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Late Weichselian and Flandrian biostratigraphy and chronology from Hochstetter Forland, Northeast Greenland

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Late Weichselian and Flandrian biostratigraphy and chronology from Hochstetter Forland, Northeast Greenland

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Two lakes on Hochstetter Forland have been analysed with respect to lithostratigraphy and pollen and algae stratigraphy. The sediments have been radiocarbon dated and these dates show that Hochstetter Forland was not covered by the Inland Ice during the Late Weichselian. The early Flandrian stratigraphic sequences of the two lakes are interrupted by barren interzones, dated at 10 100 – 8100 B. P. and 10 100 – 9200 B. P., which are partly correlated to an ice-advance. No evidence for an earlier ice-advance during the Late Weichselian has been found. Apart from the abundance of pollen grains indicating pioneer vegetation, *Artemisia* pollen grains are found in high quantities in the Late Weichselian, although it is today not found within the area. The Flandrian pollen stratigraphy indicates a development similar to that which has been found in the Scoresby Sund area. However, *Cassiope tetragona* and *Salix arctica* immigrate much earlier than further south. The Flandrian climatic optimum in the Hochstetter Forland area seems to have been reached between 6000 and 5000 B. P. The Flandrian shore-line displacement is roughly estimated.

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In the summer of 1976, the Swedish-Danish East Greenland Expedition sampled the sediments of four lake basins on Hochstetter Forland, which is situated between 75° and 76°N (Fig. 1a). The corings were carried out while the basins were still covered by 2 m thick ice.

The purpose of this part of the expedition was to analyse the microfossil content of the sediments, mainly the pollen, spore and algae content. It was hoped that this would give an idea of the vegetational and climatical development of the area. These microfossil investigations were to be combined with radiocarbon dates in order to get the obtained development picture dated. The earliest development might also be related to the glaciation-deglaciation pattern of the area described by Hjort (1981), thus resulting in a more complete development picture of the area.

In this paper the results from two of the cored lakes (Fig. 1b), the so called "Peters Bugt Sø" and "Ailsa Sø" are presented and discussed.

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Field work

The corings, carried out by H. Bruch and J. Mikaelsson, showed that the sediment thickness of the lakes in the investigated area is usually small (0.5–2.0 m). "Peters Bugt Sø" and "Ailsa Sø" were sampled with a peat sampler named the Russian sampler of diameter 50 mm and length 0.5 m (Jowsey 1966).

The samples for the pollen, diatom and radiocarbon analyses were taken in the field. Owing to the fact that some moss layers were easy to correlate it was possible to obtain double samples for two of the radiocarbon dated levels from "Peters Bugt Sø".

The sediments were classified immediately in the field. These classifications have later been transferred to the soil characterisation system of Troels-Smith (1955).

The vegetation study was mainly carried out by H. Bruch, and the vegetation around the cored lakes was studied in more detail to try and relate the pollen spectra in the sediments to today's vegetation and environment around the lakes.

Laboratory work

The pollen analyses

Owing to the usually high minerogenic content of the sediments all samples were prepared with $ZnCl_2$ according to the method described by Björck et al. (1978). In spite of the fact that this method is usually very effective, the number of pollen grains and spores was far too low in almost all samples to be able to reach more than 100–200 in the pollen and spore sum without excessive effort. This means that the sum usually varies between 100 and 200, with some exceptions where the sum is less than 100. The spores and pollen grain types included in the sum are the same as in Funder (1978), which means that the so called 'exotic pollen grains' are excluded from the sum and that the Polypodiaceae and *Lycopodium* spores (incl. *Huperzia*) are included in the sum.

The pollen diagrams

The pollen curves have been plotted by a computer. These curves (Figs 2 and 4) have then been complemented by manually drawn tables and curves in order to give a more complete stratigraphical picture of the sequences. The pollen diagrams start with shrubs and dwarf-shrubs followed by herbs and Polypodiaceae and *Lycopodium* spores. To the right of the pollen sum there are, among other microfossils, 'exotic pollen types' and green algae, and the percentages of these are calculated as % of A+x. The pollen diagrams have been divided into assemblage zones according to Hedberg (1976) and as in for example Birks (1973) named by their content of fossil pollen grains and spores. The different units have been named local pollen assemblage zones (Björck 1979) and the designations of the different zones are based on the supposed significance of different pollen grains and spores. This means that the most significant type comes first in the name and so on.

Pollen identification

The pollen grains were often very broken and corroded, which caused identification problems. This is also a reason why the sum is usually low. Reference pollen material, collected from the area, has frequently been used to determine the pollen grains found in the sediments. When determining the different *Salix* and Ericales species the same criteria have been used as in Funder (1978). The different types of Ericales pollen have frequently been difficult to determine, which means that the determinations of for example the *Phyllodoce* pollen type are uncertain.

Diatom analyses

The lake "Peters Bugt Sø" has been investigated with respect to the diatom content. Altogether ten samples were analysed, mainly in order to show if, and in that case for how long, the basin was influenced by sea water.

The preparation was as follows: 1) The samples were heated in HCl and washed with H_2O; 2) The samples were heated in H_2O_2 at a temperature of 50–60°C; 3) Repeated decanting allowed the coarser particles to settle. The samples were prepared and analysed by Mrs H. Håkansson, who also grouped the diatoms.

Determination of loss on ignition

Due to an insufficient amount of material from "Peters Bugt Sø" only "Ailsa Sø" was analysed with respect to the organic content of the sediments. Loss on ignition has been determined by drying the samples at 105°C after which followed ignition at 550°C. The loss on ignition is expressed in percent of the dry weight.

Numerical methods

The method used is principal component analysis (PCA), which is a statistical technique for describing the interrelations of a large number of correlated variables in terms of a smaller number of uncorrelated variables that are linear combinations of the initial variables. The object of the analysis is to reduce the dimensionality of the problem under study and thus clarify the patterns that are present in the data. This numerical scaling technique has been frequently used to detect structure or patterns within Quaternary pollen stratigraphic data (Adam 1974, Birks 1974, Pennington & Sackin 1975, Birks & Berglund 1979, Björck 1979). The mathematics of the method are described by Davis (1973).

In this work the zonations determined by PCA are compared with our own zonations, which has proved to be very interesting. As it is usually rather difficult to obtain a total view of a pollen diagram and the frequently small changes within it, the PCA can often be very useful when the minor statistical changes are of importance. These changes are then shown as negative or positive columns of different lengths (Figs 10, 11). Another interesting way of using PCA is to plot the mean numerical scores of the local pollen assemblage zones on the first and second principal components. These mean scores have been joined up in stratigraphic order, thus showing a statistical development picture.

Geology, morphology and vegetation on and around Hochstetter Forland

The investigated area is situated in the western central part of Hochstetter Forland, NE Greenland (Figs 1a and 1b). The foreland sediments east of the Caledonides, on Hochstetter Forland, are of Mesozoic age (Clemmensen & Surlyk 1976, Surlyk 1978). Biotite gneiss is found along the Caledonian front on Hochstetter Forland, and Precambrian sediments also occur on southernmost Hochstetter Forland (Surlyk 1978). The area is characterised by a hummocky glacial landscape, but where the Quaternary cover is thin the sedimentary rocks have a major influence on the morphology. Very few places reach above 200–300 m.

Hjort (1981) has established a glacial chronology of the area. According to him the most extensive glaciation during the Weichselian probably occurred during the first part of the Early Weichselian. This more or less total glaciation, with ice on the shelf, is called the Kap Mackenzie stadial. This stadial was followed by the Hochstetter Forland interstadial, with a general deglaciation, which is also supposed to have happened during the Early Weichselian. Some time between the Early and Middle Weichselian a glaciation of intermediate extent occurred and Hochstetter Forland was again covered by ice. This glaciation, which Hjort (1981) calls the Muschelbjerg stadial, reached "Peters Bugt Sø" as well as "Ailsa Sø". He thinks that this stadial is older than 45 000 ^{14}C-years. The following Peters Bugt interstadial characterised the major part of the Middle Weichselian (as defined by Mangerud et al. 1974). Hochstetter Forland was ice-free again and a general deglaciation of the area occurred. At some time during (or slightly before) the Late Weichselian the Nanok stadial began. This stadial was mainly characterised by a fjord and valley glaciation with many nunataks and large ice-free lowland areas such as Hochstetter Forland, with the exception of the coastal areas. Ardencaple Fjord (Fig. 1a) and Peters Bugt was occupied by a glacier, which covered "Peters Bugt Sø" as the glacier overrode marine sediments of the Peters Bugt interstadial and formed a terminal moraine just north of the lake. The maximum altitude of this distinct ridge is about 65 m a.s.l., while the marine limit corresponding to the deglaciation from this terminal zone has been determined to be about 50 m a.s.l. around the Peters Bugt area, and the age of this limit is supposed to be about 9500 B. P. The lake "Ailsa Sø" lies about 8 km ENE of this terminal zone and could thus never have been covered by any glacier since the Muschelbjerg stadial, and in fact, the whole central part of Hochstetter Forland was free from ice during the Nanok stadial. Hjort (1981) also correlates the glacial chronology from NE Greenland with that from other arctic areas, as well as with the known climatic development in these areas. These correlations tentatively

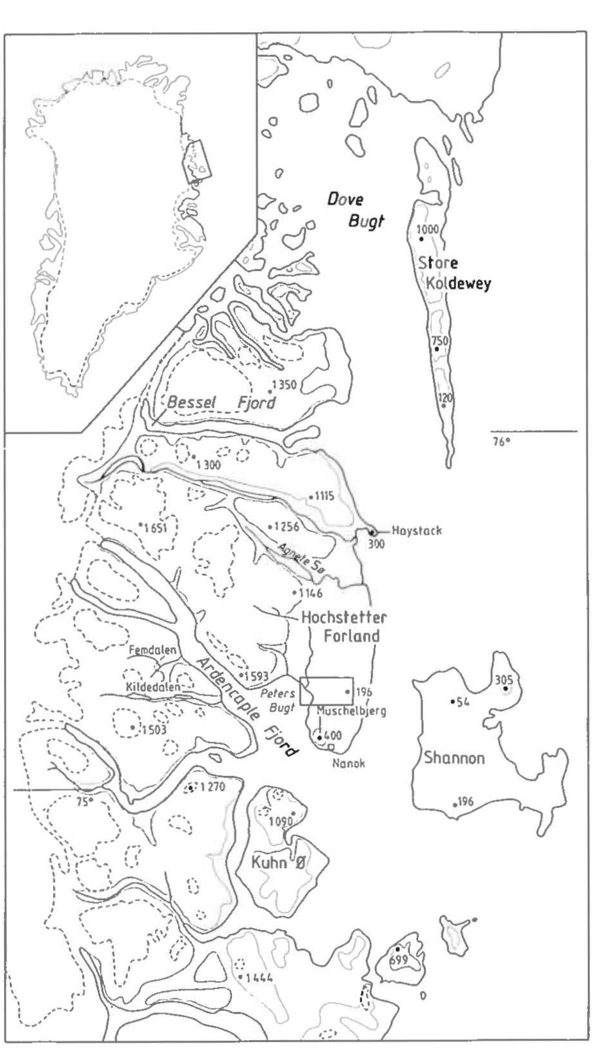

Fig. 1a. Map of Hochstetter Forland and the surrounding area with a map of Greenland showing the position of this area. The position of Fig. 1b is also shown.

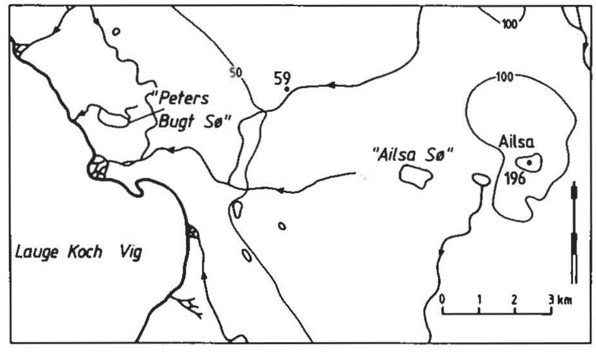

Fig. 1b. Map of the investigation area. Redrawn from the map 75 Ø 1 Hochstetter Forland (Geodetic Institute of Denmark, Greenland 1:250 000).

place the glaciation maxima during the Weichselian in NE Greenland at around 115 000 B. P., 70 000 B. P. and 10 000 B. P. The climate is high arctic. According to data from the weather stations Daneborg and Danmarkshavn (Lysgaard 1969), which lie about 75 km south and north respectively of the study area, the annual mean temperature on Hochstetter Forland is about −11°C, with the mean for the warmest month slightly less than 4°C.

The vegetation and flora of NE Greenland has been described by Gelting (1934) and Seidenfaden & Sørensen (1937). During the 1976 expedition H. Bruch and C. Hjort investigated the vegetation from Store Koldewey to Ardencaple Fjord. In a plant geographical sense the area belongs to the high arctic (Böcher 1938). Most parts of Hochstetter Forland have a comparatively rich vegetation, with *Dryas* heaths, in which however *Cassiope tetragona* is less well represented than further south and *Betula nana* is hardly represented at all. The latter species only occurs in very few localities, being close to its present northern limit. Other characteristic plants on these heaths are *Salix arctica, Papaver radicatum* and *Pedicularis hirsuta. Ranunculus glacialis* is common on the coast. On Hochstetter Forland there are large areas where, due to damming by moraines or beach ridges or just due to the extremely low slope gradient, the drainage of water is slow, the vegetation rich and shallow ponds common. Similarly, there are areas of rich vegetation where water from snow-drifts remains throughout most of the summer. In Ardencaple Fjord the arid climate is a limiting factor to plant growth and the vegetation cover clearly diminishes compared with southern Hochstetter Forland. *Empetrum nigrum* is usually found growing in small patches, and restricted to places where the micro-climate is especially favourable – and it does not produce berries every year. *Vaccinium uliginosum* is more common on the foreland than in the western mountains. The richest parts of the area studied by the expedition as regards vegetation, are Hochstetter Forland (with the exception of some coastal areas) and the western and central parts of Shannon. As far as the vegetational development of NE Greenland is concerned, correlations with studies in Central East Greenland will be made in connection with the interpretation of the pollen diagrams from Hochstetter Forland.

"Peters Bugt Sø"

The lake "Peters Bugt Sø" (75°19'N, 20°03'W) is situated 1.4 km north of the delta which bounds Lauge Koch Vig in the north (Fig. 1b). The Lake is about 700 × 300 m and the present-day water level is situated at 16 m a.s.l. with the outlet in the northwestern part. However, southeast of the lake a small delta is situated, which was probably the original threshold after the deglaciation of the area. This threshold is estimated to lie at about 25 m a.s.l. The basin is bounded by the Nanok stadial moraine *sensu strictu* (Hjort 1981) to the north and east and to the south by a shorter ridge belonging to the same terminal moraine zone, which is dated by Hjort (1981) to ≥ 9500 B.P.

The vegetation types which were mapped by H. Bruch vary much around the lake. As the lake is situated in a trough-like basin the slopes down to the lake are usually steep. However, north and northwest of the lake the slopes are more gentle.

In the polygon fissures south of the lake the vegetation is dominated by *Salix arctica, Dryas octopetala, Potentilla, Melandrium* and different *Draba* species. Here also occur small moist hollows, whose vegetation is dominated by *Cassiope tetragona*. This plant often grows together with *Papaver radicatum, Cerastium, Stellaria longipes* and *Vaccinium uliginosum*. Southwest and west of the lake there are no polygons and the vegetation becomes more dense, and *Cassiope* and *Saxifraga oppositifolia* become very common. In this area the gently sloping shore consists mainly of sand where *Hippuris* grows and wads of terrestrial and limnic mosses accumulate at the shore.

West of the lake the surroundings are more flat and towards the northwestern part the vegetation, a *Salix-Dryas-Cassiope* heath, more or less completely covers the ground. Also, in the west, green mosses and *Saxifraga oppositifolia* are abundant. At the outlet in the northwest the silty ground is flat and covered by moss underlain by 2 dm of peat. On drier spots in this very moist area *Salix arctica* dominates. *Hippuris* is common in the lake at the outlet. East of the outlet mosses grow all the way down to the shore and these are transported into the lake by water erosion.

North of the basin lies a hillock with silty polygon ground and the same type of vegetation as in the south. East of this hillock there is a kind of thin slope mire, mainly consisting of mosses, which is fed by running water from snow patches situated north of the lake. In this water *Ranunculus hyperboreus* and *Saxifraga cernua* grow. On the central northern side of the lake *Dryas, Cassiope tetragona* and *Salix arctica* are common and cover the major part of the ground. The northeastern part of the shore is covered by a 20–50 m wide zone of moss vegetation. Outside this moss zone a *Dryas-Cassiope* heath becomes rampant. In this part running water from snow-beds is also very common.

In the northeasternmost and eastern parts the same kind of slope mire occurs as in the north. However, here *Dryas* and *Cassiope* grow together with the mosses, which often grow in clumps. Outside this zone a more pure *Dryas-Cassiope-Vaccinium uliginosum* heath characterises the area east of the lake. *Betula nana* is found on small terraces 300–400 m east of the lake.

Sediment stratigraphy

The corings were carried out in the southeastern part of the lake, where the thickness of the ice was 2.0 m and the water depth 0.35 m. The sediments (Fig. 2, in pocket at back) are described from the sediment surface downwards.

0–125 cm. Layer 4. Clay gyttja, green, greyish brown. Composition: As2, Ld2, Tb+, Th+. High frequency of thin (0.5 cm) silty laminae in the uppermost 0.5 m. Moss remains at 0–4, 19–20, 29–32, 34–35, 37–39, 48–50 and 100–102 cm. Other kinds of plant remains occur sporadically between 0 and 50 cm. Between 122 and 125 cm thin laminae of different colours (black, reddish brown, yellow and green) occur.

125–150 cm. Layer 3. Silty clay, black grey. Composition: As3, Ag1. A lamina coloured by black iron monosulphides occurs between 125 and 127 cm and a sandy lamina occurs between 146 and 148 cm.

150–189 cm. Layer 2. Clayey muddy silt, grey to greyish black. Composition: Ag2, As1, Ld1. The sediment was probably coloured by iron monosulphides.

189–197 cm. Layer 1. Silty muddy clay, black. Composition: As2, Ag1, Ld1. The sediment was probably coloured by iron monosulphides.

From the sound produced when attempts were made to penetrate further, layer 1 is underlain by sands and gravels.

Radiocarbon analyses

Out of seven samples from "Peters Bugt Sø", six were possible to radiocarbon date (Table 1). The level with an organic content too low for ^{14}C-dating was 1.45–1.50 metres below the sediment surface. This level coincides with the lower part of the Peters Bugt Barren Interzone, described below. All samples in this investigation were submitted to the Radiocarbon Dating Laboratory in Lund for dating.

Sample Lu-1301 was the only sample from "Peters Bugt Sø" treated with HCl. The rest of the samples were burnt at a temperature below 650°C, so that errors due to any occurrence of carbonate or graphite are negligible. All samples were diluted with CO_2 from anthracite to allow dating. In "Peters Bugt Sø" as well as in "Ailsa Sø" the calculation of the radiocarbon age is based on a half-life of 5568 years for ^{14}C. The results are given as the number of years before 1950 (^{14}C-age B.P.). As a standard figure, 95% of the activity of the NBS oxalic acid standard is used according to international agreement. All ^{14}C-values are ^{13}C corrected for deviations from the agreed standard value of the $^{13}C/^{12}C$-ratio ($\delta^{13}C$ = –25‰ in the PDB-scale). The dates are also published in the official dating list of the laboratory (Håkansson 1978, 1981). The reliability of the ^{14}C-ages obtained will be discussed below.

Table 1. The ^{14}C-dates from the two investigated lakes.

Site	Sample depth (cm)	Lab. nr. of sample	Obtained ^{14}C-age B.P.	$\delta^{13}C$ (‰)
AILSA	9-15	Lu-1749	6,120±90	-28.1
	31-37	Lu-1748	9,540±115	-24.2
	46-48	Lu-1747	9,330±145	-25.0
	58.5-63.5	Lu-1746	11,540±135	-23.2
	77.5-82.5	Lu-1290	13,970±200	-23.2
PETERS BUGT	20-25	Lu-1745	2,390±120	-23.5
	45-50	Lu-1744	3,670±150	-22.4
	70-75	Lu-1743	4,530±130	-22.6
	95-100	Lu-1742	5,140±130	-21.6
	118-123	Lu-1741	7,440±95	-24.1
	182-187	Lu-1301	12,960±235	-22.3

Pollen and spore stratigraphy

The pollen diagram shown in Fig. 2 represents the sediments between 0.0 and 1.90 metres below the sediment surface which was situated 2.35 metres below the ice surface. Within these 190 centimetres 27 levels were analysed for pollen. However, four of these levels contained almost no pollen or spores. The diagram has been divided into five local pollen assemblage zones (P1–P5) and one barren interzone.

P1. 190–151 cm. This zone is characterised by very high values of Cyperaceae (21 to 49%) and Gramineae pollen (13 to 35%). *Lycopodium* undiff. spores attain values of more than 20% at three of the six levels. Polypodiaceae spores reach a maximum of 14%. Caryophyllaceae pollen reach values of between 2 and 9%, while the frequency of *Saxifraga* undiff. pollen varies between 2 and 6%. The values of the exotic pollen types are high. *Pinus* pollen attain values of more than 10% and the frequency og *Picea* pollen varies between 3 and 22%. *Artemisia* pollen usually reach values of more than 5% with a maximum of almost 17%.

The lowermost zone is named the Cyperaceae – *Lycopodium* undiff. – Gramineae – Polypodiaceae – Caryophyllaceae – *Saxifraga* undiff. + exotic pollen grains Local Assemblage Zone.

151–128 cm. These 23 centimetres are characterised by an extremely low content of pollen and spores. Three different levels in this interzone were analysed and altogether 7 pollen grains and 2 spores were found.

This zone is accordingly called the Peters Bugt Sø Barren Interzone.

P2. 128–98 cm. This zone is characterised by high values of *Salix herbacea* (12 to 32%) and *Salix arctica* pollen (4 to 23%). *Cassiope* pollen values reach almost 9% within this zone and the frequencies of *Betula nana* pollen vary between 1 and 7%. Gramineae and Cyperaceae pollen reach rather high values throughout the zone, which is also the case for the *Betula* undiff. pollen values. The values of *Dryas* pollen increase markedly in the middle of the zone. The exotic pollen types attain comparatively high frequencies at some of the levels. The pollen assemblage of the lowermost sample of this zone resembles the assemblage of zone P1.

The zone is named the *Salix herbacea – Salix arctica – Cassiope – Betula nana* + exotic pollen grains Local Assemblage Zone.

P3. 98–69 cm. This zone is to some extent similar to zone P2. However, the values of *Salix arctica* pollen decrease markedly, while the *Dryas* pollen values increase in comparison to zone P2. The frequencies of *Cassiope* and *Betula nana* pollen decrease, while the values of Cyperaceae and Gramineae pollen maintain about the same level as in zone P2. The frequencies of the exotic pollen types are low.

The zone is called the *Salix herbacea – Dryas* Local Assemblage Zone.

P4. 69–31 cm. The zone is characterised by markedly increasing values of *Cassiope* and *Vaccinium* pollen when compared to zone P3. *Oxyria* pollen reach maximum frequencies in this zone and the values og Caryophyllaceae pollen are high throughout the whole zone. The lowermost part of the zone is characterised by low values of Cyperaceae (10%) and *Dryas* pollen (5%).

This zone is named the *Salix herbacea – Vaccinium – Cassiope – Oxyria* – Caryophyllaceae Local Assemblage Zone.

P5. 31–1 cm. This zone is dominated by the two *Salix* pollen types. *Salix arctica* pollen reach values of more than 17%. The values of Cyperaceae pollen increase in comparison to zones P2–P4. Gramineae pollen attain high frequencies in the two uppermost levels (13 to 15%). *Betula nana* pollen almost disappear in this zone.

The zone is called the *Salix herbacea – Salix arctica* – Cyperaceae – Gramineae Local Assemblage Zone.

Algae stratigraphy and determination of the isolation level

The following levels have been analysed with respect to the diatom content: 90, 113, 119, 124, 128, 134, 143, 154, 166 and 193 cm (Fig. 3). The species have been halobian grouped according to Kolbe (1927), whose system was redefined by Hustedt (1957). According to this grouping the diatoms down to 119 cm are oligohalobous. *Fragillaria* species are extremely dominant at 119 and 113 cm, but less dominant at 90 cm. The *Pediastrum* and *Botryococcus* values increase markedly at 119 cm (Fig. 2). This strongly suggests a fresh-water environment from 119 cm upwards. At 124 cm the diatoms are mesohalobous and polyhalobous suggesting a marine environment, perhaps diluted by fresh-water. Between 128 and 143 cm, a zone corresponding to the major part of the Peters Bugt Barren Interzone, the very few diatom remains found are all partly dissolved or destroyed and they have therefore been impossible to identify. The diatoms between 154 and 193 cm are mainly polyhalobous mixed with some mesohalobous species. This strongly suggests a marine environment below the Peters Bugt Barren Interzone.

These analyses clearly show that the basin became isolated from the sea between 119 and 124 cm, which coincides with the lowermost part of the local pollen assemblage zone P2 (Fig. 2). The age of this isolation as well as the development of the environment prior to the isolation will be discussed below, but there certainly seems to be a good correlation between diatom and pollen stratigraphy with respect to the pollen frequency and the diatom content. The $\delta^{13}C$ content does not show any significant difference between the ^{14}C-dated samples (Table 1).

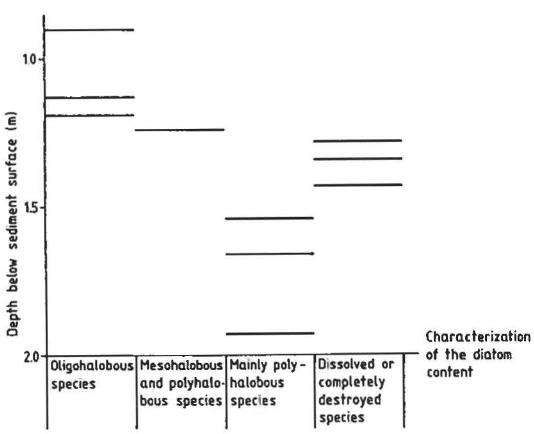

Fig. 3. Generalised diatom diagram from "Peters Bugt Sø".

"Ailsa Sø"

The lake "Ailsa Sø" (75°19'N, 19°40'W) is located 8 km ESE of the "Peters Bugt Sø" (Fig. 1b) and 3 km W of the Ailsa hill. The lake measures *c.* 800×500 m, is situated between 75 and 100 m a.s.l. and has its outlet towards the west. The surroundings of the lake are dominated by silty till.

South of the lake where the terrain is gently sloping the vegetation is concentrated in polygon fissures and minor depressions in the polygons. The vegetation consists of *Dryas* and *Salix* together with mosses. Similar vegetation can be found west and northwest of the lake except along the outlet where mosses flourish on a moist ground. Northeast of the lake the terrain is more flat and the vegetation is a thin slope mire chiefly with mosses, which is fed by running water and girdles this part of the lake in a fringe of 50–100 m breadth. A similar type of mire 100–200 m in width is found here.

Sediment stratigraphy

The corings were carried out in the central part of the lake. The ice thickness was 2.0 m and the distance to the sediment surface was a further 4.4 m. The sediments (Fig. 4, in pocket at back) are described from the sediment surface downwards.

0–13 cm. Layer 6. Clay gyttja, greyish brown. Composition: (As+Ag) 2, Ld 2, Tb+. Some moss remains between 0 and 11 cm.

13–45 cm. Layer 5. Muddy clay, greyish brown. Composition: (As+Ag) 3, Ld 1. Moss layer at 14 cm. Laminated between 20–31 and 34–45 cm. A more brown colour and no lamina between 31 and 34 cm.

45–59 cm. Layer 4. Clay gyttja, greyish brown, with grey clay lamina. Composition: (As+Ag) 3, Ld 1. Clay layers between 45–46, 48–51 and 54.5–55.5 cm. Moss layer between 53–54 cm and some moss remains between 57.5–59 cm.

59–85 cm. Layer 3. Clay with lamina of clay gyttja, grey. Composition: (As+Ag) 3, Ld 1.

85–89 cm. Layer 2. Silty clay, grey. Composition: As 3, Ag 1.

89–95 cm. Layer 1. Silt. Composition: Ag 4.

Further penetration was impossible.

Radiocarbon analyses

Six samples from "Ailsa Sø" were dated (Table 1). Sample Lu-1290 was the only sample from "Ailsa Sø" that was treated with HCl. The rest of the samples were ignited at a temperature below 650°C, so that errors due to the occurrence of carbonate or graphite are negligible. All samples were diluted with CO_2 from anthracite.

Pollen and spore stratigraphy

The pollen diagram from "Ailsa Sø" in Fig. 4 represents the sediments between 0 and 66 centimetres below the sediment surface, situated 6.40 m below the ice surface. Within these 66 centimetres, 15 levels were analysed for pollen. Two of these levels contained very few pollen and spores and are excluded from the diagram. Moreover five levels below the 66 centimetres level (66–92.5) were analysed but contained very few sporomorphs. The diagram has been divided into two local pollen assemblage zones with two subzones each (A1a, b and A2a, b) and one barren interzone.

A1a. 66–52 cm. This subzone is characterised by very high values of Gramineae (21 to 51%) and *Saxifraga* (28 to 37%) pollen. The frequency of Caryophyllaceae pollen varies between 3 and 15%, while *Oxyria* pollen values reach 18% in the uppermost sample in the subzone. The lowermost subzone is named the Gramineae – *Saxifraga* – Caryophyllaceae Local Assemblage Subzone.

52–46 cm. These six centimetres are characterised by a very low content of pollen and spores. Two levels have been analysed and 23 pollen grains were found.

This zone is called the Ailsa Barren Interzone.

A1b. 46–35 cm. This subzone is very similar to A1a. Very high values of Gramineae pollen (29–38%) are still characteristic. The *Saxifraga* pollen values vary between 10 and 22% and the Caryophyllaceae pollen frequencies reach between 11 and 16%. The frequency of *Lycopodium* spores reach a value of 15% in the middle of the subzone. In the lowermost sample of the subzone the *Oxyria* pollen value is 13% and in the uppermost sample of the subzone the *Salix herbacea* pollen value is 12%.

The subzone is called the Gramineae – Caryophyllaceae – *Saxifraga* Local Assemblage Subzone.

A2a. 35–17 cm. This subzone is characterised by very high values of *Salix herbacea* (48 to 57%) pollen, and *Salix arctica* appears for the first time with pollen frequencies of between 2 and 25%. The frequencies of *Cassiope* pollen are 3 to 9%. *Oxyria* varies between 2 and 11%.

The subzone is named the *Salix herbacea* – *Salix arctica* – *Cassiope* Local Assemblage Subzone.

A2b. 17–3 cm. This subzone is characterised by the appearance of *Dryas* pollen grains (6 to 8%). *Salix herbacea* and *Salix arctica* decrease somewhat in their pollen frequencies (36 to 31% and 9 to 6% respectively) in comparison with subzone A2a. The pollen values of *Cassiope* vary between 4 and 6%. Pollen grains of *Betula nana* appear in low frequencies (1 to 2%). *Oxyria* pollen values are 5 to 15%.

This subzone is called the *Salix herbacea* – *Salix arctica* – *Cassiope* – *Dryas* – *Betula nana* Local Assemblage Subzone.

Radiocarbon dates – discussion

Fortunately eleven of the twelve radiocarbon samples submitted were dateable. Whether or not one should rely upon the dates obtained is of major importance when interpreting the Late Weichselian and Flandrian development of the area.

The high age of the lowermost dated sample from "Ailsa Sø" (13 970 ± 200) is not very surprising as this basin, according to Hjort (1981), was deglaciated more than 45 000 years ago, while the oldest date from "Peters Bugt Sø" (12 960 ± 235) is more surprising as it is situated inside the Nanok moraine. The deglaciation from this moraine zone occurred around 9500 B.P. (Hjort 1981).

The material dated consists of clay gyttja or muddy clay. The values of loss on ignition from "Ailsa Sø" sediments vary between 7 and 10%. In the lowermost dated sample from "Peters Bugt Sø" the value is 4%. The sediment stratigraphy suggests that loss on ignition values for the rest of the dated samples from "Peters Bugt Sø" would be much higher. Low values do not, however, necessarily mean that the dates become too old. From work by for example Berglund (1976), Björck (1979) and Hilldén (1979) in southern Sweden (non-calcareous bedrock areas) it has been clearly shown that radiocarbon-dated sediments with very low loss on ignition values (3–6%) can give quite expected and accurate ages. In these cases the accuracy has been tested with the pollen stratigraphy. This test is of course impossible in Hochstetter Forland as this is the first pollen stratigraphical investigation in the area. However, correlations with the Scoresby Sund area (Funder 1978) suggest that the dates obtained could be accurate (see below). The low loss on ignition values are thus not regarded as evidence for erroneous dates. It should also be noted that most of the radiocarbon dated levels coincide with levels rich in remains of autochthonous water mosses. However, one must also be aware of the possibility of too high relative values of redeposited organic material contaminating the samples in a dramatic way (Björck & Digerfeldt 1981, Björck & Håkansson in press) causing erroneous interpretations.

All radiocarbon dated levels appeared free from carbonates when carefully tested with HCl under the microscope. Precipitated carbonates in the sediments are thus not regarded as a possible source of error.

The presence of Jurassic coal in the area (Surlyk 1978) must be regarded as a possible source of error. Due to this fact the radiocarbon dated sediment levels have undergone structural analysis. These analyses show that the amount of coal is very low in comparison with the rest of the organic material. It never exceeds 3–4%, but is usually much lower. This could mean at the most an error of about 300 years (Olsson 1979).

The $\delta^{13}C$-values in Table 1 are rather constant, and not even the supposed marine influenced radiocarbon dated level from "Peters Bugt Sø" (182–187 cm) differs much from the other values. This means that nothing can be said about the validity of the dates purely on the basis of the $\delta^{13}C$-values. It is also very hard to know whether or not a marine correction should be made for the oldest date from "Peters Bugt Sø". The diatom content shows that the basin was marine influenced, but this is not indicated by the $\delta^{13}C$-value.

The youngest dated sample from "Ailsa Sø" is about 6100 years old. If this date is correct it suggests that hardly any sedimentation at all has occurred in the lake since 5–6000 B.P. It might also indicate how large any dating errors are if the uppermost sediments in "Ailsa Sø" are regarded as being more or less recent. In this case an error of about 5000 years is indicated. The only source of error which could give an error of this magnitude is redeposited old organic material. The amount of this material would have to be very large to create such an error. According to the pollen analysis the relative amount of redeposited pollen grains and spores is very low and, as the main part of the dated organic material in most of the dated samples consists of autochthonous water mosses, we do not believe that old organic material has influenced the dates significantly. Any suggested error is in our opinion a speculation. We believe that the sedimentation in "Ailsa Sø" more or less stopped about 5000 years ago. This is supported by pollen stratigraphical correlations between the lakes. However, on comparing the two pollen diagrams, it seems as if the uppermost analysed level is influenced by the sub-recent flora. Fig. 12 shows the similarity in pollen assemblage between zones A2b, P4 and P5.

The radiocarbon age of the level 31–37 cm in "Ailsa Sø" is 200 years older than the age of the level 46–48 cm. In our opinion the older date (9540 B.P.) is erroneous as the age/depth relationship fits better if the younger date is regarded as being accurate (Fig. 6), and as will be shown later this interpretation also fits better when correlating the two pollen stratigraphical sequences. Any explanation for this erroneous date is speculative, but the most probable cause is the presence at the dated level of older organic material transported into the lake due to solifluction processes in the lake catchment.

It is obvious from the discussion above that we do not believe that the dates are characterised by any larger source of errors. The oldest date from "Peters Bugt Sø" could be younger if the marine influence and the presence of the very small amounts of coal are taken in account together with possible old organic matter. However, we keep to the original date of this level, although we are aware of its uncertainty, as well as to the others, with the exception of the date Lu-1748. The reason for this is that we do not know anything about the amount of redeposited organic material in the sediments or the hard water effect. We thus find any reduction of the obtained ages more speculative than no reduction at all.

We are aware of the fact that it is slightly controversial to rely on these dates, but as we do not have any evidence that they should be affected by any severe source of errors we trust them until other facts may prove they are completely wrong. We think, looking solely on the results obtained from this investigation, that the proposed chronology and development of the area is the most likely one for the time being.

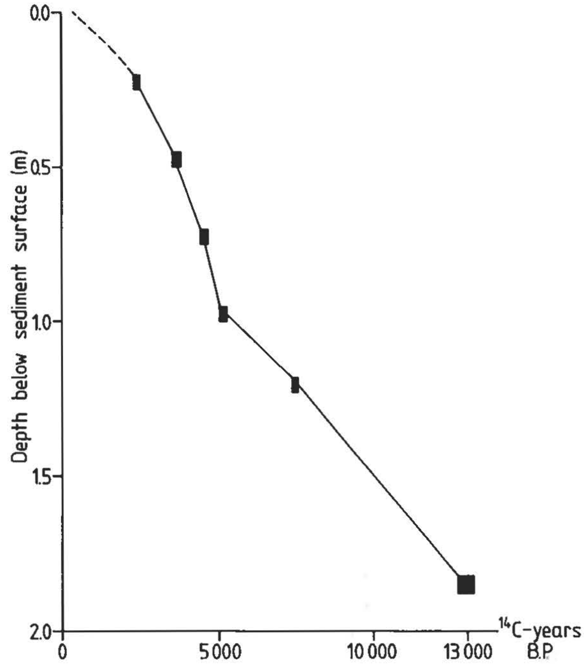

Fig. 5. Interpreted age/depth relationship in "Peters Bugt Sø".

From our experience one should not expect straight and even sedimentation curves. We have preferred to draw lines between the dated levels, leaving out Lu-1748. This means that the sedimentation rate in "Peters Bugt Sø" between 13 000 and 5000 B.P. was about 0.11 mm/year and since then has been between 0.2 and 0.4 mm/year (Fig. 5). This development, with an increasing sedimentation rate after 5–6000 B.P., is in accordance with Funder's (1978) observations from further south. In "Ailsa Sø", if straight lines are drawn between four of the five dated levels (Fig. 6), the sedimentation rate between 14 000 and 9300 B.P. was 0.07 mm/year and 0.09 mm/year between 9300 and 6100 B.P..

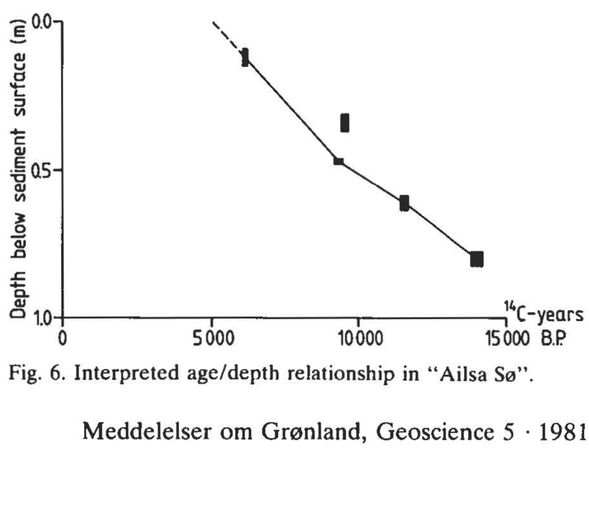

Fig. 6. Interpreted age/depth relationship in "Ailsa Sø".

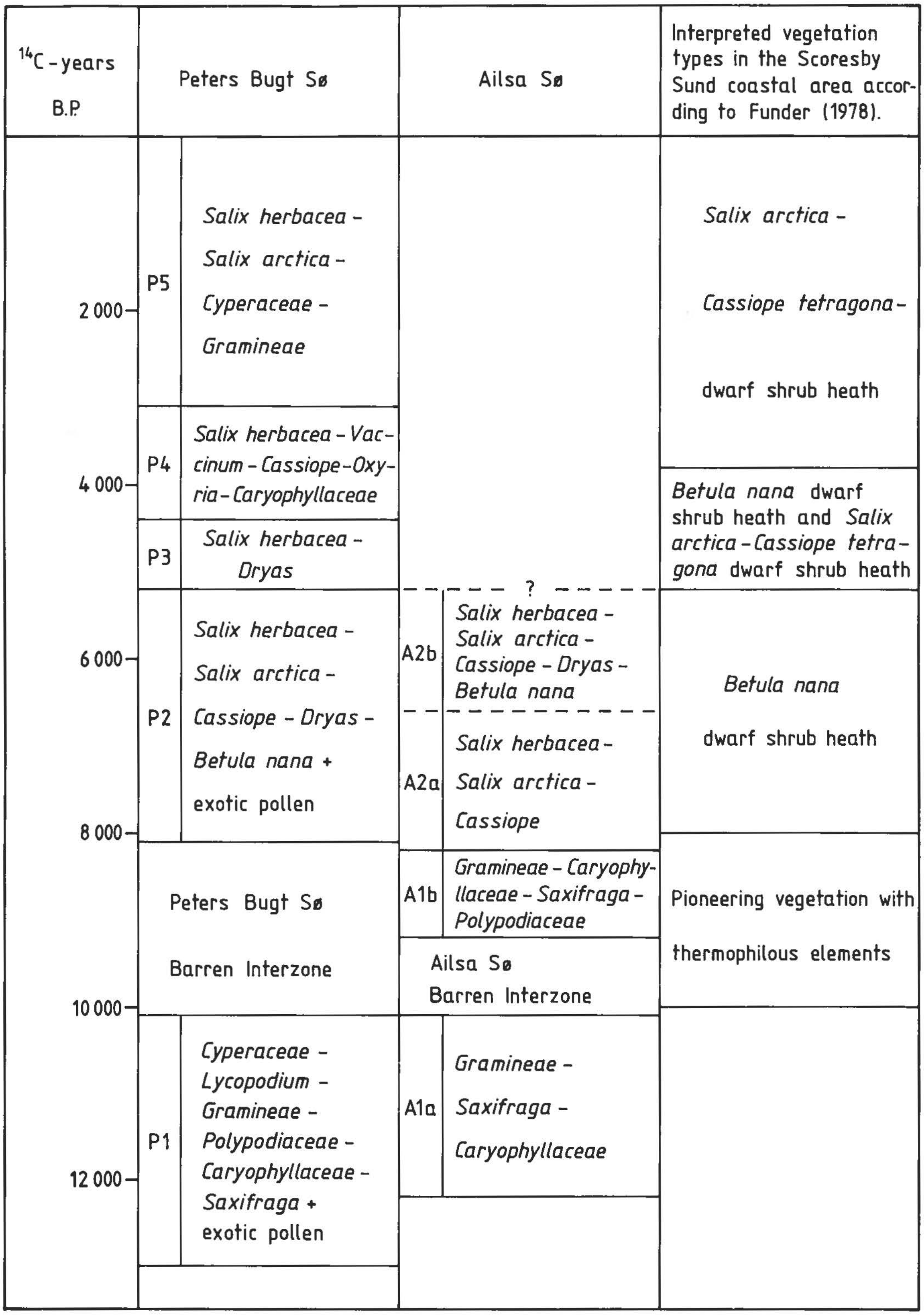

Fig. 7. The different local pollen assemblage zones from the two investigated lakes, related to radiocarbon chronology and Funder's (1978) vegetation types.

Zonal development of the vegetation

The zone boundaries have been dated from Figs 5 and 6.

Zones P1 and A1

The zone P1 in the pollen diagram from "Peters Bugt Sø" covers the period 13 000–10 100 B.P. It is an interstadial flora with a pioneer character. Grasses, sedges and herbs such as *Saxifraga* and Caryophyllaceae dominate, along with Polypodiaceae and *Lycopodium*. *Oxyria* is also included in this plant community. Exotic pollen types, such as *Picea* and *Pinus*, have high frequencies, showing the considerable importance of long distance pollen transport. Also *Artemisia* (Fig. 8) has high pollen frequencies in this zone. *Artemisia* does not grow in East Greenland today, but these rather high pollen values could suggest that it once grew in the vicinity of "Peters Bugt Sø", both prior to the barren interzone and later on (Fig. 2). However, it is well known that *Artemisia* was very common during the Late Weichselian in NW Europe. This means that its pollen could have spread to the investigated area and, as it is not present in East Greenland today, we regarded it as an exotic pollen type until more facts about its former distribution are known. The absolute pollen frequency in this zone is low, as shown by the pollen density curve (number of pollen and spores per traverse). The organic content of the sediment is low. This suggests a sparse vegetation cover and erosion of the soils surrounding the lake.

The zone A1 in "Ailsa Sø" has been divided in two subzones, A1a and A1b, covering the periods 12 200–10 100 B.P. and 9200–8200 B.P. respectively. A1 is similar to P1 with respect to the composition of species. Gramineae, *Saxifraga* and Caryophyllaceae have higher pollen frequencies and Cyperaceae, Polypodiaceae and *Lycopodium* have lower in comparison to "Peters Bugt Sø" sediments. *Artemisia* also occurs here, but generally the exotic component is of minor importance. The frequencies of *Oxyria* pollen are higher on both sides of the Barren Interzone in "Ailsa Sø" than in zone P1. Fig. 9 gives a view of the total dominance of this kind of vegetation around both of the lakes. As "Peters Bugt Sø" was situated below sea level during this period its pollen assemblage must represent a much larger area than the assemblage from "Ailsa Sø". Redeposited pollen grains do not seem to be very common, but some of the pollen types found in very small amounts (e.g. *Salix*, *B.nana* and *Thalictrum*) are probably redeposited and one must not leave out the possibility that some of the previously mentioned spore and pollen types are redeposited from earlier interglacial periods.

Barren interzones

A barren interzone from *c.* 10 100 to 9200 B.P. splits the zone A1 into two subzones. Very few pollen grains were found from this period. A local climatic deterioration seems to have restricted the vegetation temporarily but in zone A1b the same picture appears as before (Figs 4 and 10). The vegetation during this period was

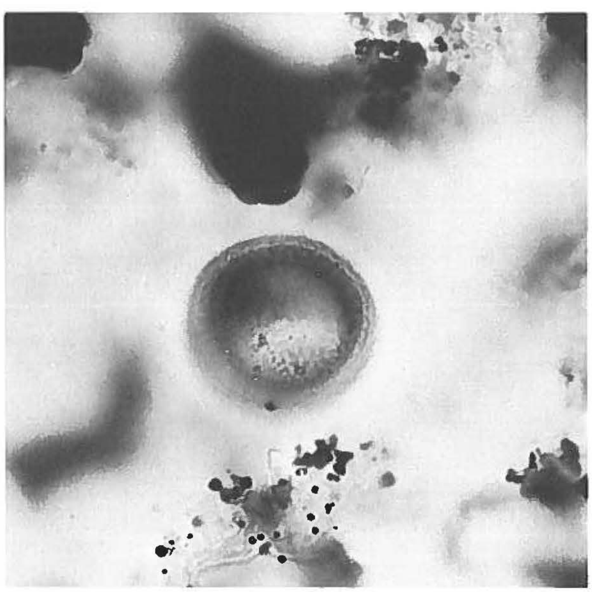

Fig. 8a. Photograph showing one of the apertures and parts of the surface of an *Artemisia* pollen grain (× 1000).

Fig. 8b. Photograph showing two *Artemisia* pollen grains characterised by the typical thick tectum. A distinct aperture is seen in one of the grains (× 1000).

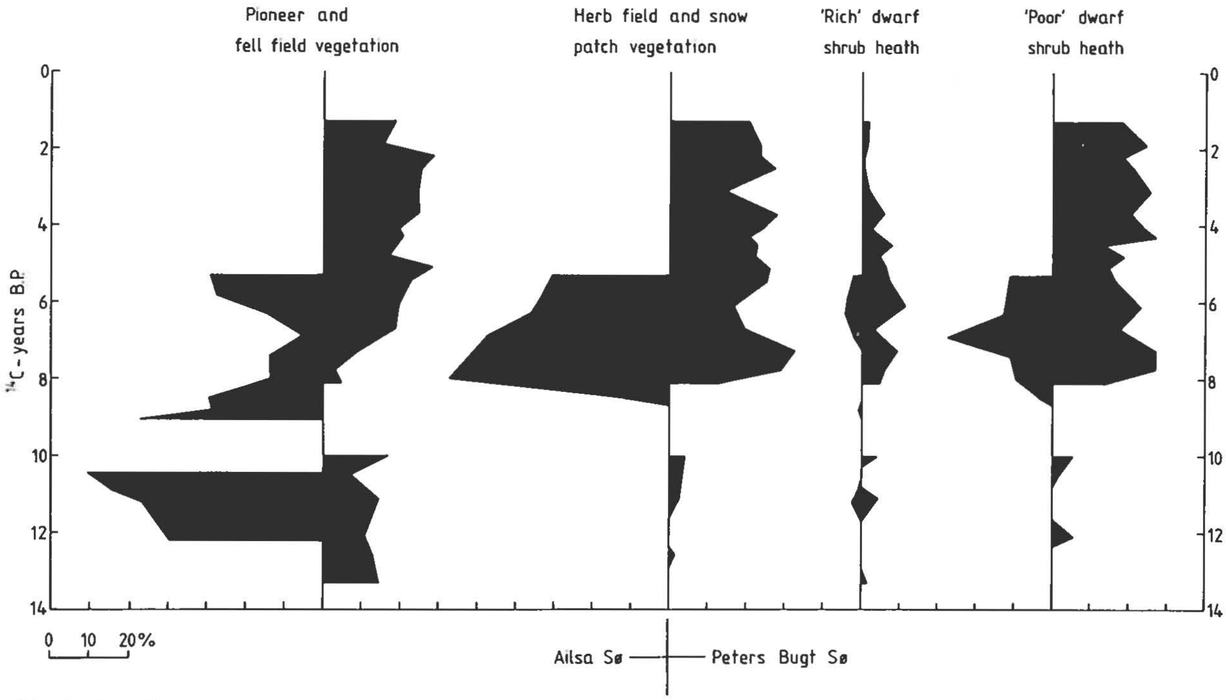

Fig. 9. Compilation pollen diagram from the two lakes. Construction adopted from Funder (1978). The plant communities are represented by the following species and pollen types. – "Pioneer and fell field vegetation": *Epilobium, Dryas, Oxyria, Polygonum viviparum, Saxifraga,* Caryophyllaceae. "Herb field and snow patch vegetation": *Salix herbacea, Thalictrum.* "Rich dwarf shrub heath": *Betula nana, Empetrum nigrum.* "Poor dwarf shrub heath": *Cassiope* tp, *Salix arctica, Vaccinium uliginosum.*

still of a pioneer type. Although the climate was probably rather favourable during zone A1b, the effect of the climate amelioration is not seen until zones A2 and P2, when the post-glacial plant immigration occurred. In "Peters Bugt Sø" the Barren Interzone lasted from 10 100 to 8100 B.P. and the pollen production was extremely low.

Zones P2 and A2

Zone P2 covers the period 8100–5200 B.P. and A2 8200–5200 B.P. (A2a 8200–6600 B.P. and A2b 6600–5200 B.P.). The very distinct change between zones A1b and A2a is obvious from Fig. 10, while the development from P1 to P2 is gradual (Fig. 11). The beginning of this period is characterised by the rise of *Salix*, both the pollen values of *Salix herbacea* and *Salix arctica.* There is also a rise in *Betula nana* as well as tree birch pollen frequencies, the latter being considered as long-distance transported. Dwarf birch seems to have been more common during this time than today. The date of immigration of *Betula nana* fits very well with Funder's (1978, 1979) ideas of immigration. The pioneer species have rather low frequencies in the lower

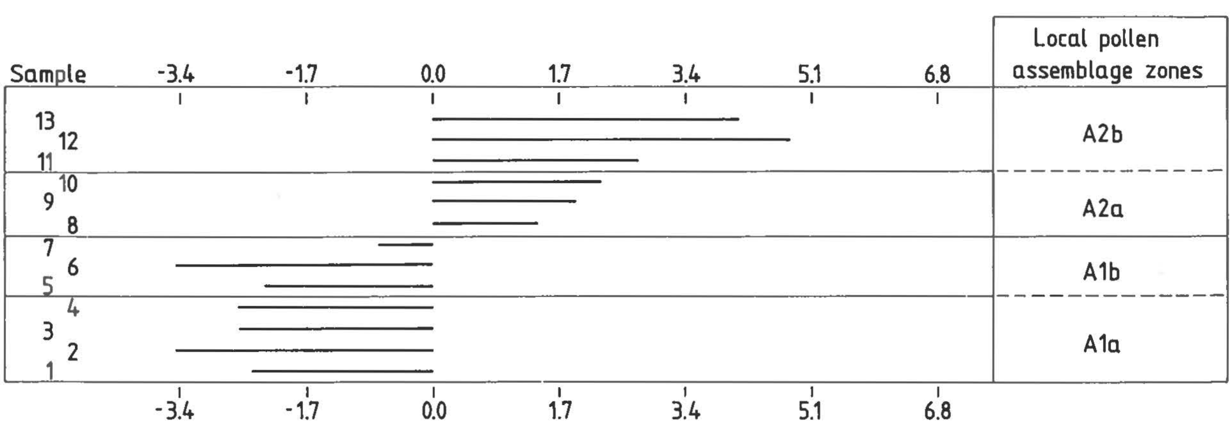

Fig. 10. Stratigraphic plot of sample scores on principal component 1 from "Ailsa Sø", based on correlation matrix of the pollen and spore types included in the "pollen" sum and related to the local pollen assemblage zones.

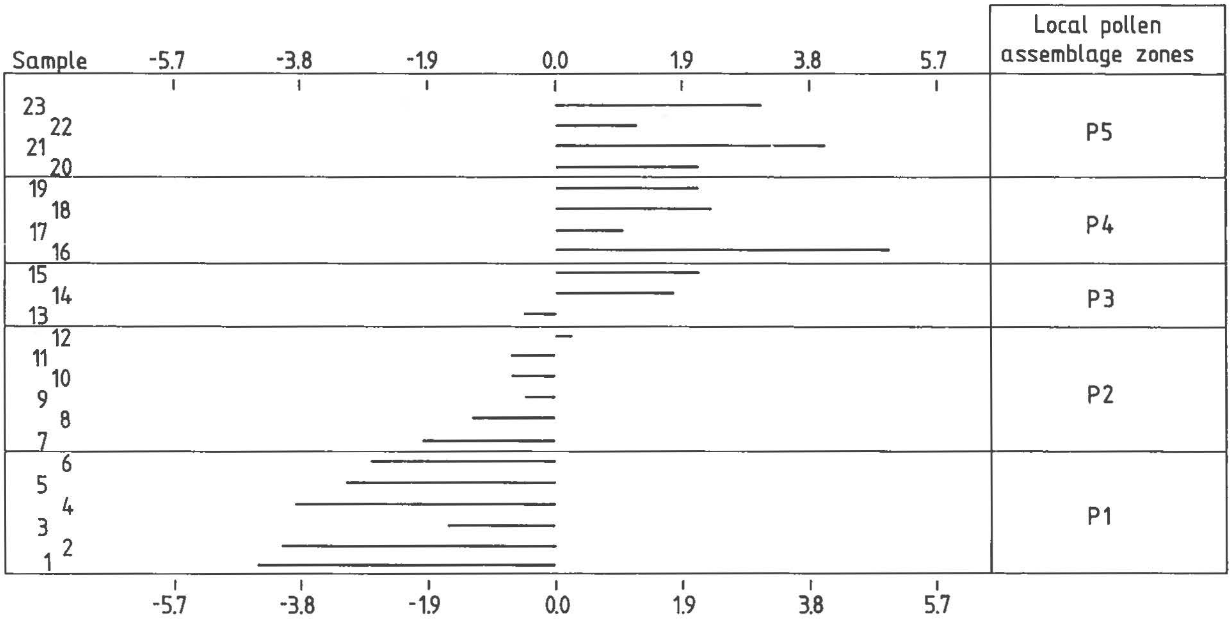

Fig. 11. Stratigraphic plot of sample scores on principal component 1 from "Peters Bugt Sø", based on correlation matrix of the pollen and spore types included in the "pollen" sum and related to the local pollen assemblage zones.

part of zone P2 and in subzone A2a and the beginning of subzone A2b. *Salix arctica* seems to have immigrated into this area *c.* 8000 B.P., possibly somewhat later to the "Peters Bugt Sø" area because of the marine influence on this lake during this time. This date can be compared with the earliest date of 5700 B.P. for the arrival of *Salix arctica* to the Scoresby Sund area (Funder 1978). *Salix arctica* is accompanied by an expansion of *Cassiope tetragona* which Funder (1978) also found in his area. *Dryas* shows a considerable rise in the middle of zone P2 and the corresponding event in "Ailsa Sø" is the reason for the bipartition of zone A2. This happened *c.* 6600 B.P. These zones are thus correlated with the period of higher summer temperatures in the Scoresby Sund area (Funder 1978).

Zones P3, P4 and P5

The development from *c.* 5000 B.P. can only be shown in the diagram from "Peters Bugt Sø". The ages of the zones are: P3 5200–4400 B.P., P4 4400–3100 B.P., and P5 3100 B.P. to recent times. *Betula nana* pollen values are low in all three zones, and the species had, as today, a restricted distribution. However, as Andrews et al. (1980) have shown from Baffin Island, even very low pollen values may indicate the presence of dwarf birch stands. This is the case at "Peters Bugt Sø", where dwarf birch stands are found 300–400 m from the lake and with no *Betula nana* pollen at all in the surface sample (Fig. 2). In zone P4 *Vaccinium* apparently plays a prominent role in the heath vegetation. From zone P3 and onwards the vegetation, already partly established in zone P2, seems to have remained more or less unchanged. The change between zones P2 and P3 is the most distinct pollen stratigraphic boundary in "Peters Bugt Sø", which is also demonstrated in the stratigraphic plot in Fig. 11. From Fig. 9 it can be seen that pioneer and fell field vegetation returned in the middle of zone P2. In addition, only minor fluctuations in the pollen diagram can be noted for the three upper zones. In zone P3 *Dryas* pollen reach slightly higher values, *Cassiope*, *Oxyria* and Caryophyllaceae have somewhat higher frequencies in zone P4, and Gramineae, Cyperaceae and also *Salix arctica* show some increase in zone P5.

Snow patch vegetation, represented here by *Salix herbacea*, seems to have had a much more important role in the vegetation on Hochstetter Forland than in Funder's (1978) area. Instead the 'rich' dwarf shrub vegetation on Hochstetter Forland was more restricted compared to the Scoresby Sund area during the times equivalent to zone A2 and zones P2–P5.

The mean scores of the local pollen assemblage zones from the two lakes are plotted on the first and second principal components (Fig. 12). The displacement between the curves shows the general difference between the two sites, but the similarities of the development are obvious. The position of A2b shows its affinity to the later development in "Peters Bugt Sø". The uppermost sample from "Ailsa Sø" may have been influenced by rather recent vegetation.

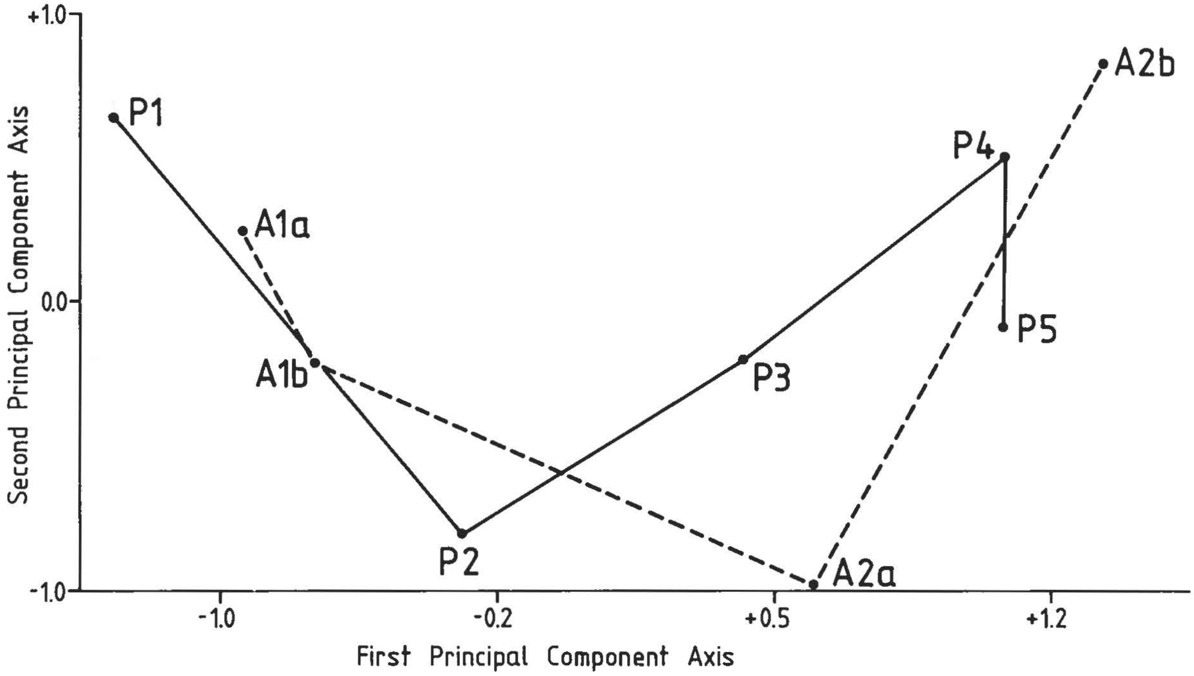

Fig. 12. Comparison of "Peters Bugt Sø" and "Ailsa Sø" using principal component analysis. The mean scores of the local pollen assemblage zones are plotted on the first and second principal components (correlation matrix) and joined up in stratigraphic order.

Post-glacial uplift

As has been described above, two different marine levels have been dated in the area. The marine limit formed during the Nanok stadial was dated by Hjort (1981) to 9500 B.P. and considered to be situated about 50 metres above today's sea level. Secondly, the isolation of "Peters Bugt Sø" from the sea corresponds to the very beginning of pollen zone P2 (Figs 2 and 3). One problem connected with the isolation of the lake (Fig. 13) has been to determine the altitude of the threshold at the time for the isolation. The change of outlet from the southeastern delta to today's outlet in the northwest must have caused considerable erosion around the lake as the water-level was lowered about 10 metres. The reason why the delta in the southeast is connected with an outlet from the lake is the presence of stream-channels on the delta surface, situated far below the marine limit which formed a long time after the deglaciation. When the outlet changed, extensive erosion must have occurred in the new outlet area as the water broke through the ridge which dammed the lake in the northwest. However, the erosion around the lake during and after its lowering should be recorded in the lake sediments. According to the sediment stratigraphy, silty laminae occur from 50 cm and upwards together with a high frequency of moss remains. This could suggest that the change of outlet corresponds to this change in lithology. The sample level 50 cm below sediment surface corresponds to zone P4 (Fig. 2), dated to about 4000 B.P. This interpretation of the change of outlet means that the threshold of the lake was situated 25 metres above present sea-level when it became isolated from the sea. As this took place in the very beginning of zone P2 the isolation is dated to about 7500 B.P. (Fig. 7).

In order to be able to calculate the post-glacial uplift on Hochstetter Forland the eustasy must be known. According to the compilations of eustatic curves made by for example Andrews (1970) and Mörner (1978) the sea-level was at 9500 B.P. situated at about −30 m, and 2000 radiocarbon years later at about −15 m. This means that the uplift was approximately 40 metres during these 2000 years with a mean rate of 2 m/100 ^{14}C-years. The mean rate of uplift since 7500 B.P. is about 0.5 m/100 ^{14}C-years. According to Andrews (1968), about 50% of the postglacial uplift in Arctic Canada occurred during the first 2000 years, which fits very well with the values from Hochstetter Forland. Andrews' post-glacial uplift curve from Inugsuin Fiord (Andrews 1968) seems to have about the same shape as a curve from Hochstetter Forland would have if based on just these two dates.

The uplift curves calculated by Ten Brink (1974) from West and East Greenland are quite different from this curve. The half-life of isostatic recovery is about twice as long on Hochstetter Forland as in Ten Brink's curves, which is indicated by his high exponential constant values. The reasons why the curves seem to differ so much could, for example, be explained by isostatic

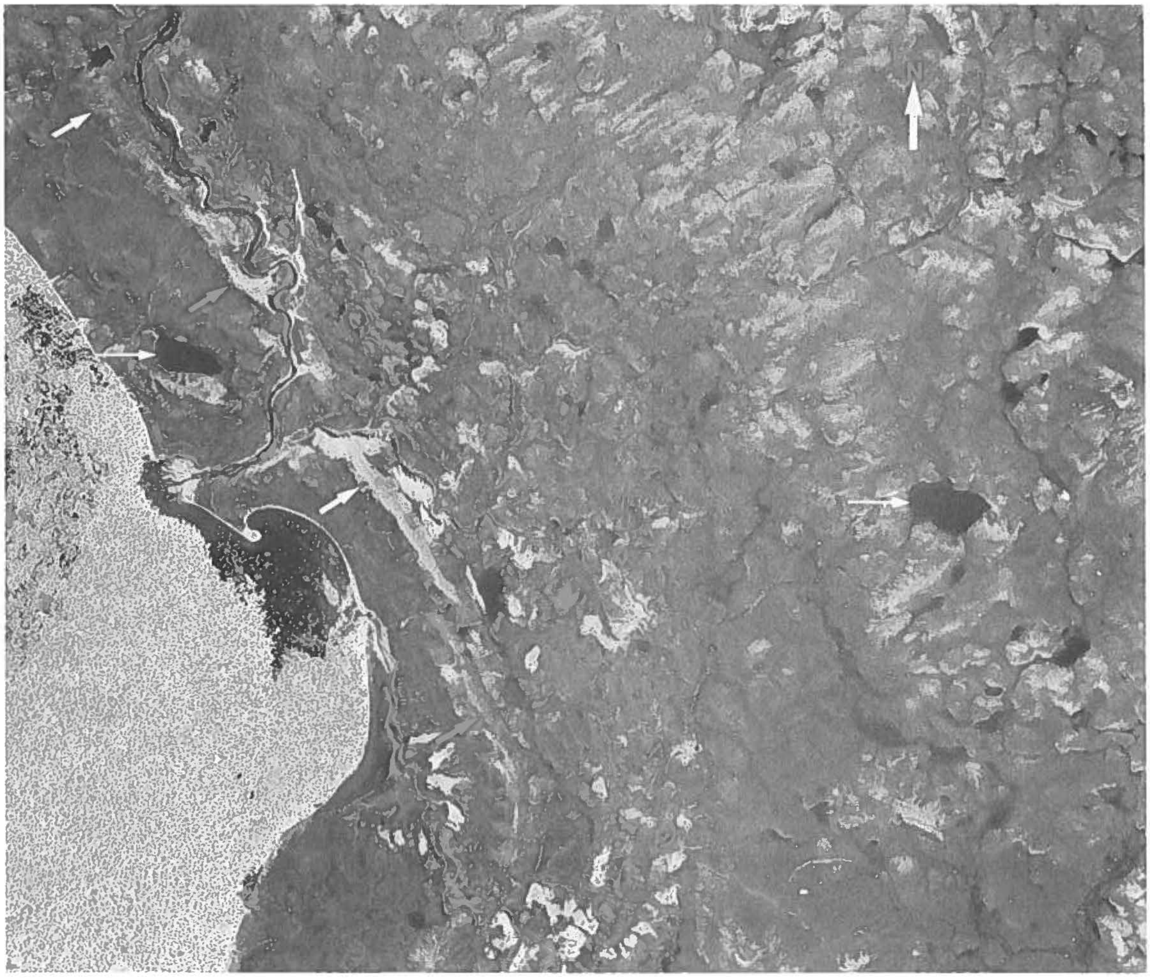

Fig. 13. Aerial photograph of the area. Thin arrows show the position of the lakes and thicker arrows show the position of the Nanok moraine. Photo 21571/51243, Grumman Ecosystems Corporation, New York.

differences between the two areas and/or the lack of a sufficient amount of dated marine levels from Hochstetter Forland. Other sources of error are the eustatic values and perhaps also the theory that uplift is driven solely by isostatic disequilibrium (Ten Brink 1974) producing exponential uplift curves. Having all these sources of error in mind we find it unrealistic to draw an uplift curve for the investigated area based on only two dated marine levels.

The climatic and glacial development based on the local biostratigraphy and the regional glacial chronology

As noted above, the pollen stratigraphy in the two lakes is relatively uniform. Also, in many ways the interpretation of the vegetational history on Hochstetter Forland after 9000 B.P corresponds to the vegetational history from the Scoresby Sund area (Funder 1978). This strongly suggests that the climatic development since 9000 B.P. has been about the same in the two areas, which means that the summer temperatures on Hochstetter Forland were possibly warmer than at present from at least 8000 B.P. These relatively high summer temperatures seem to have ended at about 5000 B.P. when *Betula nana* regressed, which was also the case at the same time in the Scoresby Sund coastal area. As Funder (1978) pointed out, there seems to be a discrepancy between the climatic optimum of East Greenland and that of the rest of Greenland. In East Greenland the optimum seems to end 1000–3000 years earlier than in other parts of Greenland such as those investigated by Fredskild (1967, 1969 and 1973) and Kelly & Funder (1974). The date of this optimum in East Greenland is more in accordance with the climatic development in NW Europe.

The development prior to 9000 B.P. is more complicated, as the bio- and lithostratigraphy vary between the lakes during this period and the correlation possibilities with the Scoresby Sund area are much more restricted than later on. However, it is of great value to compare the results from this study with Hjort's (1981) extensive investigations of the glacial chronology in the same parts of East Greenland.

As the lowermost radiocarbon dates from the two lakes are regarded as reliable, the organic sedimentation in "Ailsa Sø" started not later than 14 000 B.P. The number of pollen grains was, however, much too sparse to be able to reach a number of 50–100 grains at this level. In "Peters Bugt Sø", however, the lowermost sampled level was analysed for pollen and according to the radiocarbon date of these sediments the sedimentation began before 13 000 B.P.

As "Ailsa Sø" is situated outside the area which was covered by ice during the Nanok stadial (Hjort 1981) it is not surprising to find a high radiocarbon age from this lake, as the previous Muschelbjerg stadial is clearly older than 45 000 B.P. However, according to Hjort's chronology, "Peters Bugt Sø" was covered by ice during the Nanok stadial, which ended with a deglaciation at about 9500 B.P. He also thinks that the glacial advance could have started at about 13 000 B.P. or later. In this study the two barren interzones are correlated with the very end of the Nanok stadial. These interzones lasted, according to the sedimentation curves, between 10 100 and 8100 B.P. ("Peters Bugt Sø") and between 10 100 and 9200 B.P. ("Ailsa Sø"). The latter date fits very well with Hjort's date of the end of the stadial. As "Ailsa Sø" is situated about 8 km outside the maximum range of this stadial, this lake would have been influenced earlier than "Peters Bugt Sø" by the immigration of plants following the deglaciation. However, it is hard to explain the Nanok stadial moraine north and east of "Peters Bugt Sø" as the ice here advanced from the southwest during this stadial. The distinct moraine ridge just south and west of the lake must have originally bounded the lake also in the northwest before the outlet changed from the southeast to the northwest. This could imply that the lake was originally a kettle hole occupied by ice which melted earlier than 13 000 B.P. A piece of dead-ice in "Peters Bugt Sø" could thus be a remnant left after the deglaciation from the moraine ridge 1–2 km east and north of the lake. The glacial advance prior to this deglaciation would then be at least a couple of thousand years older than 13 000 B.P. Consequently the Nanok stadial could be divided into two glacial phases interrupted by a deglaciation phase during the main part of the Late Weichselian (Mangerud et al. 1974).

However, the bio- and lithostratigraphy from "Peters Bugt Sø" prior to 8000 B.P. could also be explained in the following way: The sediments deposited during the barren interzone could have been formed subglacially beneath ice which at that time also formed the Nanok stadial moraine. This interpretation would then support the existence of just one glacial advance during the Nanok stadial. The former interpretation is however considered more likely, as there are no clear signs in the sediments to show that a glacier has overridden the basin after 13 000 B.P. This consideration is based only on the material studied in this investigation. Instead the ice seems to have been very close to the basin during the time for the barren interzones. It is interesting to note that these two zones seem to start almost synchronously, which could suggest that this advance was very sudden. The glacial maxima seems to have occurred some time between 10 000 and 9500 B.P.

According to the date of the Ailsa Sø Barren Interzone the climate between 10 100 and 9200 B.P. seems to have been so severe that the vegetation was sparse and pollen sedimentation in relation to minerogenic sedimentation was extremely low. As has been stated above, one probable reason for the delayed pollen sedimentation in "Peters Bugt Sø" could be a delayed plant immigration. However, the main reason for this delay is probably the fact that during the Peters Bugt Barren Interzone the sediments were deposited in a more or less pronounced glacio-marine environment, which influenced the sediments to such an extent that the relative amount of pollen and spores from the coast north and east of the basin was much too small to influence the composition of the sediment. Taking into account the analyses as well as the low pollen concentrations, the glacial influence on the sedimentation seems to have more or less ended just before the isolation of the lake.

A summary of the most probable development on and around the central part of Hochstetter Forland based on the investigations from "Ailsa Sø" and "Peters Bugt Sø" is as follows:

1) A glacial advance prior to 13 000 B.P. occurred in the area, forming at least parts of the Nanok stadial moraine. The age of this advance is not known, but Hjort (1981) showed that the Nanok stadial moraine partly consists of marine sediments from the preceding interstadial, the Peters Bugt interstadial, which according to his ^{14}C-datings began earlier than 45 000 B.P. This means that at some time between 45 000 and 13 000 B.P. an advance occurred, which at least reached "Peters Bugt Sø". Boulton (1979) shows that the very end of isotope stage 3 (40 000–30 000 B.P.) in the Norwegian Sea was characterised by sub-polar water reaching quite far north, as well as by a high frequency of iceberg-derived detritus. He correlates such phases with glacial advances in the North Atlantic region. However, he cannot correlate this phase with any known glacial advance in Spitsbergen or Greenland.

2) The period between 13 000 and 10 000 B.P. seems to have been stable in respect to pollen sedimentation. It should be noted that although "Peters Bugt Sø" was, according to the diatom analyses, at that time

below sea-level the pollen and spore concentration was not extremely low. The pollen stratigraphy shows neither any evidence for significant climatic deterioration nor any signs of a glacial advance.

3) A very sudden glacial advance seems to have occurred around 10 000 B.P. The evidence for this is the fact that the two barren interzones seem to start at the same time. However, there are certainly errors in the sedimentation curves, especially during this time period. The existence of a barren interzone in "Ailsa Sø" suggests that the climate during perhaps nearly 1000 years was severe. This advance could have formed the major part of the Nanok stadial moraine, but according to this investigation it is less likely to have covered "Peters Bugt Sø".

4) According to Hjort (1981) the last deglaciation took place around 9500 B.P., which fits well with the date of the Ailsa Barren Interzone. However, according to the Peters Bugt Barren Interzone, the glaciers seem to have a major influence on the sedimentation in the fjord until about 8000 B.P.

5) A climatic amelioration prevailed in the area until about 5000 B.P. with higher summer temperatures than at present. This was followed by a climatic deterioration, which has resulted in today's vegetation on Hochstetter Forland.

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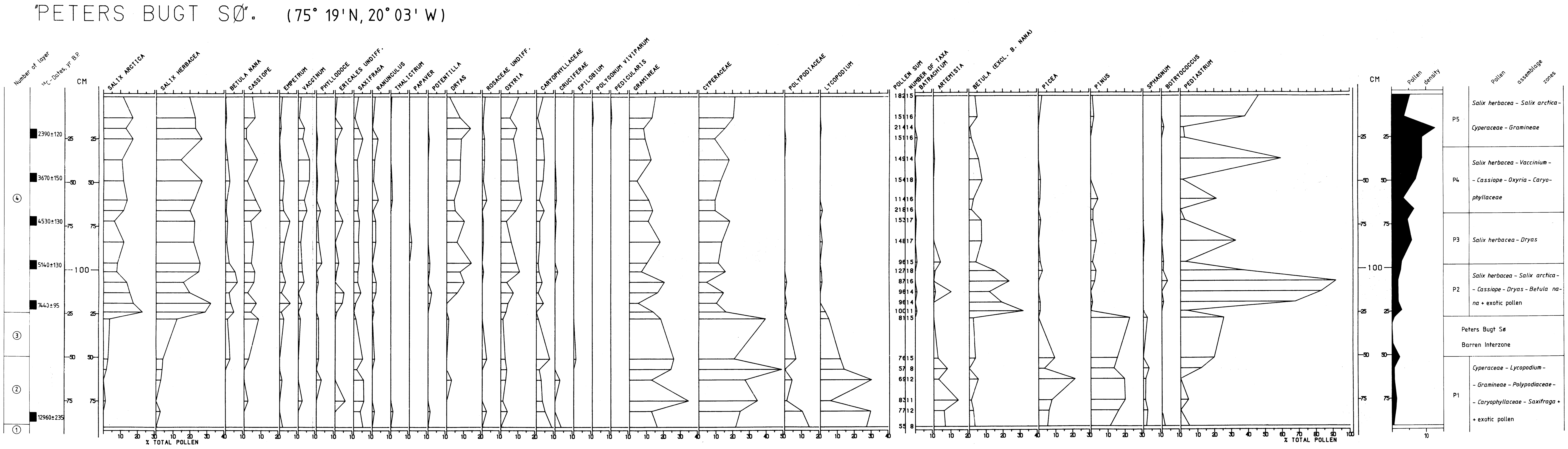

Fig. 2. Pollen diagram from "Peters Bugt Sø".

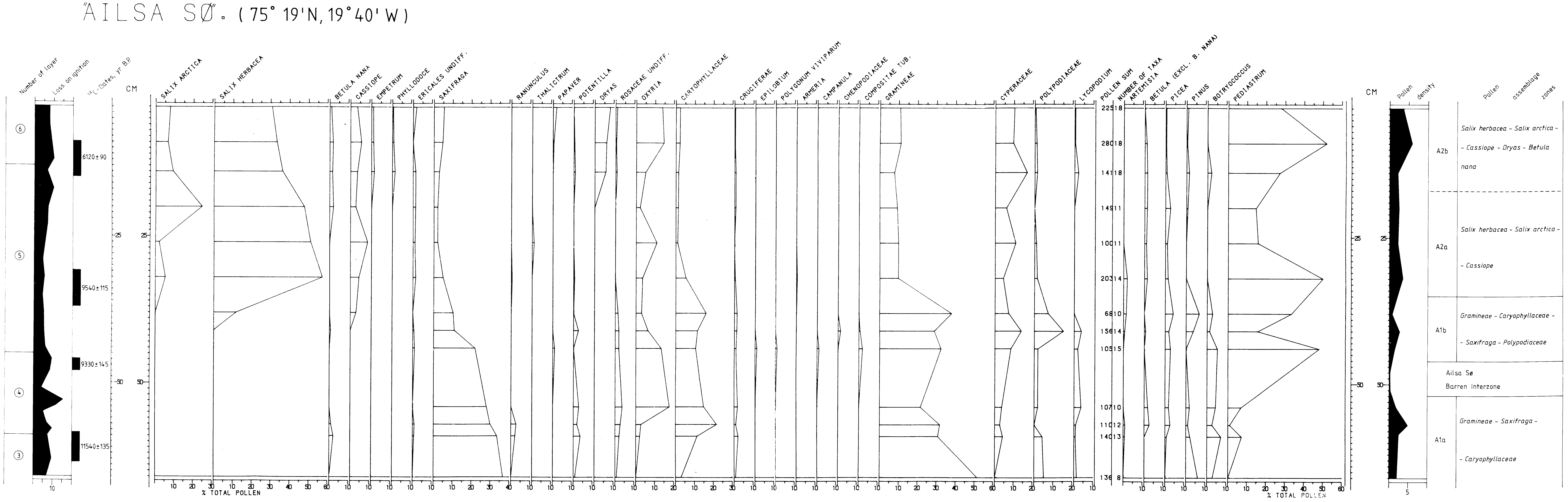

Fig. 4. Pollen diagram from "Ailsa Sø".

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