The Holocene vegetational changes on Qeqertarsuatsiaq, a West Greenland island

Bent Fredskild

Abstract

Holocene changes in vegetation and climate on a West Greenland outer coastal island were revealed by analysis of sediment cores from a lake just below the upper marine limit. The sedimentation of limnic gyttja above the marine clay began ca. 11,300 B.P. (14C years), so far the oldest dating of limnic sediments in W.Greenland. After a pioneer phase dominated by Oxyria digyna dwarfshrub heaths, first with Empetrum hermaphroditum, followed shortly afterwards by other ericaceous plants and Salix spp. that then colonized the landscape. Around 7,500 B.P., the temperature became warmer than today and Betula nana immigrated ca. 6,000 B.P. The late Holocene temperature decline was mainly registered as a decreasing of fertility of most of the ericaceous dwarfshrubs, a decrease in Betula nana pollen and an increase in Cassiope tetragona pollen. Throughout the Holocene, the initial mesotrophic lake gradually became more oligotrophic.

Key words

Holocene, Greenland, pollen analysis, radiocarbon dating, vegetation changes.

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The early Holocene immigration of plants following the deglaciation of the coastal areas of South and Southwest Greenland as well as the changes during the Holocene in vegetation and climate, have been studied by Fredskild (1973, 1983) and Kelly & Funder (1974). In 1987, a lake on the West Greenland outer coastal island of Qeqertarsuatsiaq (Fig. 1) was cored, and pollen- as well as macrofossil-samples were analysed. The deglaciation of the coastal areas of West Greenland began around 11,000 B.P. (Funder 1989, Funder & Hansen 1996). As the large area between Disko Bay and Nordre Strømfjord is a lowland area, mainly below 300 m a.s.l. (Fig. 1), any potential plant refugium on ice free areas during the last glaciation, whether on nunataks in the Sisimiut area around 66°N (Kelly1985) or on the lowland areas on the west coast of Disko (Ingolfsson et al. 1990), was quite distant.

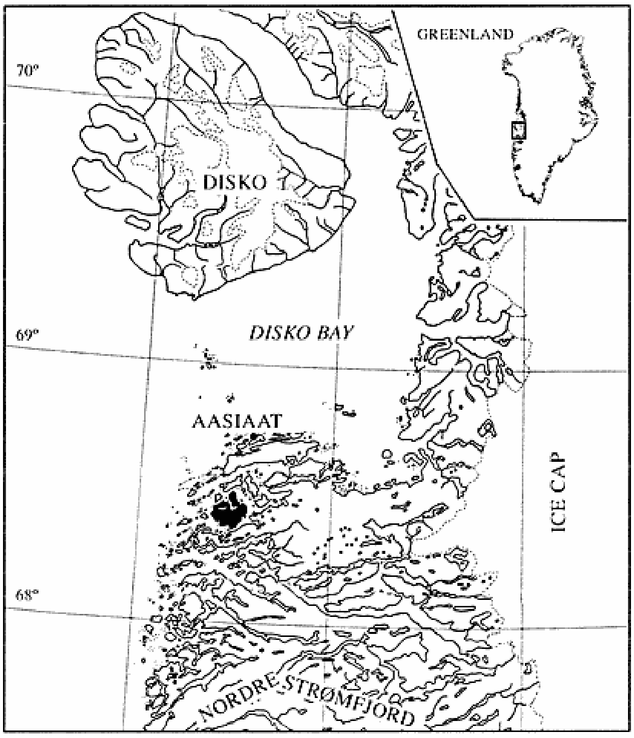

Figure 1: Map of West Greenland 67½°-70½°N. Black island: Qeqertarsuatsiaq.

Study area

Qeqertarsuatsiaq is a roundish, gneissic island, 16 km wide, on the outer coast of West Greenland, ca. 30 km south of Aasiaat/Egedesminde (Fig. 1). Like all other islands in the large archipelago, it is flat, the highest point only 230 m a.s.l. The climate is low arctic maritime, as illustrated by climatic observations 1979-1991 from Aasiat: mean yearly temperature -5.2°C, warmest month 6.2°C , coldest -19.2°C, June-August mean temperature 4.8°C. Sum of degree days above 0°C, 508. Yearly precipitation 307 mm, June-August 90 mm (Fredskild 1996).

The climate and the poor soil is clearly reflected in the vegetation which floristically belongs to the northern part of the low arctic South West Greenland floristic province (SWn, Fredskild 1996). By far the major part of the island is covered by dwarfshrub heaths, with *Empetrum hermaphroditum* the predominant species, and with many mosses and lichens. On S-facing slopes and drier sites *Vaccinium uliginosum, Betula nana,* and *Salix glauca* grow, the first almost always sterile, the latter two showing greatest fertility when growing espalier-like on steep, S-facing rocks. Predominantly nutrient-poor, mossy *Carex rariflora* fens, with *Eriophorum angustifolium* are frequent, as are snowbed communities. Willow scrubs are absent, and only a few early snowbeds faintly resemble herb-slopes. A species list together with degree of frequency of the 156 phanerogam species collected on the island is found in Fredskild & Bay (1988). Barren, windswept ridges, indicating periodically snow free areas during the winter, are absent. The many, polished rocks without higher plants are totally covered by lichens.

The plateau north of the oblong, east-west orientated study lake is dominated by *Empetrum*-moss-lichen heaths with *Salix arctica, Betula nana, Ledum decumbens, Vaccinium uliginosum,* and *Cassiope tetragona,* the latter being the only rich flowering species. There are only a few herbs present, e.g. *Carex bigelowii, C. arctogena,* and *Luzula confusa.* Such heaths also dominate the S-facing rocks on the banks of the lake. Here, *Betula nana* and *Loiseleuria decumbens* flower, and some *Salix glauca* are present. Among the few herbs observed, *Carex arctogena* is the most frequent. Broad, hummocky fens border the lake at both ends and along the southern side. On top of the hummocks, tiny fragments of *Cassiope-Empetrum-Salix arctophila* heaths are present, while between the hummocks are *Carex rariflora-Eriophorum angustifolium* fens, often with *Tofieldia pusilla.* In the fens at the western end of the lake many *Carex holostoma* and some *Eriophorum scheuchzeri* are present. The N-facing slope south of the lake consists of partly overgrown talus, which is dominated by *Cassiope*-moss heaths rich in *Salix herbacea.* Here, *Luzula confusa, L. arctica,* and *Poa arctica* are common, and *Huperzia selago* is, as in all the other heaths, fairly frequent. In the lower part some *Empetrum* and *Phyllodoce coerulea* grow. A few *Hippuris vulgaris* and sterile *Sparganium hyperboreum* were observed in the lake. The water beetle *Colymbetes dolabratus* lives in the clear, slightly acid water (pH 6.2, conductivity 26 $\mu S\ cm^{-1}$).

Field work

The altitude of the approx. 200x50 m study lake (68°26'N, 52°57'W) was measured repeatedly using two altimeters and was found to be 95(-100) m a.s.l. The uppermost former beach was 10 m and perched boulders 15 m above the lake surface. Sediment coring was undertaken from a raft using a piston sampler, with 130 cm plastic tubes with an internal diameter of 34 mm. At the depth of 2 meters, 185-190 cm of limnic gyttja covered a sandy clay layer deposited under brackish water conditions. 13 cores, of which the 6 reached the clay, were taken in the deeper part of the gyttja, 11 in the upper part. Due to the extremely watery upper part of the gyttja, neither macrofossil nor pollen samples were taken in the uppermost 16 cm, apart from a recent pollen sample, taken from the water-gyttja interface with a siphon immediately after the coring in a vertical tube. The cores used for macrofossil analyses and 14C dating were cut into 4 cm samples, pooled to bulk samples. With the exception of the deepest, the bulk samples were taken from 10-13 cores, correlated by their depth below lake surface.

The following layers were separated in the two cores used for pollen analyses:

- Layer 8 (0-89½ cm): Bright, olive-brown gyttja, upwards loose, watery, downwards more solid. Quite many mosses in the deeper part, decreasing in number upwards.
- Layer 7 (89½-99½ cm): Like layer 6 yet with more mosses.
- Layer 6 (99½-138 cm): Mossy, fairly solid, olive gyttja.
- Layer 5 (13-170½ cm): Layered, solid, olive to brownish-olive gyttja.
- Layer 4 (170½-179½ cm): Layered, solid, brown gyttja.
- Layer 3 (179½-185 cm): Layered, greyish-brown, clayey gyttja, very solid. Upwards bordered by a 1-2 mm layer of pure clay.
- Layer 2 (185-186 cm): Very thin, alternating gyttja and clay layers.
- Layer 1 (186-198 cm): Slightly sandy, bluish marine clay.

Laboratory work

One ml pollen samples, taken with a syringe in the middle of the cores every second cm, were treated by standard methods and counted absolutely, using the weighing method which allows for the calculation of microfossils as percentages, concentration and accumulation rates (Jørgensen 1967). The determination of pollen and spores has been discussed in Fredskild (1973, 1983). Not shown in Fig. 2 are: one pollen of *Montia fontana in* sample 3, of *Taraxacum* type in 7, of *Saxifraga nivalis* type in 11, 29, of *Pedicularis* in 15, of *Saxifraga caespitosa* type in 18, 27, 28, one spore of *Gymnocarpium in* 24, and of exotic pollen one pollen of *Corylus* type in 17, 19, of *Chenopodiaceae* in 22, 24, and of *Ulmus* in samples 27, 28.

Included in the diagram of limnic organisms (Fig. 3) are the remains of some animals: head capsules of midge larvae of Chironominae and Tanypodinae, and postabdomens of the cladoceras *Alona* sp., *Acroperus* sp. and *Eurycercus glacialis*.

The macrofossil samples were washed through a 0.4 mm sieve. The major part of the distigmatae *Carex* fruits (Fig. 4) were conferred to C. *bigelowii*: six in sample 174-178 cm, one in 166-170 cm, four in 158-162 cm, one in 94-98 cm. Of the tristigmatae *Carex* fruits, one in 158-162 cm and one in 118-122 cm were referred to C. *norvegica*, one in 118-122 cm to C. *rupestris*. Two Gramineae fruits in 182-186 cm are *Poa* sp. Not shown in Fig. 4 are: one fruit of *Oxyria digyna*, one of *Potentilla* sp., and one seed of *Draba* sp. in sample 182-186 cm, one fruit of *Chamaenerion latifolium* in 166-170 cm, two capsule bases of *Cassiope* in 74-78 cm, one sclerotie of *Cenococcum geophilum* in the 86-90 cm sample. Further to entomostracae the macro-remains of *Planaria* sp. (flatworm), *Apatania zonella* (caddis-fly), and Hydrachnidae (water-mites) are included in Fig. 4. Five bulk samples were dated (Table 1).

In order to prove the marine origin of layer 1, three samples were analysed for diatoms in 1987 by the late Niels Foged. In a sample approx. 10 cm below the border between layers 1 and 2 only a few diatoms were found that were indicative of "fairly high concentrations of salts, most likely brackish (-salt) water". In samples from 6 cm and 2 cm below this border "several salt- and brackish water taxa - but only few specimens, mostly fragmentary" were found. No limnic diatoms were found.

Zonation of the pollen and macrofossil diagrams

The diagrams (Figures 2, 3 and 4) have been divided into three Palaeovegetation zones P.V. zone A, B and C.

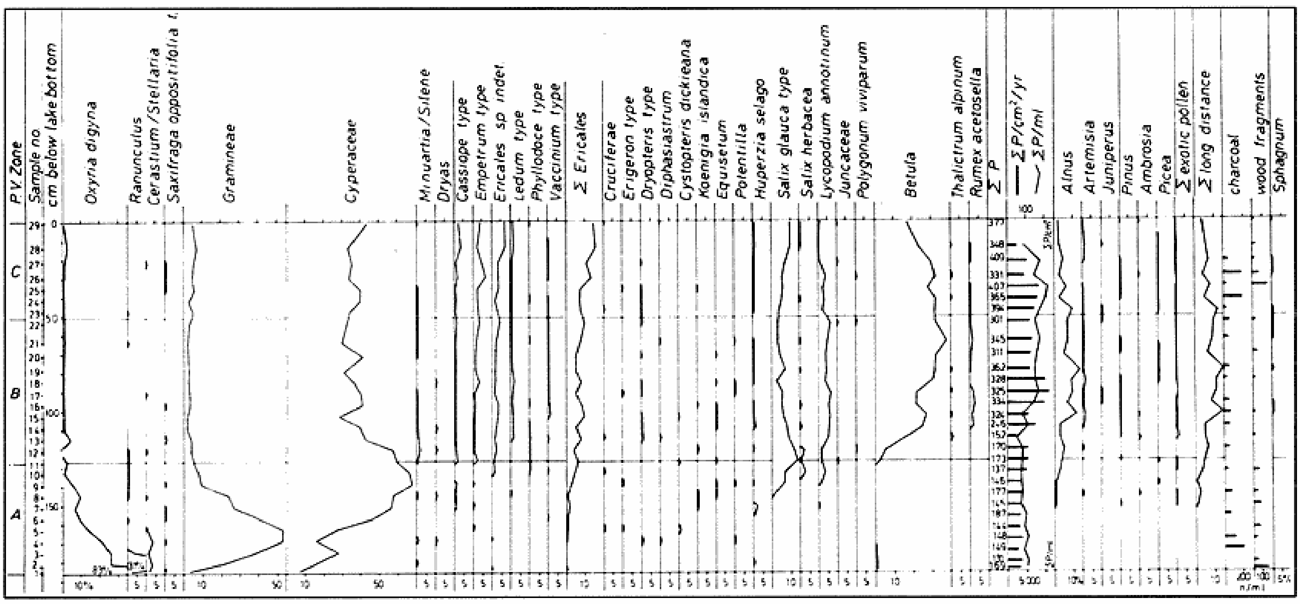

Figure 2: Pollen and other microfossils of terrestrial plants.

P.V. zones A.

As in all pollen records from South and West Greenland, the Qeqertarsuatsiaq diagram reflects a pioneer vegetation following deglaciation, consisting of widespread arctic, ubiquitous plants such as *Oxyria digyna, Saxifraga oppositifolia, Silene acaulis* and/or *Minuartia* sp., *Carex bigelowii, Chamaenerion latifolium*, and species of the genera *Draba, Potentilla*, and *Poa*. Especially in the outer coastal Greenland lake sediments, pollen of *Oxyria* may reach extremely high percentages in the early stages, e.g. 76% near Kap Farvel (59°58'N, Fredskild 1973), 75% on Nordlandet in West Greenland (64°24'N, Fredskild 1983), and 67% at Sermilik in East Greenland (64°N, Fredskild unpubl.). As this species can be observed in large numbers on freshly exposed soil, e.g. on moraines or at disappearing perennial snowdrifts, such high percentages are probably not only a result of a high pollen production of an anemophilous plant. Most likely, the many *Ranunculus* pollen, in samples 1-3, may be ascribed to *Ranunculus confervoides* and *R. hyperboreus* (Fig. 4).

A single ericaceous pollen, in sample 1 (189 cm), may possibly, like the wood fragments, be rebedded, but the presence of leaves, seeds, and pollen of *Empetrum* at 165-170 cm proves an early immigration. This concurs with the many *Empetrum* seeds found in sediment samples just above the marine clay in two outer coast lakes on Nordlandet, 450 km to the south, where the isolation was dated at ca. 9000 B.P. (Fredskild 1983). At least by the middle of zone A, many other ericaceous plants grew in the heaths. *Dryas integrifolia* was an early immigrant, whereas *Salix* spp. are not recorded until the middle of the zone. *Salix herbacea* reached its Holocene maximum in macrofossils as well as pollen by the end of the zone. The pollen of *Salix glauca* type includes *S. arctica, S. glauca*, and the major part of *S. arctophila*, but no macrofossils of these species were found.

Judging from the macrofossils, graminoids and forbs dominated in the first half of zone A, to be gradually partly replaced by heaths. As to temperature conditions in the first half of the zone, the terrestrial plants give little, if any information, as all species are today widely distributed in Greenland. The circum-Greenlandic *Ranunculus confervoides* and *R. hyperboreus* grew in the lake immediately after the isolation. *Hippuris vulgaris* immigrated in the middle of the zone, followed shortly after by the low arctic *Potamogeton pusillus* ssp. *groenlandicus*. Judging from the amount of algae, the productivity in the lake was extremely high early in the zone, peaking at approx. 7,000,000 *Pediastrum* coenobia/ml. If the estimated average sedimentation rate of 0.77 cm/100 yr is correct the yearly deposition was approx. 54,000/cm²/yr. The highest deposition found so far in 13 Greenland lakes are: 48,000 in Spongilla Sø (S.Greenland), 53,000 in Johs. Iversen Sø (W.Greenland), and 50,000 in Rundesø (NW.Greenland) (Fredskild 1973, 1983, 1985b). *Scenedesmus* sp. peaked at the end of the zone. *Lepidurus arcticus* was very frequent in the major part of the zone, decreasing markedly towards the end, contrary to *Planaria* sp., *Daphnia pulex*, and *Alona* sp. The southernmost West Greenland occurrence of the middle-high arctic *Lepidurus arcticus* is at Kangatsiaq, 20 km southwest of the cored lake, apart from a litterature reference at approx. 66°N (Røen 1962). It can be concluded that temperature conditions were colder than today in the older part of zone A. The Greenland lakes were generally eu- or mesotrophic in their early stages following deglaciation, gradually becoming more and more oligotrophic, reflected by limnophytes as well as green algae and diatoms (Foged 1977, 1989, Fredskild 1992, Bennike 1995). However, the disappearance from many lakes of some of the limnophytes cannot only be ascribed to oligotrophication, as their fertility today is also related to temperature, being always or mostly sterile on the outer coast but flowering in the warmer inland, on the same latitude. The only fruit of *Potamogeton pusillus* ssp. *groenlandicus* is found late in zone A, just before the maximum in Eupotamogeton pollen. Apart from two lakes/ponds on the climatically favourable southern Disko and one at Aasiat, fruiting *P. pusillus* ssp. *groenlandicus* has only been observed inland between 64°N and 68°N and once at 62°N. Its predominant distribution in Greenland is 60°-72½°N in West Greenland. Tiny, sterile specimens were found in two ponds and one lake on Qeqertarsuatsiaq. About 100 seeds of *Callitriche hermaphroditica* were found in sample 138-142 cm, 3 in 126-130 cm. Its predominant distribution in Greenland is 67°-70°N in West Greenland. Thus, in the later part of the zone, from c. 140 cm below lake bottom, the temperature seems to have reached that of today, in concurrance with the results from the other lake corings in South and West Greenland, indicating that the temperature ca. 7500 B.P. reached and exceeded today´s temperature This conclusion is supported by the curve of long distance pollen, beginning with sample 7 (151.5 cm), indicating that winds from south of the Laurentide ice sheet now regularly reached that far north in the Davis Strait (Fredskild 1985a).

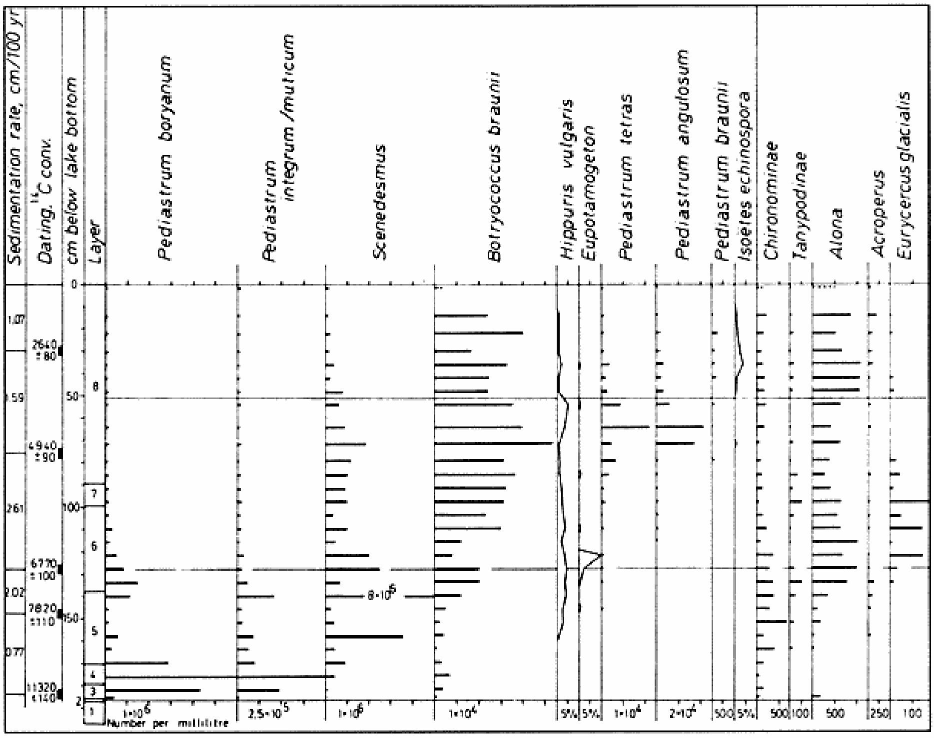

Figure 3: *Algae, pollen of limnophytes, and other limnic macrofossils. Pollen of Ranunculus sp. included in Fig. 2.*

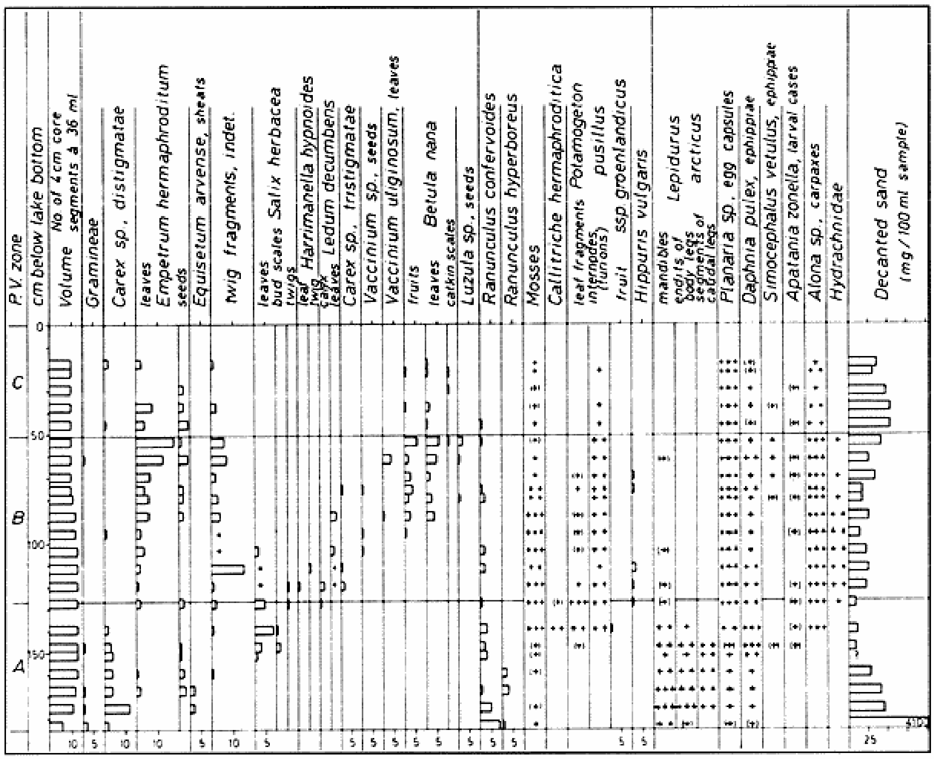

Figure 4: *Macrofossils of terrestrial plants (left), limnophytes (middle), and limnic animals (right*

Table 1: Radiocarbon datings from the Qeqertarsuatsiaq lake, with reference to the calibration curve used.

	Depth, cm	Conv. B.P.	Calibrated (± 1 std.dev.)	°C	Reference
K-5137	28-32	2640±80	810 B.C. (840-780 B.C.)	-22.4	Stuiver & Pearson 1993
K-5136	74-78	4940±90	3710 B.C. (3890-3640 B.C.)	-19.3	Stuiver & Pearson 1993
K-5135	126-130	6770±100	5610 B.C. (5700-5530 B.C.)	-16.4	Stuiver & Pearson 1993
K-5134	146-150	7820±110	6600 B.C. (6760-6470 B.C.)	-15.7	Pearson & al. 1993, Linick & al 1986
K-5133	182-186	11320±140	11280 B.C. (11440-11130 B.C.)	-21.0	Bard & al 1993

P.V. zone B

The zone border is defined as the increase in the pollen curve of the European *Betula nana*, which did not reach West Greenland until ca. 6500 B.P. In the inland areas, the increase in *Betula pollen* is very rapid, whereas at the outer coast it is more gradual, making a precise dating of the local appearance problematic (Fredskild 1991). The first *Betula* fruit was found in sample 94-98 cm, by interpolation dated to shortly after 6000 B.P. In the following period, pollen as well as macrofossils of *Betula nana* indicate favourable climatic conditions, warmer than today. The decrease in *Salix glauca* type pollen may partly be a result of competition between *Salix glauca* and *Betula nana*. Throughout the zone the cover of ericaceous dwarfshrubs seems constant, yet with a slight increase towards the end, indicated by the many *Empetrum* leaves. *Vaccinium uliginosum* leaves were found in two samples, seeds of *Vaccinium uliginosum* or *V. vitis-idaea* in three. The latter species was not seen on Qeqertarsuatsiaq, but grows in the area. Only exceptionally *Vaccinium uliginosum* produces fruits on the island. Pollen of *Rumex acetosella*, which does not grow on the island today, and of the rare *Thalictrum alpinum*, might indicate local presence. However, both species are anemophilous and their pollen has been found in (sub-)recent pollen samples outside their distribution area (Fredskild 1985b and unpubl., Björck & Persson 1981).

In the lake, the oligotrophication continued, as indicated by the spreading of *Pediastrum tetras* and *P. angulosum*. *Hippuris vulgaris* is the most widespread, ubiquitous Greenland limnophyte, occurring in 231 of 402 lakes and ponds investigated (Fredskild 1992). The pollen curve and the fruits, found only in this zone, indicate warmer conditions than today. *Lepidurus arcticus* mandibles were found in only four samples (Fig. 4), viz., from below, five, two, one, and one mandible, against 500-1000 per sample in the older part of zone A.

P.V. zone C

The border is placed at the marked decrease in the fruits and leaves of *Betula nana*. No marked changes in the pollen curves are seen at the transition between zone B and C, by interpolation dated at ca. 3500 B.P. However, the percentage of *Betula nana* pollen gradually fell to the half in the upper samples, contrary to a gradual increase in *Cassiope tetragona* and other ericaceous plants, in *Salix* (? *S. arctica*), Gramineae, and *Huperzia*, which occurs in all heath types on the island, and in the long distance *Alnus*, which was seen throughout the zone. The oligotrophication of the lake continued, as indicated by the spreading of *Isoëtes echinospora*, which was found in all samples other than the most recent one. It was not observed in the lake but may have been overlooked. It is frequent in South and Southwest Greenland, from Kap Farvel to its known present N-limit in Søndre Isortoq (65°36'N). The amount of *Hippuris* pollen decreased, and no fruits were found. In only one sample was an Eupotamogeton pollen found. Neither *Potamogeton pusillus* nor the two species of *Ranunculus* are growing today in the lake. The amount of remains of *Daphnia* and *Simocephalus* decreased through zone C.

Based mainly on the decrease in *Betula nana* it is concluded that during zone C the temperature gradually decreased.

Discussion

The oldest radiocarbon dating of marine shells from the area suggests that the coastal area of West Disko was ice free before 10,400 B.P. (Bennike et al. 1994). To date, the dating (11,320 B.P.) of the 182-186 cm sample is the oldest record of limnic sediment in West Greenland. As there seems no obvious reasons to expect mixing with older, carbon carrying sediments on this gneissic island, the dating

may be correct. This is supported by the fact that if the dating is too old, the average sedimentation rate between the two oldest datings would be higher (Fig. 3). If so, the yearly deposition in this interval of *Pediastrum* coenobia, which is the highest in those 13 Greeenlandic lakes where this has been estimated, would be even higher, but further datings from the area are needed. According to Funder & Hansen (1996), the marine limit in the Aasiat area is slightly above 120 m a.s.l. If the altimeter measurements are correct, the limit on Qeqertarsuatsiaq is 105 (-110) m or, if defined by the perched boulders 110 (-115) m a.s.l., which is in accordance with recent investigations (Anthony Long pers. comm. 1998). The initial isostatic uplift rates were very high in the area, estimated at 50 m/1000 yr at the head of Ndr. Isortoq approx. 140 km south of Qeqertarsuatsiaq (Funder 1989). These results indicate that only the first, few centuries after deglaciation are missing.

The inferred vegetational development and the datings largely follow the common West and South Greenland scheme: an initial pioneer/fell field zone with no other than the common, widespread, ubiquitous Greenland pioneer plants, a transitional *Salix*-Cyperaceae zone, an optimal dwarfshrub heath zone, covering the Holocene climatic optimum, and a dwarfshrub zone (Funder & Fredskild 1989). Once the landscape on any low arctic West Greenland outer coast island, apart from lichen covered outcrops, was all covered with heaths and fens, only very small areas were left for herb-slope and other vegetations demanding particularly favourable conditions. Because of this, the vegetational response to a climatic deterioration is not very clearly marked. It may best be illustrated as a gradually reduced fertility, shown in pollen percentages as well as in number of macro-remains of warmth demanding species such as *Betula nana, Vaccinium uliginosum*, and some limnophytes.

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may be correct. This is supported by the fact that if the dating is too old, the average sedimentation rate between the two oldest datings would be higher (Fig. 3). If so, the yearly deposition in this interval of *Pediastrum* coenobia, which is the highest in those 13 Greeenlandic lakes where this has been estimated, would be even higher, but further datings from the area are needed. According to Funder & Hansen (1996), the marine limit in the Aasiat area is slightly above 120 m a.s.l. If the altimeter measurements are correct, the limit on Qeqertarsuatsiaq is 105 (-110) m or, if defined by the perched boulders 110 (-115) m a.s.l., which is in accordance with recent investigations (Anthony Long pers. comm. 1998). The initial isostatic uplift rates were very high in the area, estimated at 50 m/1000 yr at the head of Ndr. Isortoq approx. 140 km south of Qeqertarsuatsiaq (Funder 1989). These results indicate that only the first, few centuries after deglaciation are missing.

The inferred vegetational development and the datings largely follow the common West and South Greenland scheme: an initial pioneer/fell field zone with no other than the common, widespread, ubiquitous Greenland pioneer plants, a transitional *Salix*-Cyperaceae zone, an optimal dwarfshrub heath zone, covering the Holocene climatic optimum, and a dwarfshrub zone (Funder & Fredskild 1989). Once the landscape on any low arctic West Greenland outer coast island, apart from lichen covered outcrops, was all covered with heaths and fens, only very small areas were left for herb-slope and other vegetations demanding particularly favourable conditions. Because of this, the vegetational response to a climatic deterioration is not very clearly marked. It may best be illustrated as a gradually reduced fertility, shown in pollen percentages as well as in number of macro-remains of warmth demanding species such as *Betula nana, Vaccinium uliginosum*, and some limnophytes.

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