major contributor. Of the minor elements, only Gramineae exceeds 10% of the sum. Total PAR averages about 400 grains cm^{-2} yr^{-1}. Zone 2 (76 to 55 cm, 4400–3400 ^{14}C yr B.P. or 5000–3700 cal yr B.P.) shows maximum pollen accumulation values at 750 grains cm^{-2} yr^{-1}. *Salix* and Gramineae reach high levels, Ericales is significant, along with *Potentilla, Saxifraga oppositofolia* type, *Artemisia, Rumex acetosella* type, and other herbs (this category consists of *Ambrosia* spp., Chenopodiaceae, Cruciferae undiff., *Filipendula, Galium* L., *Plantago maritima, Polyganum viviparum, Saxifraga cernua, Sparganium,* and Violaceae). *Alnus* pollen reaches values of 8 grains cm^{-2} yr^{-1} at 4700 cal yr B.P. This is considered to be the result of long-distance transport. *Alnus* immigrated to southwest Greenland between 4000 and 3500 ^{14}C yr B.P. and has a northern limit in Greenland at 66° (Fredskild and Ødum, 1990). Zone 3 (55 to 0 cm, 3400–700 ^{14}C yr B.P. or 3600–600 cal yr B.P.) shows decreasing *Betula* percentages and higher percentages of Gramineae and *Salix.* The total PAR values decrease steadily, indicating sparse vegetation cover and more open ground. Increasing Ericales percentages and accumulation values between 10.5 and 15 cm (1400–1200 ^{14} yr B.P. or 1300–1100 cal yr B.P.) reflect an increase i heath vegetation.

Macrofossil Analyses

The macrofossil concentration diagram reveals limnological changes (Fig. 10). The minerogenic-rich sediments from 92 to 70 cm have high concentrations o *Chara* and *Tolypella* oospores. Maximum values o *Myriophyllum spicatum* and *Potamogeton filiformis* ar also reached in this interval. All animals, except *Chydorus arcticus,* show low values. The organic-rich sediments from 70 to 10 cm are devoid of Characeae oospores, but contain maximum values of *Hippuris vulgaris, Potamogeton praelongus,* and other species o *Potamogeton, Spongilla lacustris, Daphnia pulex,* and Chironomidae. The late appearance of a number of water plants may reflect delayed immigration to the lake. The minerogenic-rich sediments from 10 to 3 cm again contain Characeae oospores, but now from *Nitella flexilis.* Al other macrophytes are missing or rare. The green alga *Cladophora glomerata* is common, and several of the animal remains reach maximum concentrations, notably *Eurycercus glacialis* and *Acroperus harpae.*

DISCUSSION

The first lake sediment record analyzed from Sandflugtdalen has resulted in a pollen stratigraphy that encompasses the last 5000 ^{14}C yr. The diagrams are similar to other West Greenland pollen records, with variations that may be directly related to the proximity of this site to the ice-sheet margin. The initial period, from 5000 to 4400 ^{14}C yr B.P., shows the major vegetation types already well-established. A "climatic optimum" is suggested from 4400 to 3400 ^{14}C yr B.P., with denser vegetation cover indicating warmer and slightly moister conditions. A deterioration after 3400 ^{14}C yr B.P. may be due to increasingly colder conditions. This situation generally agrees with other Greenland data (Fredskild, 1983a) as well as pollen records from Labrador (Short and Nichols, 1977), northeastern Canada (Andrews and Nichols, 1981), and Ellesmere Island (Hyvärinen, 1985) and comprehensive reviews of the Canadian Arctic and Subarctic (Ritchie, 1987). The increase in heaths between 1400 and 1200 ^{14}C yr B.P. is noted in other West Greenland cores and represents a change to cooler, humid conditions (Fredskild, 1973; Iversen, 1954; Pennington, 1980). A fell-field vegetation phase, typical for other West Greenland records for the earliest deglaciation period, is missing in this record (Funder and Fredskild, 1989).

The floodplain, which has been the source of the silt, must have developed to its present extent soon after deglaciation. The entire sedimentary sequence reflects al-

Survey of Denmark, Copenhagen. Samples of approximately 20 ml were wet sieved through a 0.21-mm sieve; fossils retained on the sieve were identified and counted under a dissecting microscope. Small skeletal remains of Cladocera have been lost, but the fraction retained on the sieve from sample to sample was constant. Selected fossils were gold-coated and photographed by SEM; these are stored at the Geological Museum, Copenhagen.

RESULTS

Sedimentary Sequence and the ^{14}C Chronology

Sediments in the Lake 31 core consist of gyttja and silt, merging downward into sandy silt (Fig. 4). Comparison of the grain-size data with eolian silt from the surrounding area reveals that the clastic lake infill is coarser (Dijkmans and Törnqvist, 1991). However, sorting of the sediment indicates eolian origin (Fig. 5). The higher sand and clay content and the relatively poor sorting of the sediment at the base of the lake infill (68 to 93 cm) suggest partial fluvioglacial origin. Because the lake has neither inlet nor outlet and the immediate surroundings are covered by vegetation, it is assumed that little or no material was washed into the lake from the surrounding slopes.

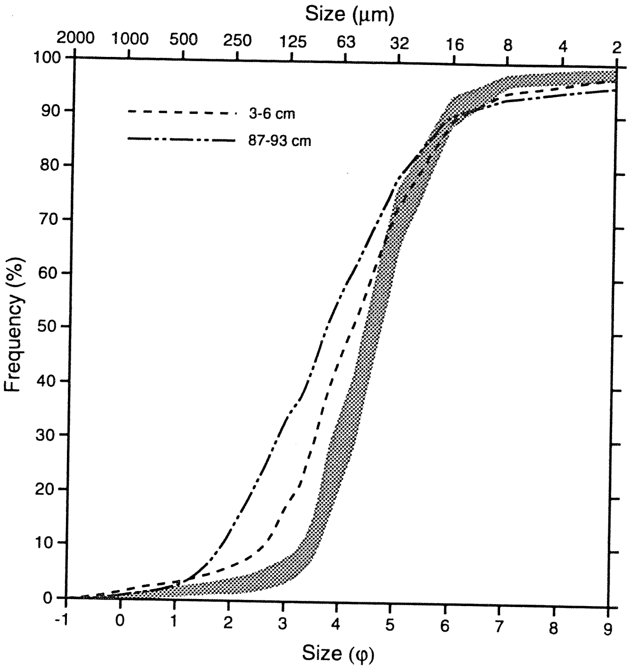

FIG. 5. Comparison of grain-size distributions of two samples from Lake 31 and eolian silt in the surrounding area (Dijkmans and Törnqvist, 1991).

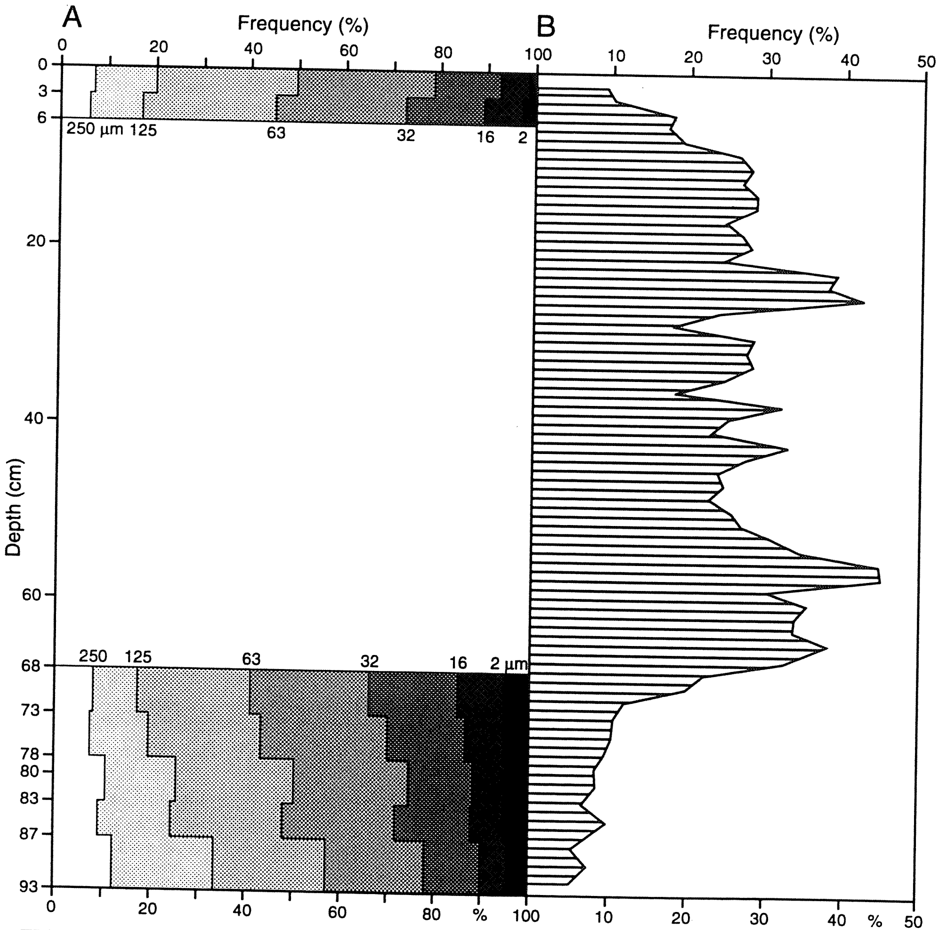

FIG. 4. Grain size (A) and percentage loss on ignition (LOI) (B) of the core from Lake 31.

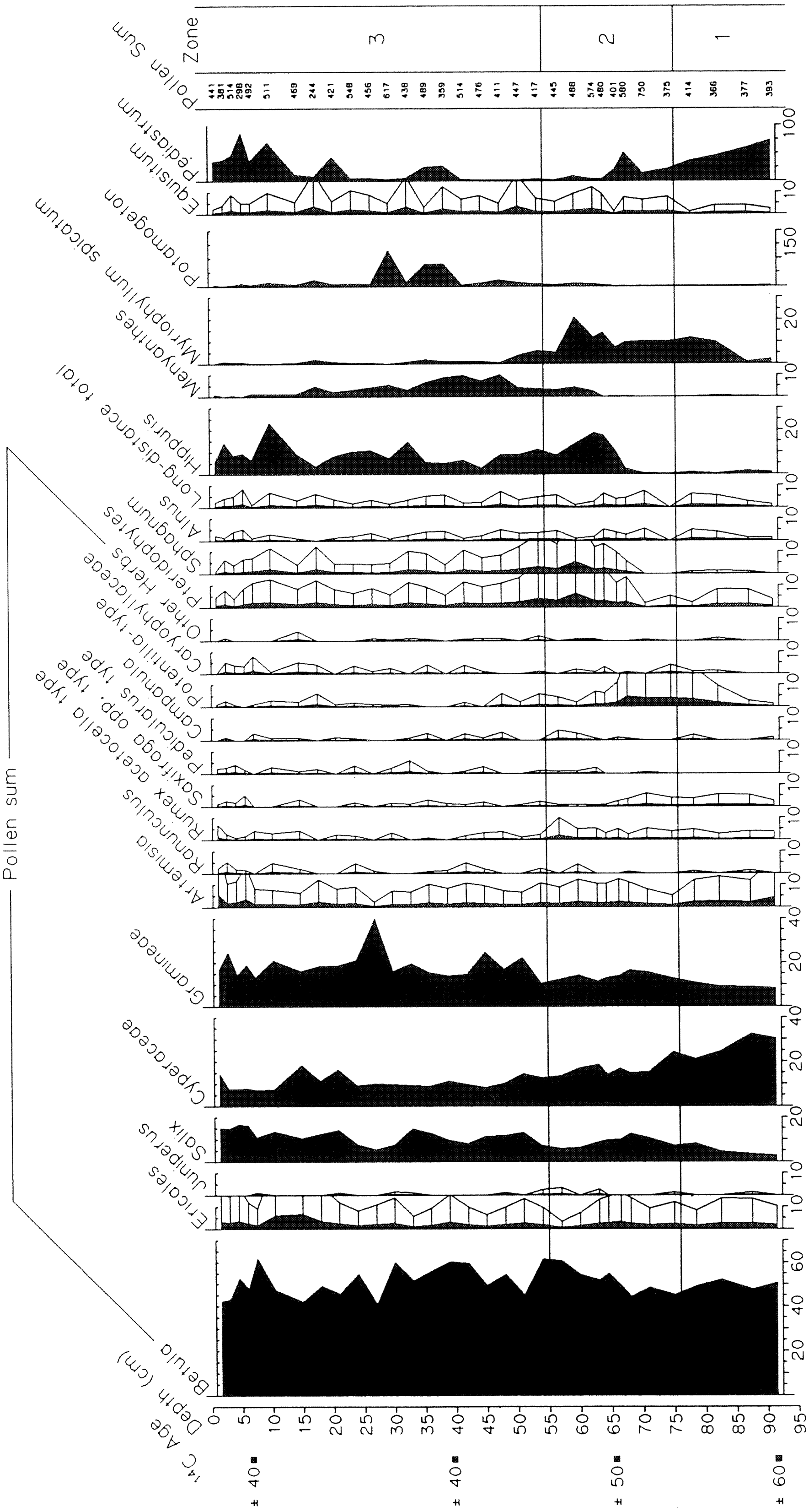

FIG. 8. Pollen percentage diagram. The pollen sum includes the total terrestrial pollen, excluding long-distance pollen, with pteridophytes, long-distance pollen, and aquatic pollen expressed as percentages of the pollen sum. The category "Other Herbs" includes *Ambrosia* spp., Chenopodiaceae, Cruciferae undiff., *Filipendula*, *Galium*, *Plantago maritima*, *Polygonum viviparum*, *Saxifraga cernua*, *Sparganium*, and Violaceae. The category "Long-distance total" includes *Alnus*, *Corylus*, *Quercus*, *Pinus*, and *Picea*. Depth bars indicate 5× exaggeration for some taxa.

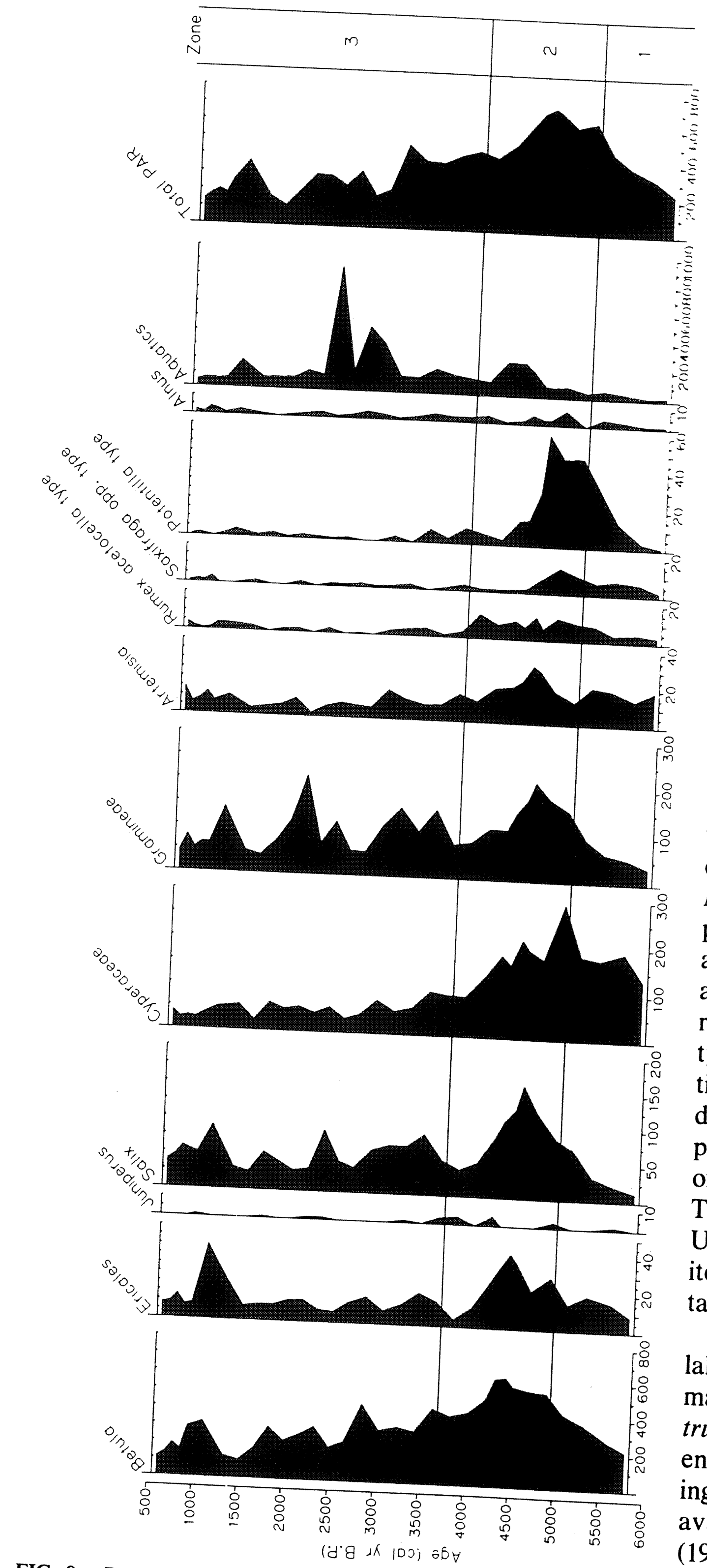

FIG. 9. Pollen diagram showing pollen accumulation rate (PAR) of major taxa, expressed as grains · cm^{-2} yr^{-1}.

ternating periods of high and low eolian activity. An ide tical trend is described at a nearby site (De Graaf *et a* 1991). Evidence for fluctuations in eolian activity c also be detected from widespread occurrences of a co spicuous paleosol in the loess-covered hills of th Kangerlussuaq area, as well as from peaty intercalatio in the eolian sand sheets (Dijkmans, 1989; Dijkmans an Törnqvist, 1991). Based on ^{14}C ages of organic beds in th eolian sediments, an increase in eolian activity followed period of stabilization and reduced activity, which en compassed 2000–1200 ^{14}C yr B.P. The existence of a sta ble period is supported by the LOI records from Lake 3 (Fig. 4) and De Graaf *et al.* (1991), although these indicat that the period started much earlier. The ^{14}C ages o Dijkmans and Törnqvist (1991) may be too young, for th samples used for dating were located just below the surface and probably were permeated by modern roots (cf. Törnqvist *et al.*, 1992). The most important pollen producers that occur exclusively on eolian sand in Sandflugtdalen are *Artemisia borealis* and *Rumex acetosella*. These taxa may indicate past fluctuations in eolian sand sheet extent. The curves of *Artemisia* and *Rumex acetosella* type correlate fairly well with the LOI data, thus confirming the conclusions about eolian dynamics. The high values of *Potentilla* prior to 4000 ^{14}C yr B.P. may also be related to sand sheet activity.

Our results show a strong paleolimnological signal in the pollen diagrams representing a succession from an early eutrophic phase with high values of *Pediastrum* and *Myriophyllum spicatum* to a mesotrophic or transition phase with high *Potamogeton, Hippuris, Menyanthes,* and Sphagnum. The subsequent decrease in *Menyanthes* and *Sphagnum* and the increase in *Pediastrum* indicate a reversal of this trend. This is exceptional compared to typical Greenland lake successions, which show a continuous trend to oligotrophication (Fredskild, 1983a). The difference between the lower and the upper eutrophic phases could be due to differences in the ion composition of the water and/or differences in lake-bottom substrate. The first phase is interpreted as a result of raw water. Unfortunately, the interpretation is hampered by the limited knowledge of the autecology of the three Characeae taxa that are found.

As Fredskild (1983a) found in his studies on Holocene lake development in Greenland, *Pediastrum* attains a maximum shortly after lake formation. The early *Pediastrum* stage can be interpreted as representing high nutrient availability. The renewed increase in *Pediastrum* during the last 1000 yr may also be the result of increased availability of nutrients due to silt influx. Fredskild (1983a, 1992) found a high correlation between productivity of algae and silt accumulation, a situation that is strongly echoed in our results.

The availability of sediment for eolian transport in Sandflugtdalen is determined by sediment supply to the

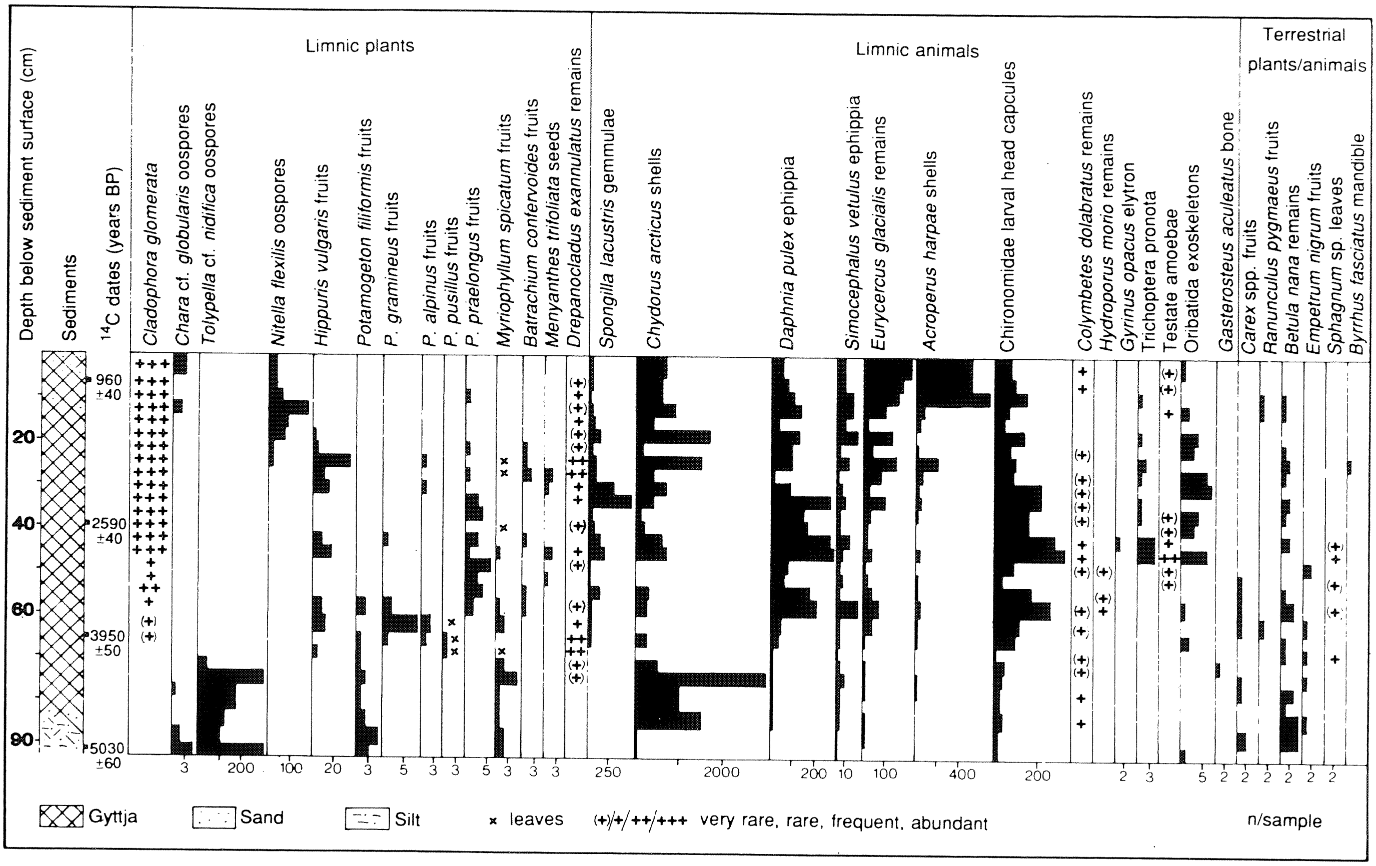

FIG. 10. Macrofossil concentration diagram from Lake 31.

floodplains. Rapid ablation increases the input of meltwater sediment to the floodplains, promoting eolian sediment transport. Readvance of the ice margin will have an opposite effect. The deglaciation pattern of the Greenland ice sheet reflects a rapid retreat throughout most of the Holocene, usually to a position beyond its present limit (Ten Brink and Weidick, 1974; Weidick *et al.,* 1990). According to Funder and Fredskild (1989), this position was reached between approximately 6000 and 3000 ^{14}C yr B.P. There has been a retreat beyond the Keglen moraine system (6500–6000 ^{14}C yr B.P.) located near Lake 31. The highest eolian input took place prior to 4600 cal yr B.P. (~4100 ^{14}C yr B.P.) and corresponds roughly to this retreat interval. The subsequent climatic cooling resulted in a stillstand, or possible readvance, of the ice margin, reflected by reduced input of clastics to the lake. The retreat beyond the Ørkendalen moraine system may explain the increased input of eolian silt after 1000 cal yr B.P.

What caused the increased ion concentrations in the lake, as indicated by the paleolimnological development? Climate change may be the forcing agent, or it may be the input of minerogenic sediment. Store Saltsø, a salt lake south of Kangerlussuaq Airport, shows evidence for lower water levels during the last millennia (Böcher, 1949, 1959). A negative water balance (the result of lower precipitation, increased evaporation, or both) must be responsible for such a phenomenon. A retreat of the ice margin could increase eolian deposition, coinciding with lower lake-water levels, which would ultimately lead to increased salt content. In the case of Lake 31, we cannot specify the original cause of increased ion-richness in the upper zone.

The effect of eolian silt input on Arctic lake sediments is poorly understood and often underestimated in reconstructions of past environmental change. Consideration of silt input in this study has enabled us to suggest patterns of deglaciation and eolian activity that can be linked to vegetation change and limnological developments in the Kangerlussuaq area.

APPENDIX

Cladophora glomerata, identified by H. Nielsen, is not previously reported from Greenland lake sediments. Three to eight species of *Chara* (depending on the species concept) are reported from low arctic Greenland (Böcher, 1954; Lægaard, 1960; De Molenaar; 1976). Oospores of both *Chara* and *Nitella* are commonly found in the older parts of Holocene lake sediments from low arctic Greenland (Fredskild, 1973, 1983b) (see Fig. 11), but not in younger sections as in Lake 31.

The genus *Tolypella* currently grows between 45° and 60°N and has not been recorded alive from Greenland (Wood and Imahori, 1965). The only Greenland fossil occurrence is of Pliocene–Pleistocene age (Bennike, 1990). Its occurrence in Lake 31 parallels *Potamogeton praelongus* (see below).

Fruits (endocarps) of five species of *Potamogeton* were recovered from Lake 31, a record from Greenland. The macrofossil diagram shows only one species, occurring toward the top of the core. Thus, the species may have become extinct in the lake. *Potamogeton gramineus* endocarps have previously been reported from two lakes from southernmost Greenland (Fredskild, 1992), and the species is currently widespread in low arctic West Greenland.

The endocarps referred to as *Potamogeton praelongus* measured 3.6 × 2.5 mm (mean length × mean breadth, *n* = 26). They correspond to *P. praelongus* endocarps in size, shape, and anatomy (Aalto, 1970; Dorofeev, 1986; Martin, 1951). This species is not an Arctic water plant and has been found alive in only one Greenland lake in central East Greenland (Lægaard, 1960) (Fig. 12). Thus, its former occurrence in Lake 31 is highly surprising. Although its endocarps were not found in the uppermost core samples, it is likely that the species still grows in the area, since it is typical of deep water, and therefore could be overlooked. There are no previous fossil records of *P. praelongus* from Greenland.

Fruits of *Potamogeton pusillus* also have not previously been found in Holocene lake sediments from Greenland, but leaf fragments have been obtained from several lakes and the species is common in the area today (Fredskild, 1992). The occurrence of fruits in Lake 31 probably reflects the warmer summers of this inland locality.

Shells of *Difflugia pyriformis* and *Centropyxis aerophila* were identified by L. Beyens. Testate amoebae have not previously been recorded fossil from Greenland,

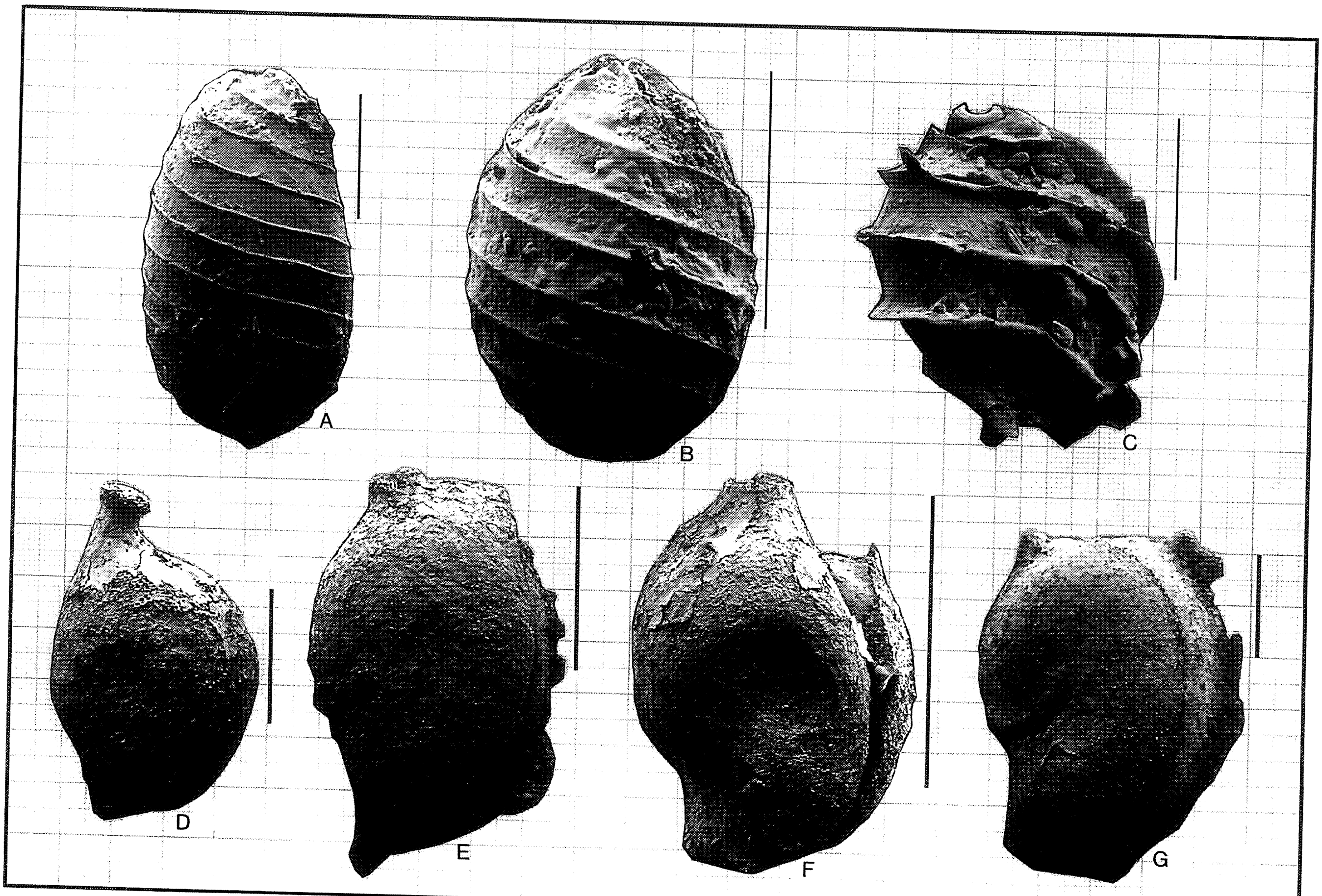

FIG. 11. SEM photographs of selected plant fossils. The specimens are housed in the type collection of the Geological Museum, Copenhagen (MGUH 22264-22270). The thin scale bars are 0.2 mm long and the thick ones are 1 mm long. (A) *Chara cf. globularis* (Characeae) oospore. (B) *Tolypella cf. nidifica* (Characeae) oospore. (C) *Nitella flexilis* (Characeae) oospore. (D) *Potamogeton gramineus* (Potamogetonaceae) endocarp. (E) *Potamogeton alpinus* endocarp. (F) *Potamogeton pusillus* endocarp. (G) *Potamogeton praelongus* endocarp.

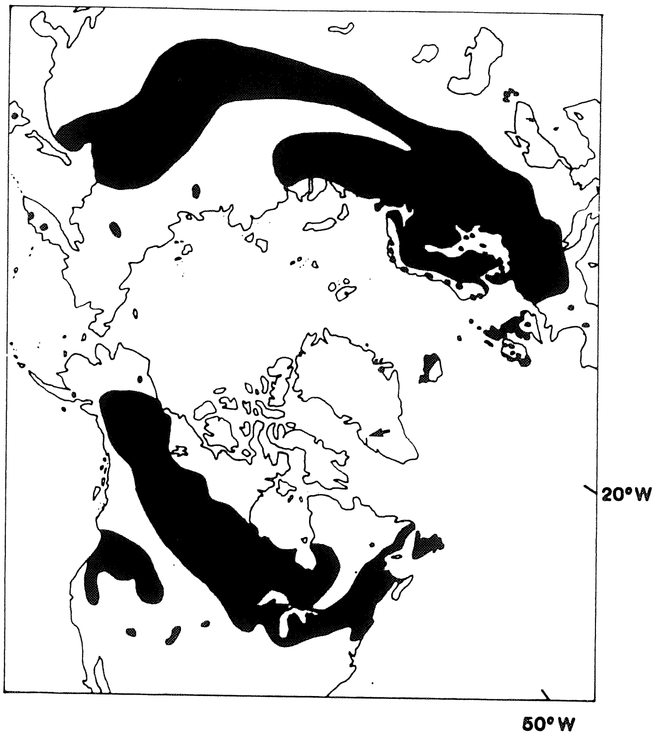

FIG. 12. Modern geographic distribution of *Potamogeton praelongus,* modified from Hultén and Fries (1986) and Porsild and Cody (1980). The arrow shows the fossil locality in west Greenland.

but both species live in the area today, and *D. pyriformis* is most common in meso- to eutrophic waters (Beyens *et al.,* 1992).

The fresh water sponge *Spongilla lacustris* is known from the Nuuk area to the south and at the head of Kangerlussuaq, where it was found in a single small lake (Fredskild, 1983b). Gemmules of sponges have not previously been recorded from Greenland lake sediments, but spicules referred to as *S. lacustris* were found in a Nuuk area lake by Fredskild (1983b).

A single but complete and well-preserved elytron of the whirligig beetle *Gyrinus opacus* was found in a sample dated to ca. 2600 ^{14}C yr B.P. The identification was confirmed by J. Böcher. The species is presently common in lakes and ponds at the headwaters of Kangerlussuaq, but this is the first fossil record from Greenland (Böcher, 1988).

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