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The Holocene vegetational development of the Godthåbsfjord area, West Greenland

Bent Fredskild

Geoscience
10 · 1983

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Holocene pollen and macrofossil diagrams from four low arctic lakes at Godthåbsfjord are presented. Each core has been divided into radiocarbon-dated palaeovegetation zones, based on the remnants of terrestric plants. The PV zones are physiognomically similar, but differences as to the composition and frequency of species can be seen between the two lakes in the interior and the two lakes from the outer coast area. The vegetation which invaded the deglaciated soil was open but rich in species, and 64 species or genera have been determined from the pioneer stage (*c.* 9400–8000 B.P.). Open soil plants were dominating, but dwarf-shrubs entered the vegetation, with species from snow-patches and snow-covered heaths dominating in the beginning. By *c.* 8000 B.P. *Salix glauca* and *S. herbacea* immigrated, and gradually the pioneer plants and chionophilous dwarf-shrubs were decimated. This *Salix-Cyperaceae* stage lasted until *c.* 6300 B.P., when *Betula nana* spread all over the area within a few centuries. A *Betula nana-Juniperus* stage lasted until *c.* 3500 B.P. In the subcontinental interior this was followed by an *Alnus crispa-Betula nana* stage, which in turn was replaced by a *Betula nana-Ericales* stage around 1800 B.P. *Alnus* has never been able to grow at the maritime outer coast, where *Betula, Cyperaceae, Empetrum* and other *Ericales* dominated after *c.* 3500 B.P. Later on, *Empetrum, Cyperaceae* and snowbed plants gradually spread at the expence of *Betula nana*.

After the deglaciation the temperature increased, reaching today's values between 8000 and 7500 B.P. At which time during the coming millennia the temperature curve peaked is not known, but it may have been fairly late, presumably during the *Betula nana-Juniperus* stage. Major climatic changes are registered in the interior at 3900–3600 and 1800 B.P., and at the outer coast at *c.* 3600 and 2500–2000 B.P.

From around 8000 B.P. the development of the lakes is fairly independent of the physical conditions of the surroundings, being dependent mainly on the trophic stages of the lakes. These pass through a succession: highly productive, eutrophic – less productive, mesotrophic – very poor, oligotrophic. As well as in the flora and fauna, these stages are reflected in the sediment, which at the beginning was a clay gyttja followed by a jelly-like gyttja and, finally, by a loose, watery gyttja consisting mainly of precipitated humus. Chemical analyses of one of the cores confirm the oligotrophication.

The pollen influx in the pioneer stage is less than 100 grains per cm^2 per year, increasing during the Hypsithermal to *c.* 300 in three of the lakes and *c.* 1000 in the richest one, but since then the influx decreases somewhat upwards.

A survey of the immigration or first appearance of some species palynologically important to South and West Greenland shows big time lags in the spreading of some species, e.g. *Thalictrum* and *Angelica,* whereas others, like *Empetrum* and *Juniperus,* have a more effective dispersal capacity.

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The present paper can be considered a continuation of the "Studies in the vegetational history of Greenland" (Fredskild 1973) which focussed mainly on South Greenland. While writing that, the urgent necessity of obtaining new material from Godthåbsfjord, especially from the outer coast area, became obvious, so four lakes were cored in 1973 and two in 1976 in different parts of the fjord area. Pollen and macrofossil diagrams have been prepared from four of the lakes, two from the interior, two from the outer coast area.

Geology, climate and vegetation

The investigated area is built up of Precambrian gneisses, with local outcrops of amphibolite. The Wisconsin glaciation, covering the whole area, possibly with some high altitude nunataks penetrating the ice, left some material in the lowland. The upper marine limit ranges between *c.* 80 m on Nordlandet at the outer coast, over 105–110 m in the central part of Godthåbsfjord to *c.* 80 m in the interior (Weidick 1975).

Table 1. Climatic observations from three stations at Godthåbsfjord (see Fig. 1).

	Period	Average				Precip.	Potential
		year C°	coldest month	warmest month	June–Aug.	year mm	evaporation mm
Godthåb	1931–56	–0.7	–7.7	7.6	6.7	515	283
Qornoq	1931–56	0.0	–8.0	9.7	8.7	335	300
Kapisigdlit	1939–56	–0.7	–9.9	10.9	9.7	255	283

The climate is low arctic with marked differences in temperature and precipication between the coast and the interior (Table 1, based on Putnins 1971). The position of the meteorological stations is shown in Fig. 1.

A comparison between the yearly precipitation and the potential evaporation at Kapisigdlit indicates a precipitation deficit illustrating the subcontinental character of the inland and clearly reflected in the vegetation. The main wind direction during the summer at Godthåb is from southwest, and because of the mountain ridges running SW–NE, the cool, moist winds often reach the head of the northern branch of Godthåbsfjord, whereas the southern branch and Ameralik fjord are in rain shadow. Five months have average temperature above 0°C. Satellite records have shown that the area southeast of Kapisigdlit is the earliest free of snow (Hanfgarn 1981).

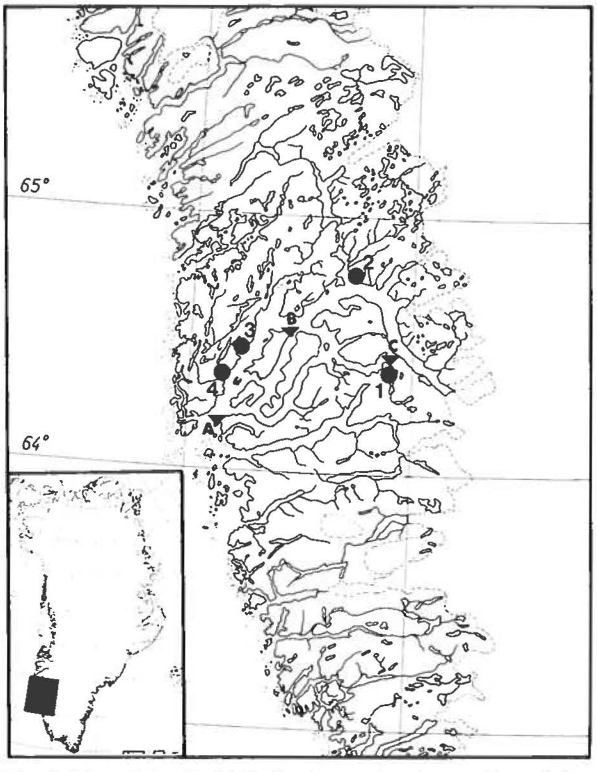

Fig. 1. Map of the Godthåbsfjord area showing position of the lakes (dots) from which diagrams are presented, and meteorological stations (triangles). 1 = Johannes Iversen Sø, 2 = Karra, 3 = Terte, 4 = Sârdlup qáqâ. A = Godthåb, B = Qornoq, C = Kapisigdlit.

The differences in the vegetation will appear when comparing the more detailed descriptions in connection with the localities investigated. In summary, the subcontinental interior is dominated by *Betula nana*-lichen-dwarf-shrub heaths on more dry soil, with *Ledum groenlandicum* and mosses on slightly more moist ground. *Salix glauca* is common in dwarf-shrub heaths, but in protected places in screes and along streams *c.* three m high copses occur, often with *Alnus crispa.* The big lowland peninsula Nordlandet, limiting Godthåbsfjord towards the west, is dominated by *Empetrum-Rhacomitrium*-lichen heaths with few *Betula nana, Ledum groenlandicum, L. decumbens* and *Vaccinium uliginosum.* The willow "copses" here are only rarely more than knee-deep. Snowbeds with *Salix herbacea* and *Harrimanella hypnoides,* and fens with *Scirpus caespitosus, Eriophorum* spp. and *Salix arctophila* are frequent.

A description of the vegetation types is given in Trapnell (1933). In recent years the Greenland Botanical Survey has been collecting in the area, and dot maps for all spontaneous phanerogams between 63°30′ and 67°10′ N have been worked out (Hanfgarn 1981). The difference in vegetation is illustrated by distribution maps for *Diphasium alpinum, Rumex acetosella* and *Alnus crispa* (Figs 2, 3 and 12).

Methods

Field work

The corings were undertaken from a one-person raft of perforated angle bars with a few boards to stand on, carried by inflatable buoys. A modified piston-sampler enables the taking in plexiglass tubes of *c.* 125 cm long, 34 mm wide cores, and by means of a vacuum breaker the piston is loosened, regardless of its position in the tube, and the core readily extruded onto a board. Series of one ml microfossil samples at an interval of 2 cm are taken from the centre of the core, whereas the usually 3 or 4 cm thick macrofossil and radiocarbon samples are accumulated from many cores, up to 26, from the same depth. The latter method may cause some inaccuracies,

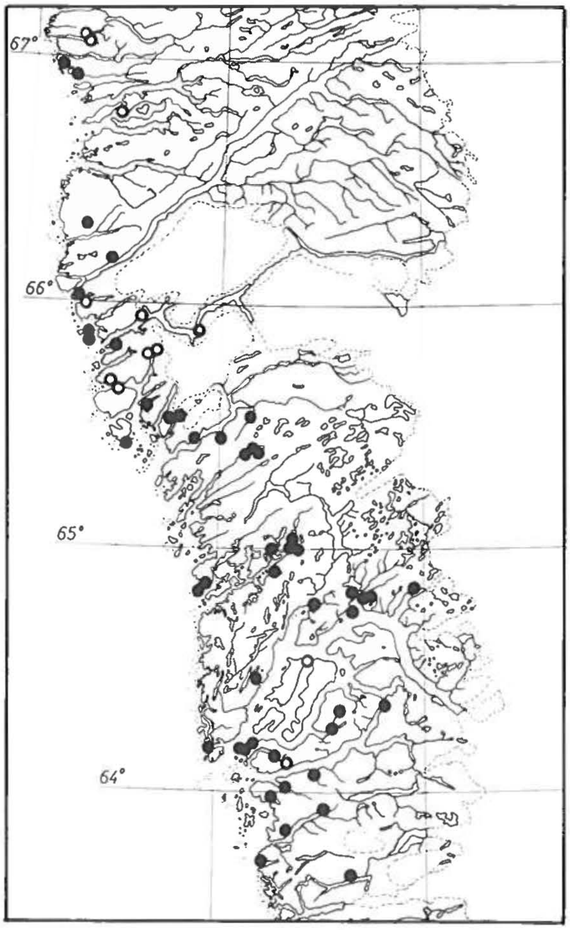

Fig. 2. Distribution between 63°30′ and 67°10′ N of *Diphasium alpinum* (after Hanfgarn 1981). Dot: herbarium collection; circle: literature reference.

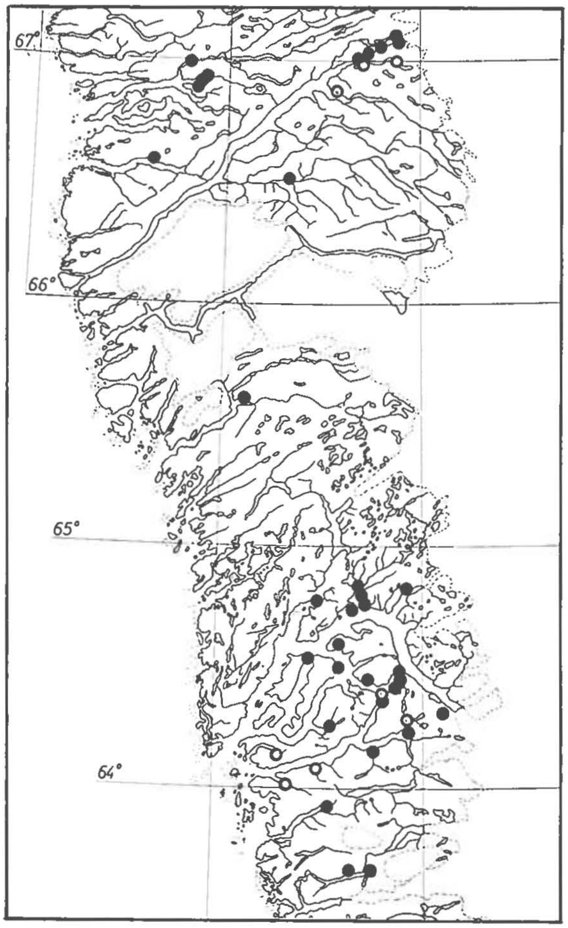

Fig. 3. Distribution between 63°30′ and 67°10′ N of *Rumex acetosella* (after Hanfgarn 1981). Dot: herbarium collection; circle: literature reference.

but usually the depth of cores can easily be correlated by means of the clay/gyttja contact or layers of deviating colour, and any error in dating is thought to be negligible and eliminated by using many cores. The water in Greenland lakes is often so clear that a coring can be placed next to the hole left by the preceding corings, and thus the whole coring operation can be undertaken within 3–4 m².

The accuracy in taking the one ml sub-samples out of the core, important for the calculation of pollen influx, has been investigated by weighing a series of 92 one ml samples, taken with the same equipment (Fredskild 1973, fig. 1) from a sealed tube with a uniform, very watery (85–92% water) *Nostoc-Pediastrum* algae gyttja from Tugtuligssuaq, Northwest Greenland. The weight per sample averaged 1.076 g (s.d. 0.0069 g, range 0.966–1.193 g), indicating that the method is reasonably good even under field conditions. Variations in influx exceeding 5–10% must be ascribed to other factors.

Laboratory work

The pollen samples, treated overnight with cold, 40% hydrofluoric acid following acetolysis, were counted absolutely, with slight modifications following the method described by Jørgensen (1967). The macrofossil samples, including the samples used afterwards for radiocarbon dating, were washed on a 0.4 mm sieve, and all or part of the finer material afterwards on a 0.2 mm sieve to catch *Juncus* seeds etc. The criteria used in determining the pollen are those mentioned in Fredskild (1967, 1973) and Funder (1978). The biggest problem is that of separating the *Ericales* pollen. Usually the determination of e.g. typical *Empetrum*, *Cassiope* and *Loiseleuria* pollen causes no trouble, but as the counting was spread over six years, during which the already large number of reference slides increased further, often with surprising results, a full consistency in determination can only be expected within a diagram, but not necessarily between the diagrams. In discussing the diagrams, the term *Ericales* is used for the sum of determined and undetermined ericaceous tetrads, whereas the term *Ericaceae* includes only the eight genera of this family plus *Vaccinium* and *Pyrola*.

In some diagrams a curve for wood fragments is given. It is based on fragments, recognizable as being from tracheids or pith rays of *Picea, Larix* or other conifers (but not *Juniperus*). Such microscopic fragments, originating mainly from the erosional effect of snow-crystal-carrying winter storms at the timberline in North America, have been found all over Greenland, including Ice Cap cores (Fredskild & Wagner 1974).

Pollen diagrams are usually divided into pollen zones or pollen assemblage zones. However, as macrofossil diagrams are also included in the attempt to reconstruct the past, the term palaeovegetation zones (PVz) will be used.

The determination of the macrofossils is based on a fairly rich reference collection and especially on the Greenland herbarium of the Botanical Museum, and in general it follows the criteria in Fredskild (1967, 1973, 1978).

The determination of the zoological remains in the macrofossil samples has not yet been completed, and the absence of a species in a diagram does not necessarily imply a real absence. *Spongilla* spicules are dissolved in the routine treatment of pollen samples. Only from one lake, Johannes Iversen Sø, a series of untreated samples was investigated to reveal the date of immigration.

Table 2. Radiocarbon datings.

	Depth, cm	Laboratory no. K–	^{14}C dating (half life 5568 yr)	δ^{13}C‰
Johs. Iversen Sø	37–40	2536	1370±70	–22.7
	73–76	2463	2280±80	–22.6
	109–112	2535	2660±80	–22.3
	121–124	2591	2980±60	–23.4
	145–148	2462	3950±85	–21.6
	205–208	2534	5030±95	–21.4
	265–268	2461	6410±80	–17.3
	301–304	2460	7770±120	–19.5
	340–346	2294	8640±130	
Karra	70–75	2997	3420±130	–24.9
	109–112	2996	5950±100	–19.9
	133–136	2995	8000±120	–18.1
	c. 149–154	2749	8740±185	–15.0
Terte, Lake A	36–38	2786	4040±90	–22.4
	60–62	2720	5580±75	–16.5
	72–74	2719	6380±105	–16.6
	92–94	2718	7450±120	–16.4
	112–114	2717	7980±120	–20.1
	126–130	2292	9000±140	
Terte, Lake B	241–247	2293	8080±130	
Sârdlup qáqâ	20–25	3196	1080±85	–23.3
	75–78	3195	3460±85	–22.7
	105–108	3194	5190±90	–21.3
	117–120	3193	5790±95	–21.5
	129–132	3192	6500±110	–21.7
	144–147	3191	7470±110	–21.8
	156–159	3190	8460±110	–21.7
	178–180	2750	8960±190	–23.9
Gytjesø	386,5–394	2295	7430±100	

Radiocarbon dates and ^{13}C measurements

28 gyttja samples and one moss sample (Sârdlup qáqâ, 178–180 cm) have been dated (Table 2). All dates referred to in the text and diagrams are radiocarbon dates. For the four lakes age/depth curves, based on calibrated dates, have been constructed (Figs 4, 6, 8, 9). Calibration is according to Damon et al. (1973) back to 6542 radiocarbon years, whereas a curve based on Stuiver (1971) has been used for older dates. These curves are best-fit curves, as sudden changes in the sedimentation rate are not to be expected in lakes of the type investigated, all but one being without inlets, and being supplied only by seeping water from the surroundings. When calculated on straight lines connecting the dates, the pollen influx showed some absurd jumps, not at all supported by the usually gradual changes in pollen content per ml. These best-fit curves are only used for calculating sedimentation rates and pollen influx.

$\delta\ ^{13}$C measurements lying between –15 and –20‰ (Table 2) show that the sedimentation in some of these arctic lakes at the beginning of their existence was mainly of submerged organisms, e.g. *Pediastrum* and other algae. Later on $\delta\ ^{13}$C ranges between –20 and –25‰, indicating that terrestric or emerged material makes up an essential part of the gyttja. As virtually no emerging hydrophytes and helophytes are found in the lakes dealt with, this indicates that the sediment in the upper part of the cores consists mainly of precipitated terrestric humus. This is in accordance with the usually amorphous character of the sediment, easily washed through the 0.2 mm sieve, and with the drastically reduced number of *Pediastrum* as compared to the deeper samples. This washing out of terrestric humus tends to give dates that are too old (see further discussion p. 24).

Chemical analyses

Chemical analyses were carried out in 1977 on 11 dried samples from Johannes Iversen Sø, at the Institute of Plant Ecology, University of Copenhagen. Total C, expressed as % dry weight, was measured after burning at 1500°C in pure oxygen. Kjeldahl N is expressed as p.p.m. of dry weight, as are the ten ions listed in Table 4. They were determined by the atomic absorption method, after boiling in 32% HNO_3 for eight hours, followed by an almost complete evaporation, boiling for 5–10 minutes in 1 n HNO_3 and filtration.

Johannes Iversen Sø (64°24′ N, 50°12′ W)

Johannes Iversen cored a number of lakes at the head of Godthåbsfjord in 1934 and published the results 20 years later (Iversen 1954). His original, very summary diagram from "Lake 100 m s.m." was redrawn and some unpublished curves were included in Fredskild (1973, plate 16). I recored the lake, situated five km southeast of Kapisigdlit, in 1973, and the Greenland Place Name Committee has accepted the proposed name Johannes Iversen Sø.

The lake, about 150 × 200 m, is situated in a hilly landscape. Just north of it is a 50 m high bedrock ridge. There is no direct inlet, only a meltwater bed with seeping water ending in a little fen limiting the lake to the west. The outlet is correspondingly poor in water during the summer. The vegetation within the nearest kilometres is dominated by dwarf-shrub heaths rich in lichens and mosses, with *Betula nana* and *Ericales,* each covering almost half the area. *Ledum* and *Vaccinium uliginosum* are most important among *Ericales, Ledum groenlandicum* especially in the lowland and in more humid heaths, while *L. palustre* ssp. *decumbens* is more common above 2–300 m and in the drier heaths. *Empetrum* dominates in the upland heaths, which also include *Phyllodoce coerulea* and in exposed places some *Loiseleuria procumbens.* The high arctic *Cassiope tetragona,* which has its southern limit just south of Godthåbsfjord, is found locally on northward facing heaths, mostly upland. *Rhododendron lapponicum* can be met with in dry heaths and on rock ledges. Even the hummocky fens are dominated by dwarf-shrubs, yet with some *Cyperaceae, Eriophorum angustifolium, Scirpus caespitosus, Carex saxatilis* and *C. rariflora.*

Salix glauca prefers moist and protected places along streams and brooklets and in ravines, where it forms low copses, but it is also an important component in the more humid heaths. *Alnus* is very rare, covering only a few per mill of the area. *Juniperus communis* is found on dry rock ledges, which otherwise harbour herbs such as *Thymus praecox, Euphrasia frigida, Potentilla tridentata, Campanula gieseckiana* and *Cerastium alpinum* and also *Poa glauca* and *Deschampsia flexuosa,* and some *Woodsia ilvenis.* Grasses are unimportant.

Sterile *Myriophyllum alterniflorum* is frequent on the lake bottom between one and three metres which is the maximum depth. Furthermore, a few *Menyanthes trifoliata* and *Sparganium hyperboreum* are found at the shore, and also some sterile *Potamogeton gramineus.* No doubt *Isoëtes setacea* is growing in the lake today, as reflected in the diagram, but it was not observed. Some *Spongilla* sp. were collected. Statoblasts of the freshwater bryozoan *Cristatella mucedo* were found, even in the recent gyttja, and the species is undoubtedly living in the lake today. pH is 5.8, conductivity 42 µmho. The water chemistry is given in Foged (1977, table 1).

Sediments

The coring was undertaken at a water depth of 280 cm. The following layers were separated (classification according to Troels-Smith 1955):

11.	0–149 cm below lake bottom:	Brownish-olive, fine gyttja, becoming looser upwards with increasing content of water. $Ld^{0}4$, (Ag + As) (+), Ga(+)
10.	149–157:	Like layer 11, but lighter in colour
9.	157–164:	Like layer 10, but darker brownish-olive
8.	164–292:	Laminated fine gyttja, mostly bright, slightly yellowish olive to brownish. Downwards more compact, jelly-like. In some parts with thin, delicate rootlets(?). $Ld^{0}4$, Dg(+), Dh(+), (Ag + As)++, Ga(+)
7.	292–298½:	Darker, more reddish-brown. $Ld^{0}4$, (Ag + As)++, Ga(+)
6.	298½–322:	Laminated, olive, slightly clayey, fine gyttja, sharply delimited upwards by a 1 cm grey, clayey layer. $Ld^{0}3\frac{1}{2}$–4, (Ag + As)½–++, Ga+
5.	322–324½:	Laminated, slightly reddish brown, slightly clayey, fine gyttja
4.	324½–333½:	Laminated, darker clay-gyttja with some sand
3.	333½–339:	Laminated, more yellowish, bright olive clay-gyttja
2.	339–362½:	Paper-thin, dark-olive gyttja layers alternating with clay layers, with sand in the deeper 5 cm. Upwards clay-gyttja layers ranging in colour from reddish over grey to olive. Thin clayey layers with sand
1.	362½–367½:	Grey, marine clay with sand

8 samples have been radiocarbon dated (Fig. 4).

Zonation of the diagrams (Plates 1–3)

Generally, a sample at every 10 cm was analysed. Apart from the pollen shown in the diagram, the following were found: *Angelica archangelica,* sample 25, 32, 35, *Callitriche* 28, *Caryophyllaceae* sp. 2, 3, *Chamaenerion* 39, *Coptis trifolia* 18, *Cruciferae* 3, 4, 7, 10, 13, 22, 35, 37, *Gentiana nivalis* 16, *Lycopodium clavatum* 11, *L. clavatum* or *Diphasium* 19, 25 (2 spores), 28, *Melandrium* 1 (3 grains), *Pedicularis flammea* 36, *Polygonum viviparum* 12, *Sagina* 2, *Salix herbacea* 6, *Subularia* 4 (3 grains), *Viscaria* 1, 2 (3 grains). The pollen of *Loiseleuria* type 3, 6, 12, and *Rhododendron* type 35, and of *Vaccinium* type 5, 25, 26, 27, 28 are included in *Ericales* sp. indet. Furthermore *Assulina* 4, 21, *Tilletia sphagni* 29, "Hystrix" 1 (numerous), 2, 3, 5, fragments of Conifér tracheids 1, 2, 4, 7, 10, 12, 30, 36. Exotic pollen are generally few, with *Pinus* as the most frequent, found in 20 pollen samples. *Picea* occurs in 12 of the samples 20–33, but outside this only in two samples. In the diagram influxes less than 5 are not marked.

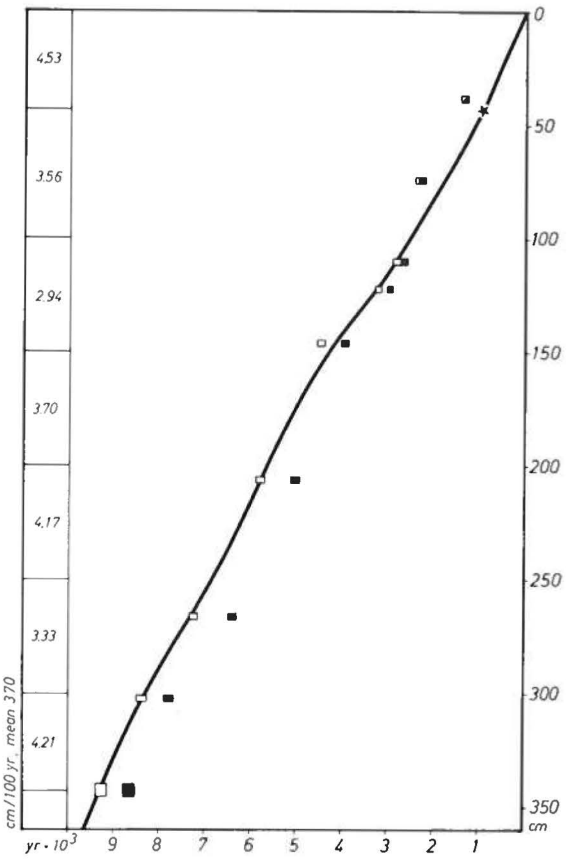

Fig. 4. ^{14}C age versus depth, Johannes Iversen Sø. Black boxes are ^{14}C dates, open boxes calibrated dates. The Norse landnam is shown by the asterisk.

PV zone A: *Gramineae-Cyperaceae-Empetrum* zone (362–310 cm)

The lake was isolated from Godthåbsfjord *c.* 9000 B.P. The deeper samples still contain remnants of the traditionally low-competitive pioneer vegetation on fresh soil: *Silene-Minuartia, Oxyria digyna, Sagina, Saxifraga* spp., *Gramineae, Cyperaceae,* but in low amounts only, indicating the final stage of this phase. At the time of isolation the lake was bordered by salt marshes with *Stellaria humifusa, Carex ursina* and *C. glareosa,* and on the moist, raised marine clay, rich in electrolytes, were *Juncus arcticus, J. ranarius* and *J. biglumis* and/or *J. triglumis,* and in addition *Carex capillaris, C. bigelowii* and *Phippsia algida.* No *Juncus* pollen were found in the deepest samples in spite of the numerous seeds, whereas scattered *Juncaceae* grains occur higher up in the diagram, possibly indicating that most *Junaceae* pollen in this and other diagrams are from *Luzula. Empetrum hermaphroditum* has its relative maximum in the middle of this zone, but it is worth noticing that the influx of *Empetrum* pollen is about as big in zone C and part of B and E. The large amount of seeds washed down to the lake is parallelled by the fairly high content of clay and sand because the soil was not yet stabilized, being covered only by an open vegetation. Pollen sample 1 contains numerous "Hystrix" of marine origin and a number of secondary pollen like *Betula, Alnus* and other exotic pollen.

Pteridophyte spores are generally more resistant to corrosion than pollen, and those spores, having a maximum in the deepest sample(s) like *Dryopteris* type and *Diphasium,* or having an isolated occurrence here, like *Gymnocarpium,* are supposed to be of secondary origin. The *Juniperus* and *Lycopodium* in sample 5 are supposed to be redeposited, cf. the maximum in exotics and in sand. At least this single *Juniperus* will not be taken as a proof of it having grown in the vicinity.

Among early immigrants Iversen (1954) also mentions *Lomatogonium rotatum, Montia fontana* and *Angelica,* besides *Atriplex.* With the present knowledge of long distance *Chenopodiacea* pollen in other Greenland lake diagrams, the latter may not have been growing here at that time (Fredskild 1973: 149).

The lake was rich, and throughout the zone mesohalobous diatoms were found. Alkaliphilous and indifferent diatoms dominate, with only one (?redeposited), not too significantly acidophilous species in one sample (Fig. 5, from Foged 1977). *Hippuris,* and from the middle of the zone also *Myriophyllum spicatum* ssp. *exalbescens,* are frequent, and the production of *Pediastrum* and *Botryococcus* is the highest so far registered in a Greenland lake. At the coring site *c.* 50000 were

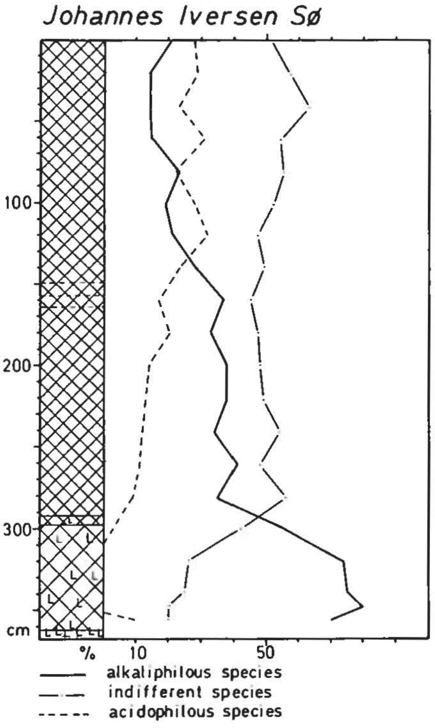

Fig. 5. pH spectra of diatoms, Johannes Iversen Sø (after Foged 1977).

sedimented per cm² per year during the maximum. However, *Potamogeton filiformis, Eupotamogeton, Menyanthes, Ranunculus confervoides, Chara* and *Nitella* were also growing in the lake, with *Ranunculus hyperboreus, Limosella* and *Subularia* blooming on the shore. Sticklebacks (*Gasterosteus aculeatus*) were abundant.

The occurrence of *Galium brandegei* (present northern limit in West Greenland 67°48', Nordre Strømfjord), *Menyanthes* (68°41'), *Subularia* (69°38'), *Myriophyllum spicatum* (70°30'), *Limosella* (70°59') and *Plantago maritima* (71°07') indicate that the climate was low arctic. *Juncus ranarius* is very rare in Greenland, being found only as a hemerophilous species at some settlements in South Greenland and also occasionally on moist clay near the sea, at lake shores or along brooklets between 64° and 68° in West Greenland and at 71° in East Greenland. On the other hand, *Lepidurus arcticus* mandibles are abundant throughout the zone as they are in "late-glacial" samples in some South Greenland cores (Fredskild et al. 1975). Apart from a relict-like, high altitude occurrence in South Greenland, *Lepidurus* today is distributed in West Greenland from 67° to 78°18'. On Ellesmere Island it has been found at Lake Hazen (81°49' N, Røen 1981). Conditions comparable of today's climate in Disko Bugt thus seem likely for this zone.

PV zone B: *Salix-Thalictrum-Cyperaceae* zone (310–264 cm)

Cyperaceae reach maximum values, *Salix glauca* and *Thalictrum* immigrate, and *Lycopodium dubium* is spreading. *Gramineae* and the pioneer plants are reduced or disappear. *Ericales,* mainly *Empetrum* and *Ledum* are gradually declining. There is a thin "tail" of *Salix* pollen in the original "Lake 100 m s.m." diagram, explained as consisting "principally of *Salix herbacea* pollen" (Iversen 1954: 88). In the present investigation 24 zone A samples from the four Godthåbsfjord lakes (5729 pollen) have been counted, and only one single pollen was found. As the coring in 1937 was done with a Hiller peat sampler, contamination is most likely responsible for the early *Salix* pollen. This seems a parallel to the two Galium Kær diagrams (Fredskild 1973, plates 12 and 14), one of which, cored by a Hiller sampler, had a "tail" of *Rumex* pollen all through, whereas in the other, sampled from an open profile in the same fen, not a single *Rumex* pollen was found prior to the Norse landnam.

Conditions in the lake were radically changed. Clay is no longer washed out by meltwater or eroded from the edge. This gradually makes the water poorer in nutrients and lowers the pH, as reflected in the decrease in alkaliphilous and emergence of acidophilous diatoms, in the decrease in Ca and other cations (Table 4), and in the decreasing algae production. *Characeae* disappear, *Hippuris* and *Myriophyllum spicatum* are reduced, but *Eupotamogeton,* at least *Potamogeton alpinus* and *P. pusillus,* are spreading, and *Isoëtes setacea* immigrates. The decreasing supply of nutrients to the lake must be caused by denser vegetation within the watershed, yet *Betula nana* is still missing as the main component, and the influx of *Ericales* and *Salix* pollen is not higher than today. Most likely a fen, straining off mineral particles as well as nutrients, bordered the lake. This could explain the *Cyperaceae* and *Sphagnum* maximum.

Climatically neither *Thalictrum* (north to 71°33') nor *Salix glauca* (to 75°22') – the only likely source of the many *Salix glauca*-type pollen – indicate any change, but the extinction of *Lepidurus* and the immigration of *Isoëtes setaca* (to 68°21'), of *Spongilla* sp. and *Cristatella mucedo* indicate a summer not very different from that of today. *Spongilla* is known from some lakes and ponds northwards to the head of Søndre Strømfjord (*c.* 67°), whereas living *Cristatella mucedo* has never been found in Greenland.

PV zone C: *Juniperus-Betula nana-Rumex acetosella* zone (264–150 cm)

Betula nana, Juniperus, Rumex acetosella, Artemisia borealis and *Selaginella selaginoides* immigrate, and because of this the pollen influx is at least doubled. The decreasing percentage curves for *Cyperaceae* and *Gramineae* are statistically caused, as their influx is almost unchanged. *Thalictrum,* pioneer plants like *Tofieldia, Plantago maritima* and *Oxyria,* and some *Ericales,* but not *Empetrum,* are the only plants with decreasing influx, but once the decrease is over, their curves, like almost all other curves, remain remarkably constant for about 2½ millennia. On the assumption of no physically conditioned change in the pollen deposition at the coring site in the middle of the lake, the habitats invaded by *Betula nana* and *Juniperus* were formerly covered by plants with little (e.g. *Vaccinium uliginosum*) or no (mosses and lichens) pollen production, and physiognomically the vegetation in the preceding zones may have resembled the "organic crust vegetation" of East Greenland (Raup 1971). *Betula* must have been at least as frequent as today, and the influx of *Juniperus* is ten times as high. Juniper leaf-tips are found in four macrofossil samples, thus indicating a growth very close to the lake.

The oligotrophication of the lake continues. *Potamogeton filiformis* disappears and the fertility of *Myriophyllum spicatum* is decreasing. The apparent discrepancy in the decrease in pollen and increase in number of fragments of the short, broadly pinnate leaves from the basal part of the stem of *Myriophyllum* in zone B and C is explained as follows: the flowering takes place in shallow water at the edge. During zone A suspended clay and the enormous amount of algae prevented sufficient light from penetrating to the bottom which at that time was 6 m below the surface. Concurrently with the decreasing algae production and the disappearance of the clay, sterile plants spread all over the bottom. A strange *Pediastrum* maximum of 1210000 coenobia/ml in sample 22 showed up only in this sample. Four neighbouring samples were prepared, and *Pediastrum* counted, but the number ranged between 45000 and 148000. *Botryococcus* has no maximum in sample 22. *Sparganium,* presumably *S. hyperboreum,* which is growing in the lake today and a fruit of which is found in zone D, immigrates in accordance with its intolerance to rich waters. *Pediastrum duplex* makes up *c.* 10% of the total *Pediastrum.* This species has only been found in this lake.

Of the species new to this zone, *Selaginella selaginoides* and *Lycopodium clavatum* (one spore in sample 11) have the southernmost north limit in West Greenland today, viz. 65°37′ and 65°38′, indicating that in zone C the temperature was like that of today. As no southern species that are absent from the area today have been found, a warmer summer cannot be proved, yet not precluded. But the frequency in *Betula nana, Juniperus, Artemisia* and *Rumex acetosella,* all indicating dry heaths and sun-exposed rocks, point beyond doubt to a more continental climate.

PV zone D: *Alnus-Betula nana-Ledum* zone (150–75 cm)

The start of the zone is defined at a marked increase in *Alnus crispa* and a decrease, not only in percentages but also in influx, in *Betula* and, most markedly, in *Juniperus.* Not only *Empetrum* but also *Artemisia* and *Rumex* decrease while *Ledum* and other *Ericales* increase. The question, previously raised by Iversen (1954), as to whether or not *Alnus* had immigrated earlier, will be discussed later (p. 19). The total pollen influx decreases slightly, mainly a result of a decrease in *Betula,* not compensated for by the increase in *Alnus.*

In the lake, marked changes also occur at the zone border. Alkaliphilous diatoms decrease, acidophilous increase. The fertility of *Myriophyllum spicatum* and *Eupotamogeton* as well as the number of sterile specimen are reduced, as is also the number of *Pediastrum duplex* and, a little later, *P. boryanum* and *integrum/muticum. P. angulosum* has a short-lived maximum at the border, *Myriophyllum alterniflorum* immigrates and *Menyanthes* becomes more frequent.

The climatic implications of the vegetational changes at the zone border are not unambiguous as to temperature, whereas the decrease in *Juniperus* and other dry ground inhabitants combined with the increase in *Alnus,* which preferably grows in copses, in ravines and along streams and rivers, point to a higher precipitation. *Ledum* spp. grow in moist dwarf-shrub heaths with a good snow protection during winter. The decreasing fertility of *Myriophyllum spicatum* and *Potamogeton* is a reflection of the oligotrophication rather than of a fall in temperature. However, the oligotrophication has not passed the boundary at which *Menyanthes* stops flowering, and the more regular flowering of this species calls for another explanation (higher temperature?). *Myriophyllum alterniflorum* emerges at the beginning of the zone. The species is distributed from Kap Farvel to 67° N. Apart from one single fertile collection at the head of Godthåbsfjord it is today only flowering in the interior of South Greenland, all other occurrences being sterile. Its immigration to Greenland seems rather accidental. Thus at Qagssiarssuk (60°09′) it emerged in a pond and a lake, 2–3 km apart, *c.* 7000 and 6000 B.P., growing together with *Myriophyllum spicatum, Potamogeton alpinus* and *P. gramineus,* and it came to a little lake at Kap Farvel *c.* 5000 B.P., but not until 3½millennia later to a tarn only 350 m away (Fredskild 1973). The fairly rich flowering in Johannes Iversen Sø in zone D seems to indicate favourable temperatures, but whether the change in humidity from zone C to D was accompanied by a change in temperature, and if so, in what direction, cannot be deduced from the palaeobotanical evidence.

PV zone E: *Betula nana-Ericales* zone (75–0 cm)

The most conspicuous changes at the boundary are the reduction in *Alnus,* absolutely as well as relatively, and the relative increase in *Betula. Juniperus* at first exhibits a slight decrease, which in the middle of the zone is followed by another decrease. *Empetrum* and *Ledum* increase slightly. In the lake the flowering of *Myriophyllum alterniflorum* and *Menyanthes* is highly reduced. In the middle of the zone a sudden and very pronounced maximum in charcoal marks the Norse landnam *c.* A.D. 1000. Contemporary with this event is a slight decrease in *Juniperus* and a hint of an increase in *Rumex acetosella,* which was introduced to South Greenland by the Norse settlers, but had spread to the Godthåbsfjord area prior to 6000. B.P. Apart from this, no major change in the native vegetation is registered in this lake, *c.* 3 km from the nearest Norse farmstead.

As the *Alnus* decline at the opening of the zone is not followed by an increase in *Juniperus* and other dry soil inhabitants, but rather an increase in the amount of *Ericales* in the *Betula nana* dwarf-shrub heaths, a decreasing temperature is supposed to cause the reduction. This climatic change may well be a combination of a decreasing temperature and a slightly increasing humidity.

Common to both diagrams from this lake and to the one from "Lake 8 m s.m." (Iversen 1954, redrawn and extended in Fredskild 1973) is the flowering of *Myriophyllum alterniflorum* and *Menyanthes* until the middle of zone E and then again in a short period towards the end. *Myriophyllum* is sterile in both lakes today. It is tempting to relate these changes in the flowering to the climatic fluctuations shown in the Greenland Ice Cap by Hammer et al. (1980), supposing this flowering is only dependent on temperature. Parallel changes in the water chemistry seem less plausible. Thus the intervening colder period could have resulted in the recurrence-surface like overgrowing at Itivnera, 10 km from Johannes Iversen Sø, dated at 630 ± 100 B.P. (Fredskild 1973). This period also saw the extinction of the Norse Western Settlement in Godthåbsfjord.

Gytjesø (64°23.5′ N, 50°21.5′ W)

A lake, 57.3 m a.s.l. (average of two hand-level measurements), was cored in 1973. 395.5 cm of limnic gyttja, with leaf fragments of *Myriophyllum spicatum* in the deeper part, overlies marine clay. The diatom analysis shows an oligotrophication, most similar to that of Johannes Iversen Sø, see Foged (1977), also for a description of sediment, vegetation and water chemistry.

Karra (64°46′ N, 50°35′ W)

This *c.* 300 × 140 m lake is situated 265 m a.s.l. (altimeter) at the point between Godthåbsfjord and Ilulialik. To the north and east are steep, 2–300 m rocks, to the west and south are low gneiss ridges. There is a little inlet, but the major part of the drainage water does not pass through the lake, which is 12 m deep at the maximum. The sides within the lake are very steep, locally more than 30°.

The vegetation around the lake consists mainly of *Betula-Ledum groenlandicum*-lichen heaths with some *Salix glauca* and fewer *Empetrum* and *Vaccinium uliginosum*, and of fen-like communities dominated by *Scirpus caespitosus* and with many *Eriophorum angustifolium*. Grasses are few: a few *Hierochloë alpina* and *Trisetum* sp., and also *Calamagrostis langsdorffii* which is only found in the scattered willow copses. A few *Alnus-Salix glauca* copses are found on the slope to the north of the lake, and *Juniperus* is growing espalier-like on the drier part of this slope. But apart from such small, protected habitats with a special flora, the vegetation is generally much more outer coast-like than was expected so close to the head of the fjord. This is caused by the topography which offers no protection against the winds from southwest. Only a few *Isoëtes setacea* and sterile *Sparganium hyperboreum* are growing in the lake, which also holds some *Spongilla*. *Sparganium* is fertile in the outlet stream. pH is 6.7, conductivity 16 μmho.

Corings

The water depth at the coring site was *c.* 5 m. Some tilting was seen in the deeper, laminated layers. Nine cores had contact with the underlying clay or at least with the thin, easily recognizable layers just above the contact, in particular with a one mm thick grey, pure clay layer at 145 cm depth. Layers 2 and 3 vary in thickness. The deepest radiocarbon sample consists of the deeper half, i.e. 3–4½ cm, of layer 3, taken out of seven of the cores. The two following radiocarbon samples are from the same cores, whereas the uppermost is from five cores, beginning at or just below the lake bottom (which could not be seen from the raft). As the coring in 1976 took place during a storm, some inaccuracy in the exact depth of these five cores cannot be excluded. Layers 2 and 3 were thicker in two of the cores. The lower half of the pollen series (samples 1–17, 19) is from one of these, from which also the macrofossil samples from layer 2 and 3 have been analysed separately (Plate 4, Core D).

Sediments

7. 0–122½ cm:	Fine amorphous gyttja, very watery, especially near the top, with a trace of clay and sand. Dark brown, with a slightly brighter band at *c.* 118–109 cm
6. 122½–129:	Like layer 7, but olive in colour
5. 129–136:	Laminated, fine gyttja, olive tones dominating, slightly glossy when cut with a knife
4. 136–145:	Laminated, fine gyttja. The more or less clayey layers are sharply delimited in brownish tones. Glossy when cut, jelly-like
145:	A one mm thick, bright grey, clayey layer
3. 145–154:	Like layer 4, delimited downwards by a one mm thick dark brown gyttja layer, followed by *c.* one cm clay
2. 154–166½:	Alternating layers of thin grey clay and yellowish to olive gyttja
1. 166½–168:	Sticky, grey clay. In some cores this layer is sandy or gravelly clay

Pollen analyses

Pollen types and other microfossils not shown in the diagram are: *Salix herbacea* type, sample 11, *Rhododendron* type 12, 18, *Bartsia/Euphrasia* 14, 35, *Pedicularis* 29, *Phleum* type 32, *Polygonum viviparum* 33, *Ranunculus* 1, *Sagina* 3, *Triglochin palustre* 23, *Viola* 27, *Cystopteris fragilis* ssp. *fragilis* 7, *Assulina* 10, 16, 24, 34, *Tilletia sphagni* 22, 24.

Furthermore the diagram does not show pollen content values less than 15 in columns with a unit of 100, and less than 100 in columns with a unit of 1 000. The very loose, watery nature of the sediment in the topmost

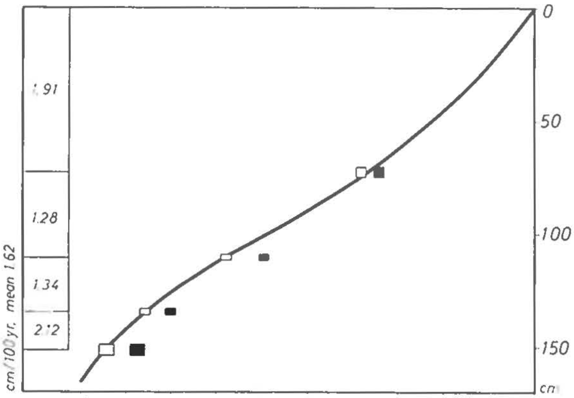

Fig. 6. ^{14}C age versus depth, Karra. Black boxes are ^{14}C dates, open boxes calibrated dates.

30 cm prevented the taking of 1 ml samples and thus the calculation of the pollen content.

Zonation of the diagrams (Plates 4–5)

PV zone A: *Empetrum-Gramineae-Saxifraga-Minartia/ Silene* zone (168–156 cm)

A pioneer vegetation presumably invaded the slopes at a time when some ice still remained on top of the hillocks, causing meltwater carrying large amounts of clay and sand to pass through the lake. Notable are the many remnants of *Empetrum*. Other pioneer plants are: several *Saxifraga* spp., *Oxyria, Chamaenerion latifolium, Minuartia* and/or *Silene acaulis, Tofieldia, Huperzia, Sagina, Carex nardina, C. bigelowii, C. bicolor* (to 71°45′ N) and *Potentilla* sp. Simultaneously with the start of the gyttja sedimentation, the lake is invaded by *Nitella, Potamogeton filiformis* (north to 71° in West, 74° in East Greenland), *Hippuris* and, at the edge, *Ranunculus hyperboreus* and *Subularia*. Generally speaking, the distribution of *Characeae* in Greenland is unknown, only some scattered finds of 2 species of *Chara* and 3 of *Nitella* are recorded, and thus no climatic deduction can be made. But *Lepidurus* was living in the lake.

PV zone B: *Cyperaceae-Empetrum-Oxyria-Loiseleuria* zone (132–156 cm)

The achenes of quite many sedges – at least 11 species of *Carex* – have been found in the macrofossil samples from zones A–C, reflected also in a maximum in *Cyperaceae* pollen. *Oxyria* and many other pioneer plants are still frequent. Part of the fern spores included in the *Dryopteris* type may well be of one or more species of *Woodsia*, as a number of spores, still enclosed in the characteristic sculptured perine, have been found. Without the perine, such spores are indistinguishable from *Dryopteris* spores. Ericaceous dwarf-shrubs are spreading, including *Empetrum, Vaccinium uliginosum* (leaves), *Harrimanella hypnoides* (seed) and *Loiseleuria* and *Phyllodoce* (pollen). The three last mentioned species as well as *Huperzia* point to a climate allowing abundant snowbeds and snow-protected heaths, which, however, did not prevent *Artemisia, Plantago maritima* and *Botrychium* from finding suitable habitats on the slopes. Some big grass pollen have been referred to *Alopecurus alpinus* type. This species has its southern limit today at 67°, but unfortunately the determination of this type, which also includes *Phleum commutatum*, is not fully reliable (Fredskild 1967), and no macrofossil was found. The productivity in the lake is gradually decreasing. *Eupotamogeton* show up in the pollen diagram.

PV zone C: *Cyperaceae-Salix* zone (108–132 cm)

Besides *Cyperaceae*, most pioneer plants are still frequent in this zone, the opening of which is defined by the contemporary immigration of *Salix glauca* and *S. herbacea*. The immigration of *Gymnocarpium* (known today as far north as 68°42′ on the mainland and at hot springs on south Disko) and *Thalictrum*, both species typical of willow copses, indicate that, like today, small copses and herb-slopes may have been found in protected sites surrounded by otherwise outer coast-like, snow- and rain-demanding heaths. The relative maximum in *Alnus* pollen has no corresponding maximum in pollen content/ml. This will be discussed later. The oligotrophication of the lake continues. *Potamogeton filiformis, Hippuris* and *Eupotamogeton* become extinct during this zone, and *Nitella* is severely reduced. The extinction of *Lepidurus* just below, and the immigration of *Cristatella* just above zone border B–C reflect the general temperature increase.

PV zone D: *Betula nana-Juniperus-Lycopodium dubium* zone (108–71 cm)

The explosive spreading of *Betula nana* and above all *Juniperus* reduces *Ericales* and the pioneer plants, at least relatively. However, a calculation of the pollen influx shows slightly higher influx of *Ericales* in zone D than in the preceding zones. *Gramineae* reach the highest influx values of the whole diagram at the zone border C–D. *Lycopodium dubium*, growing in snow-protected heaths and in copses, is more frequent, as is *Diphasium*. Unfortunately it is not possible to separate spores of *D. alpinum* from *D. complanatum*. *Rumex acetosella, Angelica* and *Selaginella* immigrate. Conditions must have been warm and comparably dry. *Potamogeton* spp. and *Hippuris* disappear from the lake, *Isoëtes* and *Cristatella* immigrate.

PV zone E: *Betula nana-Alnus crispa* zone (71–41 cm)

Alnus is spreading, *Juniperus* decreasing and almost all pioneer herbs are gone. The influx of *Ericales* is more than double that of zone D, and *Ledum* has a continuous curve. The percentages of *Alnus* are three times as high as today. Conditions must have been warm and humid. No changes are registered in the lake.

PV zone F: *Betula-Ericales* zone (41–0 cm)

Alnus decreases, and the reduction in *Juniperus*, which began by the end of zone D, is continued. *Betula* and *Ericales* increase, but otherwise no major changes in the pollen spectra are registered. Single pollen of some pioneer plants reappear. In the middle of the zone a short-lived peak in charcoal reflects the Norse period.

The conditions in the lake did not change during six millennia. Presumably the oligotrophication at a certain level was stopped as a result of the yearly meltwater supply which prevented the lake from being totally without macrophytes. Other lakes in the vicinity, but at a higher elevation today have a conductivity as low as 5.1 μmho.

Terte, Lake A (64°28′ N, 51°35′ W)

The lowland peninsula Nordlandet is extremely rich in lakes. Two of these, 12 km NNE of the former settlement Sârdloq, were cored in 1973. Series of pollen and macrofossil samples have been analysed from one of them, Lake A. Foged (1977) has published diatom analyses including a diagram of pH groups and water chemistry from this 250 × 90 m lake, which in his paper is called Sârdlup timâne taserssuaq. It is more than 7 m deep and drains a fairly large area rich in fens and moist dwarf-shrub heaths. The outlet is big enough to allow arctic char to go up into the lake. The elevation is 61 m a.s.l. (hand-level measurement).

The heaths are dominated by *Empetrum*, which is by far the most common plant in the area, having a very wide ecological amplitude ranging from hummocky fens to rock ledges, that in the interior would carry an open vegetation of xerophytes with *Artemisia, Saxifraga paniculata* and *Thymus. Betula nana* is subdominant in the lichen heaths, but covers an area only *c.* ⅓ of that of *Empetrum*. Monocotyledons are frequent: *Hierochloë alpina, Deschampsia flexuosa, Trisetum* spp., *Festuca vivipara, Carex brunnescens, C. bigelowii* and *Calamagrostis langsdorffii*. Neither *Vaccinium uliginosum*, most often sterile, nor the two species of *Ledum* are as frequent as in the interior. *Loiseleuria* is common, preferring windswept ridges, late snow-protected *Salix herbacea* heaths and the edge of snowbeds. *Lycopodium dubium* and *Diphasium alpinum* are frequent.

Fragments of herb-slopes with *Taraxacum, Potentilla crantzii, Sibbaldia procumbens, Veronica alpina* and *Stellaria longipes* are seen in protected places, and a few *Juniperus*, pressed to southward-facing rocks, were observed. *Alnus* does not grow on Nordlandet. The widespread, usually hummocky fens are dominated by *Salix arctophila*, growing on the sides of the hummocks, and by *Scirpus caespitosus, Carex bigelowii* and *Eriophorum angustifolium*, growing between the hummocks. *Isoëtes setacea* and *Sparganium hyperboreum* are found in almost every lake and pond, *Hippuris* and *Ranunculus confervoides* are frequent, *Menyanthes* rare and often sterile. Neither *Potamogeton* nor *Myriophyllum* were observed in any of the many lakes and ponds searched. The vegetation in Lake A is restricted to a shelf in the southern end. *Isoëtes setacea, Hippuris, Ranunculus confervoides* (which was seen flowering under as much as 30 cm of water), and a few *Callitriche hamulata* were observed growing here. *Drepanocladus exannulatus* and *Calliergon sarmentosum* grow at greater depths. pH is 5.6, conductivity 43 µmho. The pH diagram is shown as Fig. 7.

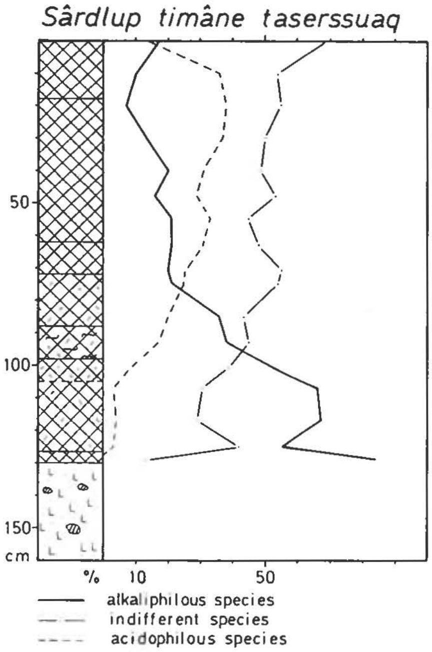

Fig. 7. pH spectra of diatoms, Terte, Lake A (after Foged 1977).

Corings

The lake was cored in 1973 at two depths, viz. at 510 cm water, with 220 cm gyttja overlying clay and sand, and at 325 cm water, with 130 cm gyttja. A comparison between the very characteristic layers just above the base of the gyttja proved these to be identical. The thicker gyttja at greater depth is therefore a result of increasing sedimentation with depth, and not caused by any lacuna at the beginning of the gyttja sedimentation. The following sediments were separated at 325 cm depth:

9. 0–17½ cm:	Bright, greyish-olive, watery, loose, amorphous gyttja. Ld^{0}4, (Ag + As)+, Ga(+)
8. 17½–62:	Darker, more brownish-olive fine gyttja. Ld^{0}4, (Ag + As)+, Ga(+)
7. 62–72:	Like layer 8, but with a greyer tone
6. 72–88:	Fine detritus gyttja with delicate rootlets. Ld^{0}3½, Dg ½, Dh+, (Ag + As)+, Ga(+)
5. 88–98:	Felted, fine detritus gyttja with many mosses and caracasses of *Eurycercus glacialis*. Ld^{0}2½, Dg 1, Tb^{0} ½, (Ag + As)+
4. 98–105:	Detritus gyttja, rich in *Eurycercus* and other Entomostrac remains. Ld^{0}3, Dg 1, (Ag + As)+
3. 105–126½:	Detritus gyttja with *Eurycercus* and other remains, single rootlets(?). Structure firm, easily cut by knife, with glossy surfaces. Ld^{0}3½, Dg ½, (Ag + As)+
2. 126½–130:	Paper-thin, fine detritus gyttja layers of varying colours, jelly-like, glossy. Ld^{0}4, (Ag + As)+
1. 130–160:	Marine clay with sand and small stones

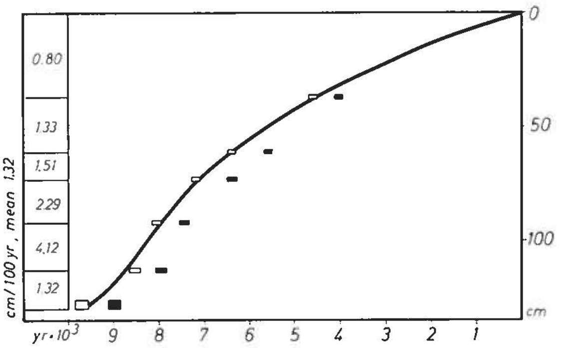

Fig. 8. ^{14}C age versus depth, Terte, Lake A. Black boxes are ^{14}C dates, open boxes calibrated dates.

Pollen analyses

Not shown in the pollen diagram are the following microfossils: *Arnica* in sample 10, *Chamaenerion* 10, 22, *Elymus* 9, 20, *Juncus/Luzula* 6, 16, *Melandrium affine/triflorum* 7, *Polygonum viviparum* 15, *Saxifraga nivalis* type 4, 15, *Viola* 5, *Viscaria* 10, 23, *Cystopteris fragilis* ssp. *fragilis* 5, *Dicranum elongatum* 16, *Tilletia* 12, 18, 20, microscopic wood fragments 2, 3 (4 fragments), 4, 9 (2), 11, 12 (2), 15, 17, 23, 35. Furthermore, a few "Hystrix", indicating outwash of marine sediments, possibly carrying secondary pollen, were found in samples 2, 5, 6, 7, 14, 15. A content of less than 100 pollen per ml is not shown in the diagram.

Zonation of the diagrams (Plates 6–8)

PV zone A: *Cyperaceae-Gramineae* zone (130–115 cm)

Roughly 80% of all pollen are from monocotyledons. Only a few pioneer plants were found, among others *Minuartia groenlandica,* characteristic of gravelly and sandy places on rocks at the outer coast north to 67°. Dwarf-shrub heaths are not as widespread as today judging from the pollen influx. As a result of topography, with no torrents bringing in clay, rebedded pollen are insignificant. *Angelica,* found in two samples, today has its northern limit on Disko, where it is linked to "hot" springs. Otherwise, its northern limit is at 68°. This, together with the occurrence of *Minuartia groenlandica,* points to a temperature not much below that of today. The many *Ranunculus* pollen undoubtedly originate from *Ranunculus confervoides,* growing in the lake, which is very rich, with many *Myriophyllum spicatum* and *Hippuris,* and besides also *Potamogeton filiformis, Eupotamogeton, Subularia* and *Nitella. Lepidurus arcticus* is frequent.

Zone B: *Cyperaceae-Salix-Ericales* zone (115–91 cm)

Salix immigrates and *Ericales,* of which *Empetrum* makes up only half, increase. *Salix herbacea* and *Ledum* have maximum frequencies in this zone. The pioneer plants continue, mainly undisturbed. *Sphagnum* has a short maximum at the beginning of the zone, just like in Johannes Iversen Sø. A pollen of *Viola* sp. in sample 5 is interesting in that the northernmost of the four Greenland *Viola* species, *V. labradorica,* has its northernmost occurrence today at 65°40'. This corroborates the assumption of a temperature like that of today. The number of *Myriophyllum spicatum* and *Nitella* decrease, but the production of *Pediastrum* doubles, and *Potamogeton pusillus* immigrates. A single pollen of *Menyanthes* is found, and towards the end of the zone *Isoëtes* immigrates, contemporaneously with the beginning of a decrease in alkaliphilous and increase in acidophilous diatoms (Fig. 7). *Lepidurus* becomes rarer, occurring for the last time in macrofossil sample no. 7.

PV zone C: *Cyperaceae-Salix* zone (91–69 cm)

Alnus is increasing. The number of pioneer plants diminishes, and many of these disappear for good, judging from the pollen diagram. The first pollen of *Harrimanella/Cassiope* emerges, though a leaf of *Harrimanella* was found in zone A. Several leaves are found in the second half of the zone and the beginning of the following. *Salix glauca* type reaches its maximum in the beginning of the zone, simultaneously with a minimum in *Ericales.* From this time the *Ericales* curve, now mainly made up by *Empetrum,* is slowly but steadily increasing up to the top of the diagram. *Lycopodium dubium* and *Diphasium,* in all probability *D. alpinum,* increase. *Woodsia* is found in most samples. The increase in *Ranunculus* seems connected with an increase in *Ranunculus confervoides* achenes. *Cristatella* immigrates contemporaneously with a species of *Nitella,* having oospores quite different from those in the deeper samples. *Subularia* is frequent. The number of leaf fragments of *Potamogeton pusillus* is diminishing, and accordingly the maximum in *Eupotamogeton* pollen towards the end may be caused by *Potamogeton alpinus,* of which achenes were found in sample 10 and 11. The acidification of the lake continues, and the productivity decreases.

PV zone D: *Betula-Empetrum-Cyperaceae-Juniperus* zone (69–20 cm)

Like in the other diagrams the *Betula* curve increases steeply, indicating that conditions had long been favourable for it. *Juniperus* immigrates as do *Rumex acetosella* and *Coptis. Gymnocarpium,* rare in the area today, is rather frequent in the beginning. *Cyperaceae* gradually decrease, *Empetrum* increases while most other curves show no changes in the terrestric vegetation.

The oligotrophication of the lake continues. *Potamogeton filiformis* has disappeared, and during the zone *Myriophyllum spicatum,* both species of *Nitella, Ranunculus confervoides* (according to the macrofossil diagram) and *Cristatella* also succumb. *Filinia* (a Rotatorie, Müller 1970) emerges.

The changes in the pollen curves hardly permit any conclusion as to a change in climate, as the immigration of *Betula, Juniperus* and *Rumex acetosella* at this time primarily is a function of dispersal efficiency. Nevertheless, compared with zone E, it seems justified to postulate slightly warmer and/or drier conditions in zone D.

PV zone E: *Betula-Empetrum-Cyperaceae* zone (20–0 cm)

The *Juniperus, Betula* and *Alnus* curves are decreasing, *Empetrum* and *Diphasium* increasing. If the recent pollen sample is representative for the monotonous vegetation many kilometres around the lake, then *Betula* is roughly 5–8 times overrepresented in relation to *Empetrum*, according to the estimate of their area cover made in the field (1:3). Based on investigations of area cover compared with recent pollen spectra in inner Godthåbsfjord, Iversen (1947) found *Betula* to be three times overrepresented, *Ericaceae* five times underrepresented. As *Empetrum*, the only anemophilous species among *Ericales*, is more common on Nordlandet, the result is in agreement with Iversen's statement. Almost no macrofossils are found, and the sediment mostly reminds one of precipitated humus, which is confirmed by the decreasing $\delta\ ^{13}$C.

Terte, Lake B (64°27.5′ N, 51°35′ W)

A tiny, shallow lake, 100 × 50 m, 51 m a.s.l. (handlevel), is situated 0.6 km south of Lake A. The term lake is used in accordance with Røen (1962) to characterize a water body, regardless of size, that does not freeze solid, contrary to a pond. The greatest water depth is 175 cm in the middle, and here 241½ cm gyttja overlies marine clay. *Isoëtes setacea* and sterile *Sparganium hyperboreum* grow in the lake, and *Spongilla* is frequent on the bottom. pH is 5.8, conductivity 46 μmho. During the taking of subsamples from the cores, the following macrofossils were observed: *Cristatella* statoblasts, *Myriophyllum spicatum, Potamogeton pusillus, Lepidurus, Gasterosteus, Daphnia pulex, Juncus, Nitella.* Foged (1977) has determined the diatoms in a series of samples from this lake (under the name of Kigssaviat taserssua) and published a pH-diagram as well as water analyses. A sample from 235½–241½ cm has been radiocarbon dated to 8080 ± 130 B.P., indicating an initial uplift rate of 10 m in *c.* 900 years (cf. the isolation of Lake A).

Sârdlup qáqâ (64°24′ N, 51°41′ W)

A tarn, 300 × 40–50 m, 3 km north of Sârdloq, at an altitude of *c.* 140 m (altimeter), was cored in 1976. It is situated in a very rugged landscape with polished gneiss rocks. The vegetation has a much more outer coast character than that at Terte, with *Empetrum*-lichen heaths everywhere, and with many *Salix herbacea-Harrimanella* snowbeds with *Loiseleuria. Betula nana, Ledum groenlandicum* and *Vaccinium uliginosum* are few, but *Huperzia, Phyllodoce, Carex bigelowii* and *Luzula confusa* are frequent. To the west of the tarn is a snowbed, which at the end of August still stretches almost to the edge of the water. In the northeast corner is a tiny herb-slope with *Hieracium, Alchemilla alpina, Pyrola minor, Gnaphalium norvegicum, Sibbaldia* and *Gymnocarpium,* surrounded by a small *Salix glauca* copse. On steep, dry rocks *Thymus, Potentilla tridentata, Campanula gieseckiana, Saxifraga paniculata, Minuartia rubella, Viscaria, Woodsia ilvensis,* etc. are growing, and a few m^2 are covered by *Juniperus.* A *Carex rariflora-Eriophorum angustifolium-E. scheuchzeri* fen with *Carex saxatilis, Salix arctophila* and *Drepanocladus exannulatus* covers the continuation of the little valley, and here is the outlet. *Isoëtes setacea, Callitriche hamulata* and sterile *Sparganium hyperboreum* are growing in the lake, and in a little pond, formed by the outlet, are many *Hippuris.* pH in the lake is 6.0, conductivity 40 μmho.

Corings

The tarn is very deep, with steep underwater slopes, but at the outlet-end a shelf could be cored. At a depth of 265 cm the following layers were separated:

10. 0–80 cm	Fine, amorphous, watery gyttja. Bright brown from 80–65 cm, looser structure and a greyish tone 65–50 cm, dark brown to the lake bottom, structure loose, gritty. The uppermost 20 cm so liquid that one ml samples could not be taken without a syringe, which was not at hand
9. 80–132:	Brown, watery gyttja with a few rootlets(?). At 101 cm a bright, 1 cm layer, seen in all cores. In most cores tiny fragments of twigs were found at *c.* 95 cm
8. 132–135:	Very dark brown gyttja
7. 135–141½:	Laminated gyttja, mainly dark brown tones, slightly clayey
6. 141½–158:	Laminated gyttja and clay gyttja, with varying content of mosses and clay
5. 158–173½:	Laminated, bright brown clay gyttja, with thin, pure clay layers, and sometimes mosses, slightly sandy
4. 173½–175½:	Sandy clay-gyttja, rich in mosses
3. 175½–178:	Clay with some gyttja and a few mosses, sandy
2. 178–180:	Sandy clay with many mosses
1. 180–186:	Sandy clay

The deepest radiocarbon dating was done on *Drepanocladus exannulatus* washed out of layer 2 in 26 cores. The $\delta\ ^{13}$C measurement (–23.9‰) falls in the general range of terrestrial plants, thus indicating that the moss had been washed out from the shore. Another

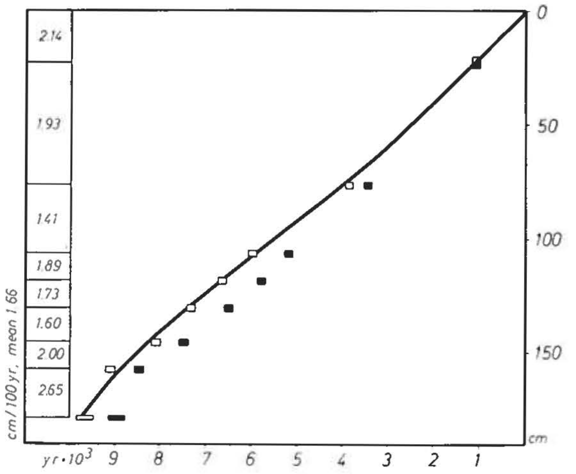

Fig. 9. ^{14}C age versus depth, Sårdlup qáqâ. Black boxes are ^{14}C dates, open boxes calibrated dates.

explanation would be that the basin at that time was filled with dead ice, covered by till (the sandy clay, layer 1) and that the lake began as a marsh or a pond in which the moss was exposed to the air, similar to the ice-block depression described by Wright (1980). However, most measurements of $\delta\ ^{13}C$ of aquatics have been carried out on plants like *Potamogeton, Myriophyllum, Chara* and *Nitella,* not on mosses, which only utilise dissolved atmospheric CO_2. Further, most measurements have been on plants in the temperate zone, and Stuiver (1975) suggests decreasing ^{13}C content with higher latitude. This may be supported by the value of –21.0‰ on a sample of submerged *Drepanocladus exannulatus,* picked up from holes in the ice of a pond near Baird Inlet, Ellesmere Island (Blake 1981). He also claims that the basal moss layer in the coring on Pim Island, northeast of Baird Inlet, exhibiting a deficit of –30.8‰, was not washed out but had been growing submerged. This is also supposed to be the case with the basal moss in Sârdlup qáqâ lake. The uncertainty as to the $\delta\ ^{13}C$ range for submerged plants is also stressed by Olsson & Osadebe (1974) in that their "range blocks" for freshwater plants, stretching from –8 to –24‰, are left open above and below.

Pollen diagrams (Plates 9–11)

Besides the microfossils shown in the diagrams, the following were found: *Cerastium* cf. *cerastoides* in sample 5, *Chamaenerion/Epilobium* 28, 38, *Coptis* 41, *Diapensia* 38, 40 (2 grains), *Galium* 8, *Plantago maritima* 5, *Polygonum viviparum* 24, 32, 44, *Potentilla crantzii* type 18, *Cystoperis fragilis* ssp. *dickieana* 34, *Woodsia* 45, *Microthyrium* 19 (3). Samples 42–46 have not been counted absolutely. *Alopecurus alpinus* type also includes *Phleum commutatum*. *Vaccinium uliginosum* type has been included in the curve: *Ericales* excl. *Empetrum*. A calculated pollen content less than 30/ml is not marked in the diagram for species with an abscissa unit of 100. The corresponding threshold numbers with units of 1 000 and 2 000 are 100 and 250 respectively.

Zonation of the pollen diagrams

PV zone A: *Oxyria-Minuartia rubella-Silene acaulis* zone (180–167 cm)

Pioneer plants are dominating: *Oxyria, Minuartia rubella, Silene acaulis, Sagina, Saxifraga* spp., *Koenigia, Sedum, Carex bigelowii, C. rufina* and other Carices, *Gramineae,* and also some *Ericales* form part of the vegetation: *Empetrum, Loiseleuria* and presumably *Harrimanella* (one pollen of the type in sample 3, leaves of the species in zone B). The productivity in the water is great, with a maximum sedimentation of 10000 *Pediastrum boryanum*/cm²/yr. *Hippuris, Eupotamogeton, Nitella* and *Ranunculus confervoides* are growing at the edge of the lake, and a rich animal life is indicated by the numerous fragments of *Tricoptera, Lepidurus, Daphnia pulex* and *Simocephalus vetulus.* Of the plants determined *Carex rufina* is the species, which today has the southernmost north limit, viz. c. 70°.

PV zone B: *Cyperaceae-Gramineae-Oxyria-Ericales* zone (167–155 cm)

The first pioneer phase, lasting 2–300 years, passed on to another pioneer phase, in which *Cyperaceae* and *Ericales,* first *Empetrum* and *Loiseleuria,* later on *Phyllodoce, Ledum* and *Harrimanella,* gradually conquered some of the ground on which the species of low competitive power had first settled. The lake is still rich. The *Eupotamogeton* pollen most likely come from *P. pusillus. Subularia* is only registered by means of pollen.

PV zone C: *Cyperaceae-Salix-Ericales* zone (155–131 cm)

With the opening of this zone a number of species immigrate: *Salix glauca, S. herbacea* (and *S. arctophila*?), *Angelica, Artemisia, Thalictrum, Gymnocarpium, Lycopodium dubium* and *Galium* sp., and a little later *Botrychium.* The curves for *Alnus* and *Diphasium* increase. The curve for *Ericales* decreases, but the influx is about the same as in zone B.

A single pollen of *Myriophyllum spicatum* was found in sample 14, but from that time the productivity of the lake is appreciably reduced, parallelling the diminishing outwash of clay and thereby the supply of ions. An *Eupotamogeton,* presumably *P. pusillus* judging from the many leaf fragments, easily recognizable because of the venation and the mucronate tip, flowers frequently at the start of the zone but more sporadically upwards. *Isoëtes* immigrates and *Sparganium* is spreading, all signs of a progressing oligotrophication and acidification.

The immigration, or rather the emergence, of the first pollen of several species in one and the same sample, in this case no. 8, may well be fortuitous, as strict contemporaneity like this is not observed in any other diagram, or it may be a reflection of the very local conditions, as this lake is the smallest one investigated. Beyond doubt the temperature was increasing, but the many *Salix herbacea, Phyllodoce, Huperzia* and *Ledum* point to a heavy snow-cover. It has not been possible to determine the many *Draba* seeds to species. *D. lactea, glabella, norvegica* and *aurea* have seeds resembling the subfossil. While in the other three lakes the immigration of *Salix* is contemporaneous with the extinction of *Lepidurus*, this Entomostrac survived here until after the middle of the zone, thus supporting the picture of cool, local conditions. Correspondingly, the immigration of *Cristatella* is postponed.

PV zone D: *Cyperaceae-Betula nana-Ericales-Juniperus* zone (131–80 cm)

Betula immigrates, but when the overrepresentation of *Betula* pollen is taken into account, it can be seen that *Betula* can never have played any conspicuous role in the vegetation cover, and the same applies to *Rumex acetosella,* which also appears now. After a short while, nearly all the pollen curves attain levels which remain almost unchanged during the coming 6000 radiocarbon years, while a few curves gradually decrease a little, such as *Cyperaceae* and *Alnus,* or increase, such as *Empetrum.*

Isoëtes, Sparganium, presumably *S. hyperboreum,* and sterile *Potamogeton pusillus* are the dominating phanerogams in the lake, and *Drepanocladus exannulatus* is supposed to have been growing on the lake bottom like today. The animal life seems reduced, at least as regards species with resistant caracasses. An interesting detail is seen in the larval houses af *Apatania zonella.* In the deeper layers the larvae used sand grains in building up their houses, but with the filling-in of the basin with gyttja and overgrowth by fen vegetation at the edge where this is not solid rock, the accessibility of sand is minimized. The larvae therefore had to use fragments of *Cristatella* statoblasts, of seeds and fruits and of wood and similar firm material, being itinerant macrofossil samples.

PV zone E: *Cyperaceae-Empetrum-Betula nana* zone (80–0 cm)

The separation of an upper zone is rather artificial and not well-founded, and it is based mainly on the slight decrease in *Juniperus, Rumex acetosella, Rhododendron, Loiseleuria, Alopecurus alpinus/Phleum commutatum,* and the increase in *Diphasium* (supposedly *D. alpinum*) and *Empetrum.* In the lake *Cristatella* becomes extinct, possibly as a response to decreasing temperature. The drastic decrease in the number of macrofossils per volume and the change in sediment must be ascribed to changes in sedimentation at the coring site, possibly connected with a shift towards the centre of the lake in the position of the edge of the shelf. If the coring site lies at the position of the foot of the shelf slope during zone A–D, macrofossils would have had a tendency to accumulate here. The shape and the depth from surface of the shelf-slope transition in an arctic lake depends on the thickness of the winter ice. A thicker ice floe eroding the shelf during spring may well cause an outward displacement of the edge of the slope. Be this as it may, the development in the vegetation points to a gradual cooling and a greater snow-cover. From around 50 cm below the bottom, minor but important changes in the pollen spectra can be seen. *Cassiope/Harrimanella* pollen, represented by only two grains in the preceding 10 samples, now occur constantly, *Diphasium* increases, *Alnus* and *Lycopodium dubium* decrease. These may be reflections of a gradual climatic change, which slowly alters the vegetation towards that of today's outer coast, dominated by *Empetrum* dwarf-shrub heaths.

The vegetational development in the Godthåbsfjord area and a comparison with other parts of Greenland

Terrestric vegetation

In spite of the differences caused by local topography, the diagrams show that the vegetation at the lakes investigated has passed through similar stages, especially in the first period after deglaciation: a pioneer stage, an *Ericales* stage, a *Salix-Cyperaceae* stage, a *Betula-Juniperus* stage, an *Alnus-Betula* stage in the interior, and a *Betula-Empetrum* stage. Apart from the pioneer stage, the differentiation between the outer coast and the interior is reflected through all the diagrams. For many reasons a strict contemporaneity between the phases is hardly to be expected, and would also be difficult to prove because of uncertainties connected with the dates, which are based on material from many cores of which only one has been pollen-analysed, and on material which often contains terrestric, older humus, washed out into the lake. Fig. 10 gives a survey of the zones, with the ^{14}C ages based on a best-fit curve for each lake. In addition the average pollen influx is given for each zone.

The pioneer stage (*c.* 9400–*c.* 8000 ^{14}C years B.P.)

The fresh, very unstable, minerogenous soil, still with permanent snow-drifts and dead-ice lumps, was invaded by the widespread, ubiquitous arctic pioneer plants which undoubtedly survived the glaciation on nunataks and other unglaciated areas. Two of the lakes were not isolated from the fjord and because of this do not register the beginning of this stage. The following species or genera have been proved:

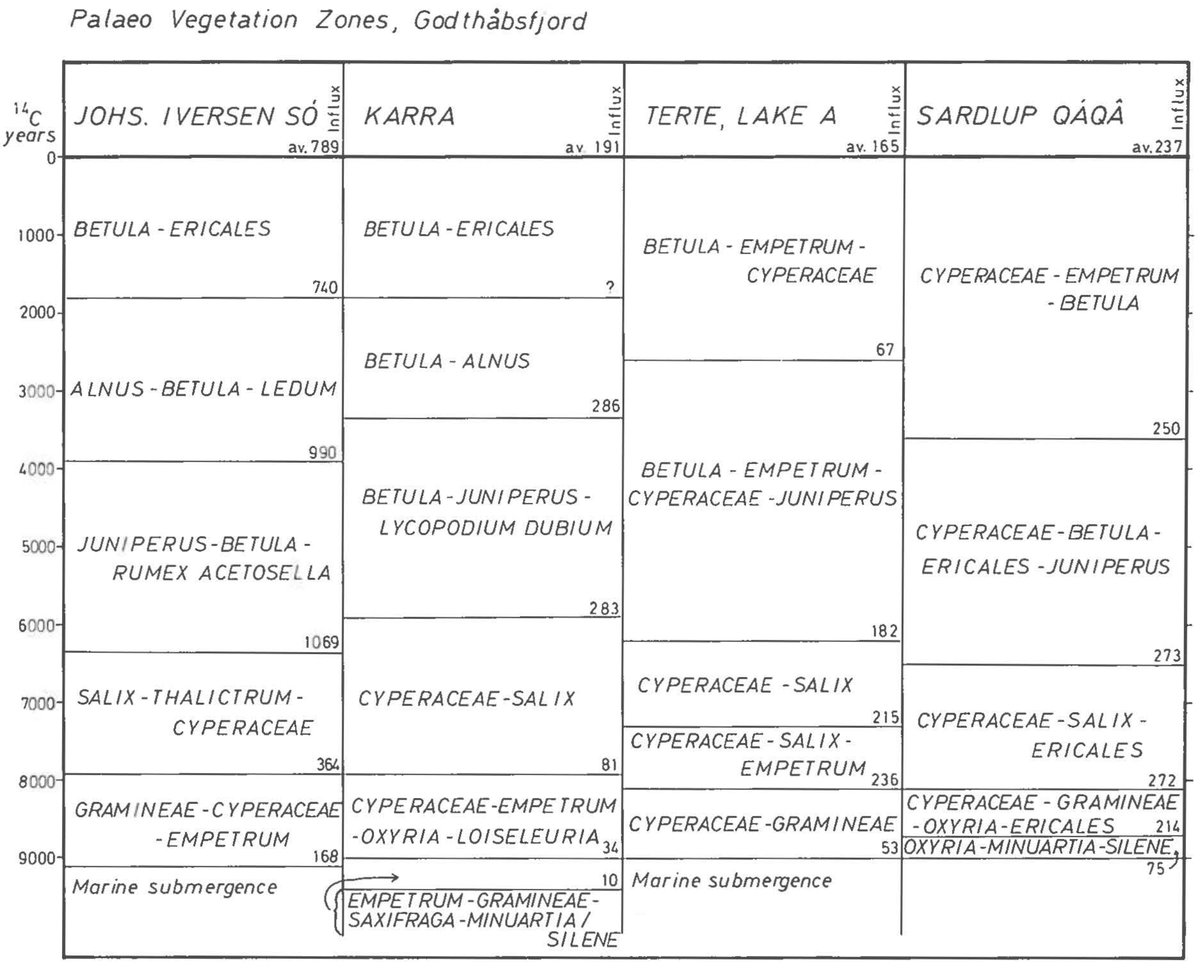

Fig. 10. Palaeovegetation zones of the Godthåbsfjord area. The pollen influx is given for each zone as well as the Holocene mean for each lake.

Plants on open soil, frost-boils, outwash plains, etc.:
Saxifraga nivalis type, *S. oppositifolia* t., *S. caespitosa* t., *Koenigia islandica*, *Sagina*, *Stellaria longipes* t., *Minuartia rubella*, *M. groenlandica*, *Silene acaulis*, *Cerastium-Stellaria* t., *Oxyria digyna*, *Plantago maritima*, *Tofieldia*, *Sedum* (incl. *Rhodiola*), *Phippsia algida*, *Juncus biglumis*/*triglumis*, *Carex capillaris*, *Chamaenerion latifolium*.

Plants at seashore or on moist, ion-rich, minerogenous soil:
Carex ursina, *C. bicolor*, *C. glareosa*, *Juncus ranarius*, *J. arcticus*, *Stellaria humifusa*, *Elymus mollis*.

Plants on rocks, screes, fell-fields:
Poa glauca, *Botrychium*, *Gymnocarpium*, *Woodsia*, *Cystopteris fragilis* ssp. *fragilis* and ssp. *dickieana*, *Dryopteris* t., *Campanula*, *Melandrium*, *Carex nardina*, *Erigeron*/*Gnaphalium*, *Taraxacum*/*Hieracium*, *Artemisia* (single grains may be long distance transported).

Plants on lake shores:
Carex rufina, *Limosella aquatica*, *Subularia aquatica*.

Plants from fen-like communities:
Carex saxatilis, *C.* cf. *canescens*, *Equisetum*, *Galium brandegei*.

Plants in snowbeds:
Harrimanella hypnoides, *Carex lachenalii*.

Heath plants:
Empetrum hermaphroditum, *Loiseleuria procumbens*, *Ledum*, *Phyllodoce coerulea*, *Rhododendron* t., *Vaccinium uliginosum*, *Diphasium* (presumably *D. alpinum*), *Huperzia selago*, *Dryas*, *Carex bigelowii*, *C. norvegica*, *C. arctogena*, *Poa pratensis*/*arctica*.

Other plants:
Angelica, which today is most frequent in herb-slopes, in moist willow copses and at springs, can also be

met with in moist screes, along brooklets and in stony riverbeds. Finally some genera with many species like *Potentilla, Luzula* and *Festuca.*

When soil conditions were more stabilized, the ericaceous dwarf-shrubs spread. Some of the species (*Loiseleuria, Ledum* and *Harrimanella*) are not represented until pollen sample 2 or 3, but this most likely is caused by the low content of pollen in these first samples. *Empetrum* seeds are the most common macrofossil in the deepest samples in all lakes, presumably because their wall is very thick and resistent compared with the minute, delicate seeds of the *Ericaceae,* but the pollen curves reveal that the anemophilous *Empetrum* on average only makes up half of the pollen of Ericales. This overall picture of the earliest vegetation is in accordance with that from Frederikshåb district, 2–300 km further south in West Greenland (Kelly & Funder 1974) and South Greenland (Fredskild 1973), besides in East Greenland (Funder 1978, Björck & Persson 1981) and unpublished diagrams from Northwest Greenland. The open soil pioneer vegetation can be found everywhere in Greenland on fresh, unstable soil, but on the basis of indices of some of the other plants proved, the climate is thought to be like that of today a few degrees further north, with the same difference between the maritime outer coast and the more continental interior.

The *Salix-Cyperaceae* stage (*c.* 8000–*c.* 6300 B.P.)

The immigration of *Salix,* both *S. glauca* and *S. herbacea* (nothing is known of the immigration of *S. arctophila*) has little influence on the vegetational development. No doubt *S. glauca* first and foremost entered the dwarf-shrub heaths, which at the beginning of the stage are still dominated by *Ericaceae* over *Empetrum,* and *Salix herbacea* entered the snow-patches and snow-protected heaths. There is a time lag in the spreading of *Salix,* since both species arrived at Frederikshåb *c.* 9000 B. P., in the interior of South Greenland *c.* 8000 B.P. and possibly a little earlier at Kap Farvel, the southernmost tip of Greenland. Alone, the emergence of *Salix* does not indicate a climatic change, and no unambiguous climate indicator species immigrates during this stage. But towards the end the decrease in the ratio *Ericaceae*/*Empetrum* and in open soil pioneer plants indicate less snow to cover the heaths and to cause unstable soil. Furthermore, the extinction of *Lepidurus arcticus* in the lakes between 8000 and 7500 B.P. points to an increase in temperature.

The *Alnus* curve increases in all diagrams, reaching a first maximum in the upper half of the zone, which supports the assumption of an early immigration. However, a closer study of the material from West and South Greenland tends to blur the picture. The problem has been discussed in detail by Fredskild (1973: 198), who argued that the *Alnus* maximum 7000–4000 B.P. was caused by long distance pollen, and by Kelly & Funder (1974: 14), who showed that "The values for the mid postglacial period of high *Alnus* frequencies at Frederikshåb and south Greenland although usually much higher than the surface values, are still within the same order of magnitude range and are therefore neither too large to be exotic nor too small to represent local scattered communities". They conclude that "although the exotic pollen hypothesis is attractive there does not seem to be any firm evidence yet to preclude the possibility of the growth of *Alnus* copses in the Frederikshåb area, with the sharp rise of *Alnus* pollen at *c.* 7600 B.P. marking the immigration of the species into the area". (loc. cit.: 16).

Fig. 11 shows the pollen frequency, mostly in terms of influx, in each pollen sample in 12 diagrams, viz. from the left: three from the outer coast area at Kap Farvel (Isoëtes Sø, Kløftsø, Spongilla Sø), two from the sub-

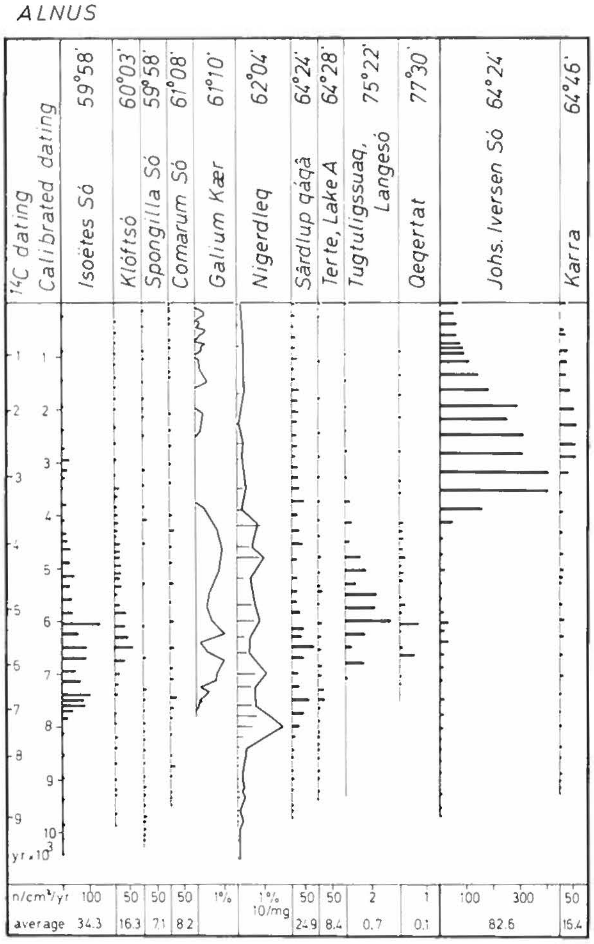

Fig. 11. *Alnus* pollen frequencies in West Greenland lake sediments: influx (bars), percentages (curves) or number per mg (lines). Note change in unit. The ten lakes to the left are outside today's distribution area of *Alnus crispa* and the two lakes to the right are inside.

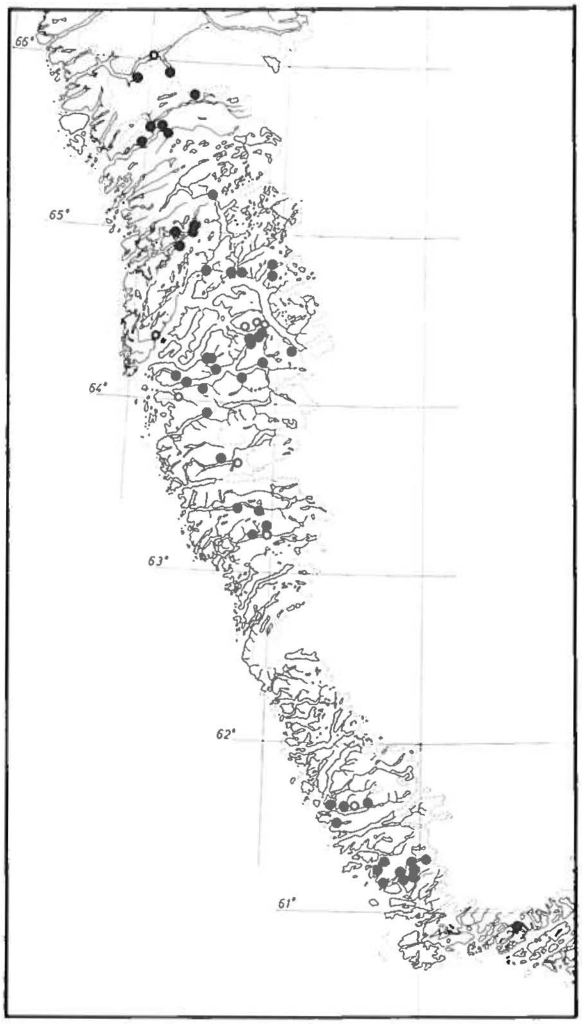

Fig. 12. The total Greenland distribution of *Alnus crispa*. Dot: herbarium collection; circle: literature reference.

arctic interior of South Greenland (Comarum Sø, Galium Kær), one from Frederikshåb area (Nigerdleq, redrawn from Kelly & Funder 1974), two from Nordlandet (this paper), two from NW Greenland (Tugtuligssuaq and Qeqertat, B. Fredskild unpublished) and finally the two diagrams from the area at the head of Godthåbsfjord where Alnus is growing today (Fig. 12).

From the beginning all but the two northernmost diagrams show a "tail" of low *Alnus* influx. Then *Alnus* increases between 7600 and 7000 B.P. by a factor of 5–20 in the lakes at 62°–64° N, and at around 7000 B.P. by a similar factor in the lakes at 60°–61°. The six deepest samples in the Langesø diagram have no *Alnus* pollen ($\Sigma P = 885$), but shortly before 6000 B. P. *Alnus* emerges, and in the coming two millennia an influx of 1.5, corresponding to 4–13% of the total pollen (excluding non Greenland taxa), is registered. Between 4000 and 3000 B.P. a decrease in *Alnus* is seen in most diagrams outside today's *Alnus* area, whereas the two lakes within this area show an increase, most pronounced in Johannes Iversen Sø.

As for *Alnus* influx outside and inside the present *Alnus* area, there is a large overlap in West and South Greenland records, as appears from Table 3, with 1–15(20) outside against 1–78 inside. Corresponding percentages are 0–6.5 and 2–20%. Two Tauber traps placed in the interior of South Greenland for one summer showed *Alnus* percentages of 1.2 and 1.6%, with an influx of 5.0 and 5.5%. *Alnus* is a prolific pollen producer, but obviously the growth of a few scrubs can not be proved in the lake sediments, as shown in the Neria diagram (Kelly & Funder 1974). This is a parallel to *Betula nana* in Northeast Greenland, where Björck & Persson (1981) found no *Betula* pollen at all in a recent sample in a lake with small, scattered dwarf birch stands of *Betula nana* fairly close to the lake.

Alnus immigrated to the south of Labrador *c.* 9000 B.P., the influx increasing to maximum values at around 6000 B.P. at Whitneys Gulch, Quebec, and Eagle Lake, Labrador (Lamb 1980). About 7200 B.P. alder thickets spread along the coast at Hamilton inlet, Southeast Labrador, and from there towards the interior in the following centuries, with *Alnus* peaks of 50 to 90% between 6500 and 6000 B.P. By *c.* 6000 B.P. a

Table 3. Alnus pollen frequencies in recent Greenland samples.

Recent gyttja samples	Percentages			Influx		
	n	av.	range	n	av.	range
Outside *Alnus* area						
S Greenland, outer coast	21	1.52	0.18–5.8	3	7.7$^+$	4.9–12
S Greenland, interior	6	0.51	0–1.1	3	7.5$^+$	2.6–13
SW Greenland	3		*c.* 1–4	2		1.1–3.8
W Greenland, outer coast	2		5.9–6.5	2		4.1$^+$–*c.* 15–20*
Within *Alnus* area						
SW Greenland	1	*c.* 2		1	0.9	
W Greenland, interior	6	12.5	7.4–20	2		*c.* 15–20*–78$^+$

$^+$ Average of recent PV zone, * extrapolated.

birch-fir community immigrated to western Lake Melville and spread eastwards, reaching almost to the coast by 5500 B.P. (Jordan 1975). Alder thickets remained along the coast until the present day. Further north in Labrador, a similar vegetational succession is registered at many sites with metachronous *Alnus* peaks, the latest being registered in the interior *c.* 5600 B.P. Here *Alnus* pollen makes up 75% of all pollen (average of seven diagrams, Morrison 1970). At most sites the shrub tundra sooner or later gave way to open spruce woodland. Short & Nichols (1977) date this event to be between *c.* 4500 and 4200 B.P. West of Ungava Bay the initially rich herb tundra was metachronously replaced by a dense shrub tundra with abundant *Alnus crispa* and *Betula glandulosa* during the two millennia after 6200 B.P. (Richard 1981). A climatic deterioration around 3500 B.P. caused an almost synchronous decline in *Alnus* pollen and a replacement of the vegetation by the present day poor tundra type.

The influx of *Alnus* pollen to sites far north of its present area has repeatedly been proved, recently for example by Nichols et al. (1978), and Andrews & Nichols (1981), and the importance of alder thickets in Labrador between *c.* 7200 and 4200 B.P. seems mirrored in the South and West Greenland diagrams. As to the immigration of *Alnus* to Greenland, my conclusion, using the phraseology of Kelly & Funder (1974), is that although the hypothesis of an early immigration is attractive, there does not seem to be any firm evidence yet to preclude that the immigration of *Alnus crispa* to West Greenland did not take place until *c.* 3500 B.P. If the hypothesis of an early immigration is maintained, it must be carefully considered why the highest percentages and influxes outside the *Alnus* area, both past and present, are found in those lakes, the surroundings of which seem most inhospitable to *Alnus,* and around which the plant definitely does not grow today. Incidentally, these lakes also show the highest percentages and influxes of other long distance pollen (Fredskild in print).

The *Betula nana-Juniperus* stage (*c.* 6300–3500 B.P.)

As long as the opening of a stage is characterized by a species with an effective dispersal capacity, only a very small time lag is expected within a limited area, as is shown by the almost identical dating of the *Betula nana* immigration in the Godthåbsfjord area to around 6300 B.P. But when it comes to a reduction of an already established population of a certain species as a result of climatic change and possibly also competition, metachroneity must be expected. This stage, with its maximum in *Juniperus* and *Rumex acetosella,* is considered the warmest and driest in this part of Greenland.

The *Alnus crispa-Betula nana* stage in the interior and the first part of the *Empetrum-Cyperaceae-Betula nana* stage at the outer coast (*c.* 3500–1800 B.P.)

There seems to be a time lag of about half a millennium in the immigration of *Alnus* to the two lakes in the interior (*c.* 4000 B.P. in Johannes Iversen Sø, *c.* 3400 B.P. in Karra), and also a similar time lag in the signs of a greater humidity, as reflected in the decrease in *Juniperus* and *Rumex acetosella* and in the increase in *Ledum.* The ^{14}C dating of the Norse landnam in Johannes Iversen Sø is *c.* 300 years too old, and as the deficit in ^{13}C in this radiocarbon sample is similar to that in the one, dating the *Alnus* spreading, it can be concluded that this event and the contemporaneous climatic change to more humid, but still warm conditions happened at or shortly before 3500 B.P. On Nordlandet a not too well marked vegetational change is detected around 3600 B.P. at Sârdlup qáqâ, on the basis of an increase in *Diphasium,* whereas in Lake A the decrease of *Juniperus* and *Rumex acetosella* is entirely gradual. However, an increase in *Diphasium* and *Ledum* may also be traced here at the middle of the millennium.

The *Betula nana-Ericales* stage in the interior and the second part of the *Empetrum-Cyperaceae-Betula nana* stage at the outer coast (*c.* 1800–0 B.P.)

In the interior, an *Alnus* decrease and an increase in *Betula* and *Ericales* are interpreted as reflecting a change towards cooler and presumably also more humid conditions, with *Betula nana* dominating the dwarf-shrub heaths. On the other hand the change to more humid conditions at the outer coast is disadvantageous to *Betula,* and here *Ericales, Cyperaceae* and snowbed plants profit by the change. In the Sârdlup diagram, minor changes, for example an increase in *Harrimanella/Cassiope,* indicate that cooler, more humid conditions set in around 2500–2000 B.P. But it must be admitted that lake diagrams are not as useful in registering climatic changes as are peat profiles. In the Godthåbsfjord area, peat growth formation started under a dwarf-shrub heath on a raised beach at Itivnera at *c.* 3200 B.P. (Fredskild 1973), and *c.* 630 B.P. this peat changed to a peat formed under a moist, fen-like community.

Climatic changes

The inferred climatic changes can be summarized as follows: The temperature rose from 9000 B.P. onwards and between 8000 and 7500 B.P. reached today's values. It increased during the following millennia, which saw the warmest and driest time spell, but at what time the temperature curve peaked cannot be deduced on the basis of lake diagrams. It may have been fairly late. A more moist, but still fairly warm period is registered in the interior from *c.* 3900 B.P. (or some centuries later, if the ^{14}C dates in Johannes Iversen Sø are too old). From *c.* 1800 B.P. conditions become more humid and cool. Minor fluctuations in the coming period can be traced in the changes in peat formation at Itivnera, and maybe also in the flowering/non-flowering of *Myriophyllum alterniflorum* in the lakes. On Nordlandet more moist and presumably also cold conditions set in *c.* 3600 B.P., followed by a new deterioration between 2500 and 2000 B.P.

These climatic events show an overall similarity with the Holocene climatic history of the low and subarctic Greenland (Fredskild 1973, and in print) and Canada (Ritchie & Hare 1971, Nichols 1975, Jordan 1975, Andrews & Nichols 1981, Richard 1981, Macpherson 1982), where a marked temperature decline is registered 4000–3500 B.P. and another one around 2000 B.P. In discussing the Neoglacial history of West Greenland Kelly (1980) concludes that glacierisation began to increase about 3500–3000 B.P. Although there is evidence of severer climate around 2000 B.P. the glacierisation did not reach its maximum until another phase after 1000 B.P. This is in accordance with the results obtained from the Camp Century core (Dansgaard et al. 1973), showing a prolonged duration of a climatic optimum from 8000–3500 B.P. followed by two early Neoglacial cold intervals 3500–3000 and 2800–2400 B.P.) and a complex one in the late Neoglacial.

The vegetational and climatic history of East Greenland is different. Here the temperature was higher than today's already by 8400 B.P., and the Hypsithermal, characterized in the Scoresby Sund area by "rich" *Betula nana* heaths and subarctic, marine invertebrates, lasted until some time between 6000 and 5000 B.P. Since then, "poor", high arctic *Salix arctica-Cassiope tetragona* heaths covered the outer coast and part of the interior (Funder 1978). Corresponding trends have been shown further north on Hochstetter Forland by Björck & Persson (1981), thus linking the Holocene development to that of Northwest Europe.

Palaeolimnology

Between 8500 and 8000 B.P. the climatic amelioration appears to have passed the threshold for all macrophytes found, and two species only, *Isoëtes setacea* and *Myriophyllum alterniflorum,* had not emerged. Apart from the latter, the flowering of which may be related to temperature (p. 10), it seems likely to relate the succession, the flourishing, and in many cases eventually the extinction, of the limnic organisms to the trophic state of the lake. Every lake cored so far in South and West Greenland runs through a succession of stages, starting fairly eutrophic, passing through a mesotrophic stage and ending in an oligotrophic stage. As to the macrophytes this is illustrated in Fig. 13, which is a parallel to the diagrams from South Greenland (Fredskild 1973, 1977). Species preferring lakes with high conductivity, like *Myriophyllum spicatum, Potamogeton filiformis,* and *Charophytes* (Fig. 14), serve as pioneer plants in the ion-rich lakes which are still supplied with clay and ions washed out from the surroundings not yet covered by a humus-accumulating vegetation. The primary production in this initial stage is very high, with deposition of up to 50000 *Pediastrum boryanum* coenobia per cm² per year in a rich lake (and 1500 in a poor). The *Botryococcus* curves are often parallel to the *Pediastrum boryanum* curves. *Pediastrum*

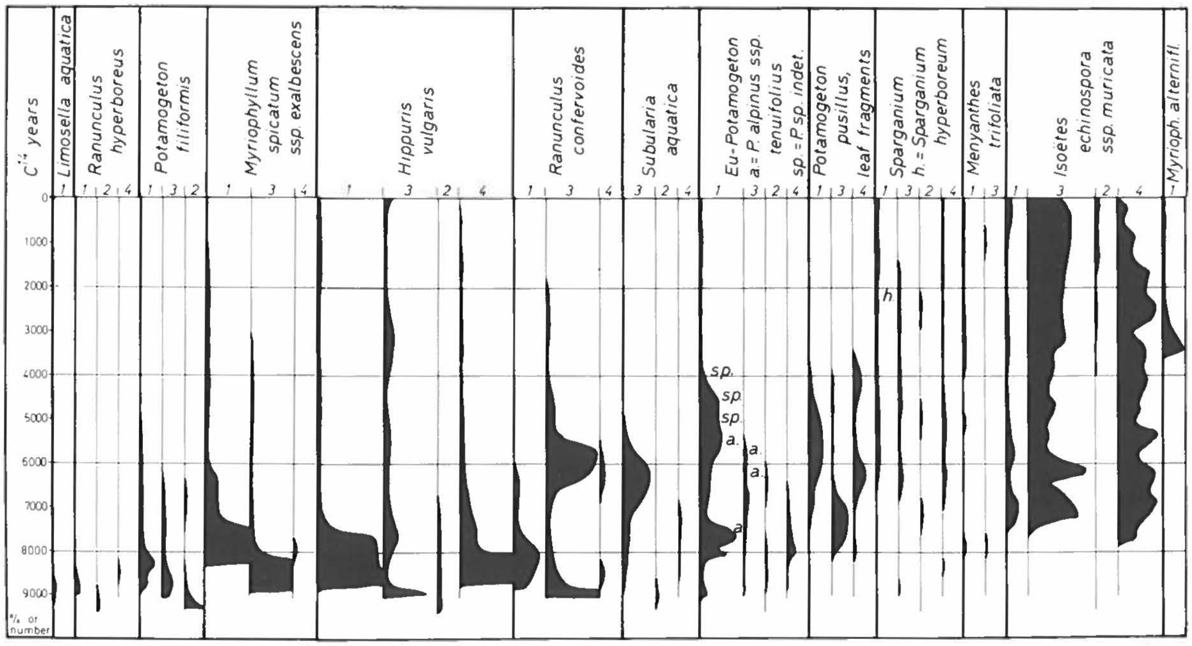

Fig. 13. The Holocene development in macrophyte vegetation of four lakes at Godthåbsfjord (Nos 1–4: see legend to Fig. 1). The curves are based on frequency of pollen, spores, seeds, fruits and leaf fragments.

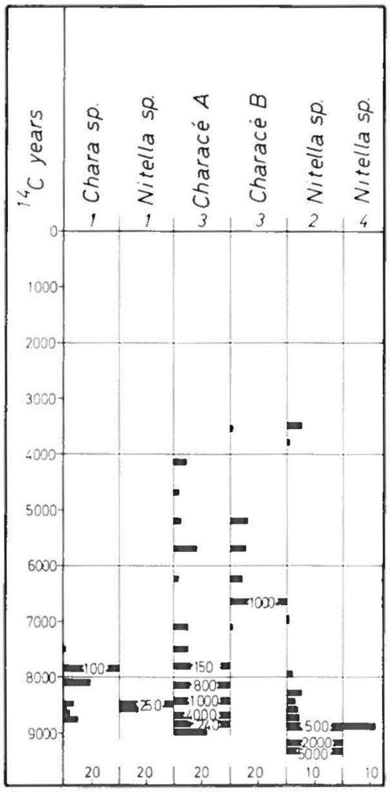

Fig. 14. The number of oospores of *Charophytes* in four lakes at Godthåbsfjord (Nos 1–4: see legend to Fig. 1).

integrum/muticum has a maximum, usually immediately following that of *P. boryanum,* and often of a similar size. Consequently, the animal life in the lakes was very rich, but investigations of this have not yet been completed. The extinction of the medium and high arctic *Lepidurus arcticus* and the spreading of the low arctic *Spongilla* sp. around 8000 B.P. (Fig. 15) are ascribed to increasing temperature.

Spongilla sp. had until recently been collected only in the Kap Farvel area and at the head of Tunugdliarfik (61°09′ N, Fredskild 1973). It was repeatedly found at Godthåbsfjord, in the interior as well as on Nordlandet, still in oligotrophic waters. In 1977 I found it at the head of Søndre Strømfjord in a tiny lake with *Myriophyllum spicatum, Potamogeton filiformis* and *Menyanthes,* indicating that its preference for oligotrophic waters does not prevent it from living in richer waters (supposing it is the same species). This was also shown by Holmquist (1973) who found *S. lacustris* in 11 lakes between 65° and 69°23′ N in Alaska and Yukon, in which the conductivity varied between 12 and 310 μmho, pH 6.3–8.2. *Daphnia pulex* is a common circum-Greenlandic species, whereas *Simocephalus vetulus* has its northern limit at 74° and *Eurycercus glacialis* at 72° N. *Gasterosteus* is known as far north as 74°. So far, *Cristatella* has not been found alive in Greenland, but its statoblasts have been proved in Holocene deposits from South Greenland (Fredskild et al. 1975) and in interglacial deposits in North Greenland (Fredskild & Røen 1982).

Contemporary with the often drastic reduction in the species characterizing the eutrophic stage, is the immigration of *Potamogeton pusillus* and *Isoëtes setacea,* and the more frequent occurrence of *Sparganium* (*?hyperboreum*). *Pediastrum duplex* (in one lake only), *P. angulosum, P. tetras* and *P. braunii* have successive, but much smaller maxima after the reduction in *P. boryanum* and *P. integrum/muticum,* and usually *P. kawraiskyi* is the last immigrant. The deposition of *Pediastrum* ranges between 2 and 40 coenobia/cm^2/yr in the uppermost samples. The oligotrophication and acidification are also reflected in the diatoms in the Godthåbsfjord lakes (Foged 1977) as well as in other lakes (Foged 1972). In the ultimate, oligotrophic stage the number of species and individuals of macrophytes and of animals is severely reduced.

The length of each stage, its diversity as regards species, and its productivity is highly dependent on the soil in the catchment area, as is the present vegetation in

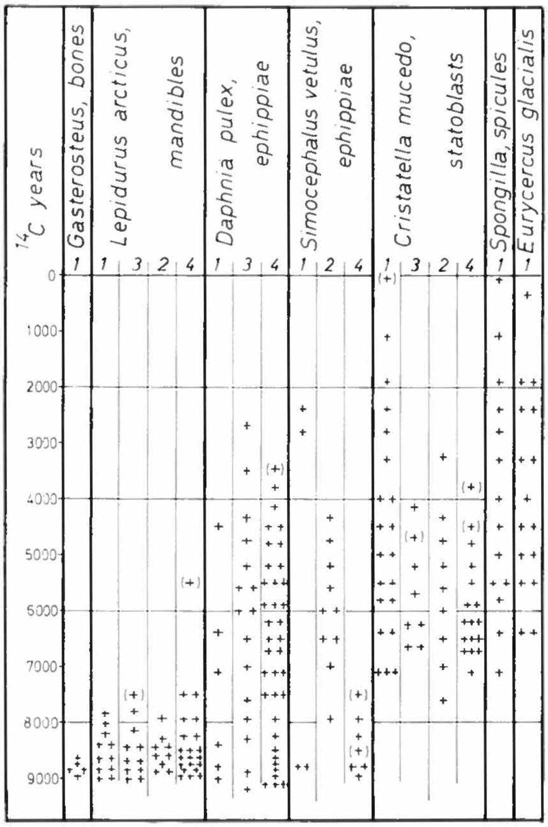

Fig. 15. Some zoological remains in four lakes at Godthåbsfjord. The frequencies range from hundreds: +++, to a single: (+). *Spongilla* spicules have only been searched in one lake. (Nos 1–4: see legend to Fig. 1).

the lakes and ponds. This seems convincingly illustrated by the former and present distribution of *Myriophyllum spicatum*. At Godthåbsfjord it occurred at an early stage in eight of ten cored lakes. The two lakes in which it has not been proved are Karra and one other from which only one pollen sample has been analysed. It is now extinct in all these lakes. The present-day distribution of this species (Fig. 16) and of *Potamogeton filiformis* seems to be related to the occurrence in certain areas of lakes with high conductivity (but usually with a skew composition of ions) rather than to climate, though the temperature and length of summer do of course limit the distribution towards the north.

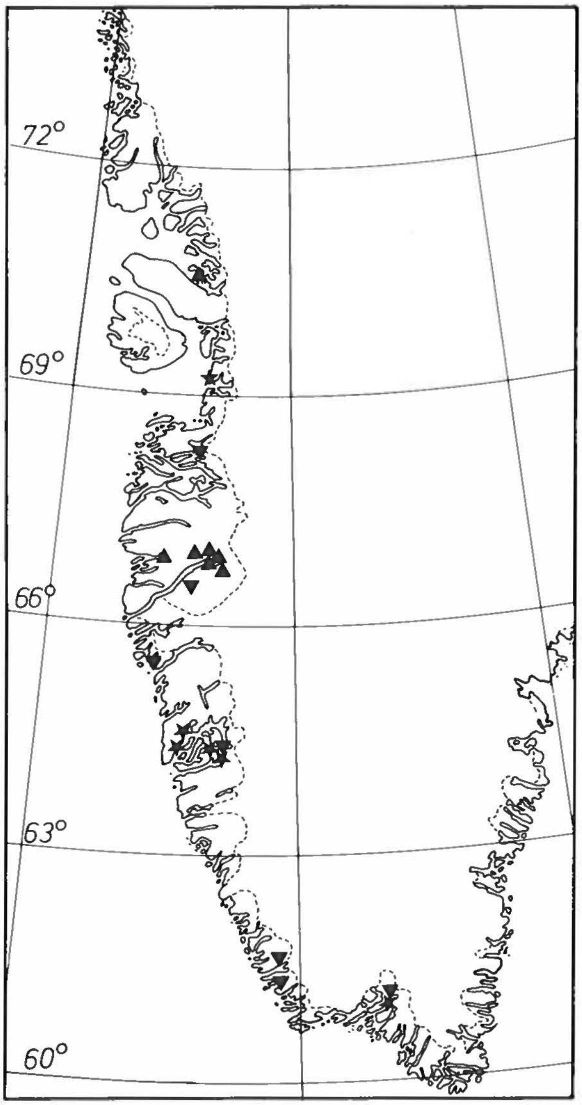

Fig. 16. The present and former Greenland distribution of *Myriophyllum spicatum*. Triangle: present, fertile occurrence; inverted triangle: present, sterile occurrence; star: former occurrence, now extinct.

A negative correlation between values for loss on ignition and ^{13}C content of lake sediments in four East Greenland lakes is indicated by a regression line in Funder (1978, fig. 12). The explanation suggested is that "in periods when large amounts of minerogenic material were washed into the lake there was also a relatively large supply of organic detritus, whereas in periods with smaller supply of minerogenic material the organic production in the lake is responsible for a higher proportion of the sedimentation" (Funder 1978: 32). However, the seemingly highly significant correlation coefficient implies identical or at least very similar physical, chemical and biotic conditions in and around the four lakes on which the line is based.

Contrary to what may be the case for the East Greenland lakes there is a clear positive correlation between productivity of algae and content of minerogenic material in the West Greenland lakes. The extremely high algae production in the first stages of the latter may well hide a possible effect on ^{13}C content caused by washed out organic material, but as the curves of *Pediastrum* and *Botryococcus* in the East Greenland diagrams do not show such a correlation, that may explain the seeming discrepancy.

Changing sedimentation rates, density and water content of the gyttja make the actual change in chemical conditions of the lake during time hard to decifer. Only if these variables are known is it possible to reconstruct the annual deposition. The density and water content must be measured immediately after the extrusion of the cores, but this took place in the field, where no laboratory was at hand. However, experience obtained from recent measurements on sealed tubes brought home from other Greenland lakes, allows a rough estimate. Most important is the water content. In the watery gyttja, usually forming the upper half of the sediment in oligotrophic lakes, the water content varies between 88 and 93%. If the content in a sample is estimated at 90% and in fact was 92%, the calculated yearly deposition is 20% too high. On the contrary, an incorrect estimate of the density does not give similarly incorrect results. The sedimentation rates are given in Fig. 4. To get an idea of the yearly deposition, the following estimates have been made: density 1.3 in layer 2, decreasing to 1.1 in layer 6 and then to 1.05 in layers 7–11. Water content 70% in layer 2, 75% in layer 3, 80% in layer 6, 85% in layers 7–8 and 90% in layer 11. If these estimates are correct, most ions and other parameters show a more or less pronounced decrease during the life of the lake, most often by a factor 10. Fe decreases from 71 g/m²/yr on an average of sample 1 and 2, to 38 in sample 4, which is the uppermost clay gyttja sample, to 11 on an average of samples 9–11. Similar numbers are for Ca: 23 – 8 – 2.4, for K: 20 – 7 – 0.9, Mg: 13 – 5 – 0.7, Na: 7 – 2.7 – 0.3, Mn: 0.9 – 0.4 – 0.1, Zn: 0.18 – 0.08 – 0.03, Pb: 0.10 – 0.04 – 0.01, Cu: 0.09 – 0.06 – 0.07, P: 0.25 – 0.15 – 0.10, C: 5.3 – 6.2 – 4.6, organic matter: 10 – 24 – 10, inorganic matter: 152 – 70 – 26. Kjeldahl N ranges

Table 4. Chemical analyses of samples from the Johannes Iversen Sø core.

					P.p.m., dry weight											
Sample no.	Depth, cm	Layer no.	Loss on ignition, %	Total C, %	Cu	Pb	Zn	Fe	Mg	Na	Mn	Ca	K	P	N
11	31–34	11	27.8	11.9	172	27	79	29300	1880	649	244	5910	2090	239	1210
10	79–82	11	26.4	12.2	204	31	117	28000	2150	744	244	6940	2850	251	3780
9	127–130	11	29.6	14.6	223	38	96	34700	2030	835	219	7510	2430	262	864
8	175–178	8	25.4	13.6	198	44	137	42600	4270	1220	307	7350	5410	223	1310
7	223–226	8	25.5	11.2	211	45	146	40900	4970	1490	358	7510	6310	288	763
6	259–262	8	24.7	11.4	208	57	152	45300	5380	1990	408	6640	8640	181	916
5	295–298	7	22.2	12.3	146	48	132	50300	5260	2320	398	8550	8260	192	1290
4	319–322	6	26.3	7.6	69	46	99	46500	6030	3260	472	9890	8690	188	635
3	337–340	3+2	20.4	8.7	156	76	177	56700	6230	5450	501	9680	9260	218	800
2	355–358	2	6.4	4.2	74	64	118	45800	8530	4910	615	15660	14300	145	1520
1	360.5–362.5	2	?	2.5	42	70	112	42700	7360	4110	545	13390	10850	173	601

between 2.2 and 0.27. Even considering the uncertainties in the calculation, the overall trend in the deposited matters confirms the picture of the trophic development of the lake, testified by the plant and animal life.

Many of the results obtained are surprisingly similar to results from the oligotrophic – but recently badly polluted – lake Trummen (Digerfeldt 1972), situated in a granite region in southern Sweden. Five metres of brown to dark green-brown detritus gyttja here overly 42 cm clay gyttja of Preboreal age. Raw and mainly unleached mineral soils existed around the lake at the transition between Younger Dryas and Preboreal, and the chemical analyses, as well as analyses of pollen, diatoms and macrofossils, show a progressing oligotrophication in the course of time. By way of comparison the following results from Trummen can be mentioned, with the results from the clay gyttja first: Fe: 65 – 1 g/m²/yr, P: 0.3 – 0.015, total C: 38 – 5, Kjeldahl N: *c.* 2.5 – 0.4, dry matter: 500 – 30, minerogenic matter: 300 – 40, loss on ignition: 13 – 28%. Ca, Na, Mg and K are expressed as mg extractable ions per unit volume, and are therefore not comparable with the results from Greenland, but analyses, expressed as g/m²/yr from 2.8 m gyttja deposited in the past millennium from lake Järlasjön near Stockholm (Digerfeldt et al. 1975) show an annual accumulation of the same order of size for these four ions plus Cu and Zn.

The average Holocene sedimentation rate in the four West Greenland lakes varies from 1.32 to 3.70 cm/100 yr. For shorter periods the rate ranges between 0.80 to 4.53, when determined by linear interpolation between consecutive, calibrated radiocarbon dates (Figs 4, 6, 8, 9). The highest rate is found in the interior lowland.

Pollen influx

The average pollen influx for each PV zone is shown in Fig. 10. These are in keeping with earlier results from South Greenland, where the influx for most recent pollen zone averages 177, 318 and 327 in the three outer coast lakes and 1 710, 2 610 and 2 650 in one inland lake and two very small inland basins respectively; the figures for the very small basins are not strictly comparable with those for the lakes. Based on the number of pollen per mg in the Nigerdleq diagram (Kelly & Funder 1974) a cautious estimate gives an average influx for the entire Holocene of 150–200. The values for the recent PV zone in the two outer coast diagrams from Godthåbsfjord are 67 and 250, in the interior 286 (penultimate zone) and 740, again with the highest numbers inland. Three high arctic Greenland lakes have been analysed (B. Fredskild unpublished). On a peninsula in Melville Bugt, a lake Langesø on Tugtuligssuaq (75°22′ N) is surrounded by bare ground with *Cassiope* heaths and snowbeds. The lake has no major inlet, but receives only meltwater from the 10–20 m high, rocky slopes surrounding it. The pollen influx, averaging 16 for the last 8 000 years, decreases in the recent pollen zone to 8. A neighbouring lake receives a lot of washed down, mostly corroded pollen from a 400 m high slope, and the influx accordingly is ten times as great. None of the lakes investigated in South and West Greenland are of the latter type. On Qeqertat in Inglefield Bredning (77°30′ N) a lake surrounded by *Carex stans* fens and *Cassiope-Salix arctica* heaths has an average influx of 7 during Hypsithermal, decreasing to an average of 1 for the recent pollen zone (Fredskild in print). This is in accordance with the results from Ellesmere Island, where Hyvärinen & Blake (1981) found an influx of 5–15 in early Holocene, decreasing to *c.* 1 in the subrecent samples.

Pennington (1980), on the assumption of a sedimentation rate of 1 cm in 30 yr for the upper, nearshore sediment, estimated influx values of 393–828 for four lakes at the head of Søndre Strømfjord (67° N), and of 172–251 for four lakes on Disko (69°15–30′ N). Furthermore, she compared these and other low arctic Greenland influx values with Late Devensian values from the British Isles, concluding that the present day vegetation and climatic conditions in many respects illustrate the late-glacial vegetation and climate of Northwest Europe.

The Greenland results also compare well with the North American, where values for the initial herb zone following the deglaciation are 500–1000 in Rogers Lake, Conn. (Davis 1969), 200–600 in Chalmers Bog, Alberta (Mott & Jackson 1982), 300 in Quebec (Richard 1971) or even lower (Mott & Farley-Gill 1981). Average pollen influx over the past 6–7 millennia for three lakes on Île du Diana in the northwestern part of Ungava Bay, today covered by herb tundra, ranges between 75 and 415. Corresponding values for the last millennia for a lake west of Ungava Bay in the shrub tundra, are 730, and for two lakes in the forest tundra 50 km further south, 1320 and 2120 (Richard 1981).

As in the South Greenland diagrams the pollen influx increases from low values during the pioneer phase to maximum values during Hypsithermal, often followed by a decrease which is not caused by a major change in the composition of the vegetation to less pollen producing species, but rather in a reduced viability of the species, due to climatic deterioration, or by a reduced number of individuals of pollen producing plants. Lichens and mosses may have conquered their area.

Immigration or appearance of some palynologically important species

Kelly & Funder (1974) present a table of approximate dates of appearance for species at localities in West Greenland. An up-to-date summary (Table 5) needs only a few comments (for dates marked with an asterisk): *Salix glauca* and *Thalictrum* possibly immigrated much earlier at Kap Farvel, see discussion in Fredskild (1973: 83). One single *Juniperus* pollen was found in the interior of Godthåbsfjord 300 years earlier and one on Nordlandet 500 years earlier. *Rumex acetosella* and *R. acetosa* were introduced to South Greenland by the Norsemen. No grains were found in the interior, prior to the landnam, and at the outer coast only two grains, both in the lake in which the most long distance pollen, for example 55 *Ambrosia* in the same period, were found. A single spore of *Gymnocarpium*, possibly redeposited, was found in a clayey sample at 8500 B.P. The report of an early *Betula* immigration to the Disko Bugt area, prior to 7850 B.P. (based on unpublished material by Kelly and mentioned in the table in the 1974 paper as well as in Funder (1979)), seems invalid, and may be based on rebedded material. Later analyses of dated samples from two corings in the same area, and corings in three lakes on Disko itself, have shown no *Betula nana* in *c.* 7000-year old samples (S. Funder, personal communication, and my own investigation). A hyphen denotes that the species is not growing in the area today. *Selaginella* has not been collected on Nordlandet.

Acknowledgements

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Table 5. Time of immigration or appearance of some species to West Greenland from Kap Farvel to Godthåbsfjord. Dates are ^{14}C years B.P.

	Interior Godthåbsfjord	Nordlandet	Frederikshåb	Qagssiarssuk	Kap Farvel
Oldest pollen sample	9300	9000	9600	8600	9400
Salix glauca	8000	8100	8900	8000	7200*
Salix herbacea	7900	8100	?	?	7200
Alnus crispa	3900	–	?	–	–
Juniperus communis	6400*	6400*	7000	6900	7000
Betula nana	6400	6500	–	–	–
Angelica archangelica	5700	8100	>9600	8500	9000
Thalictrum alpinum	7500	8300	8800	8000	7500*
Selaginella selaginoides	6400	–	7500	6700	6500
Coptis trifolia	5200	4900	?	5200	7000
Rumex acetosella	6100	6300	?	1000*	1000*
Gymnocarpium dryopteris	8400	8100	?	7000*	>9400
Botrychium sp.	9200	8500	9500	>8600	>9400
Thymus praecox	?	4200	5000	6000	3500

* see text.

Copenhagen, for having undertaken the chemical analyses, to students and colleagues for their help during the work in the field and at the museum, and to Birthe Hammer for her painstaking work with the manuscript. The many radiocarbon datings have been granted by the Geological Survey of Denmark. They were made at the Radiocarbon Dating Laboratory of the Geological Survey of Denmark and the Danish National Museum by Dr. Henrik Tauber.

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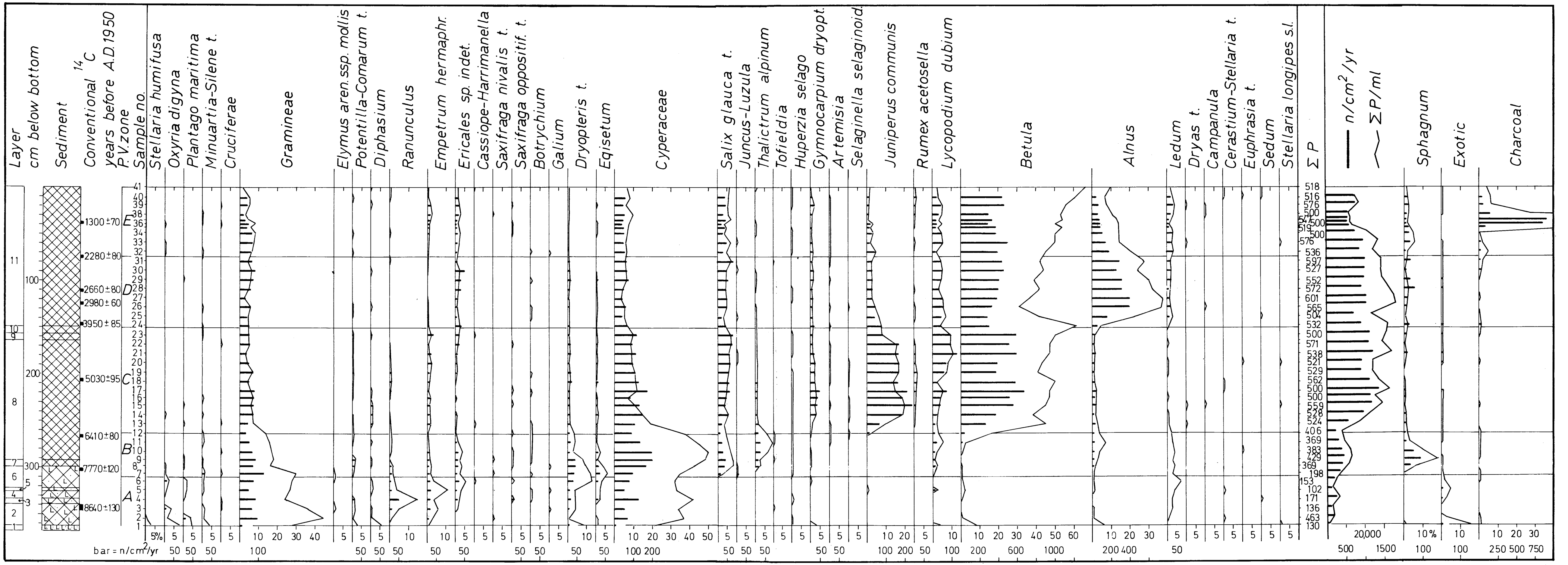
Plates

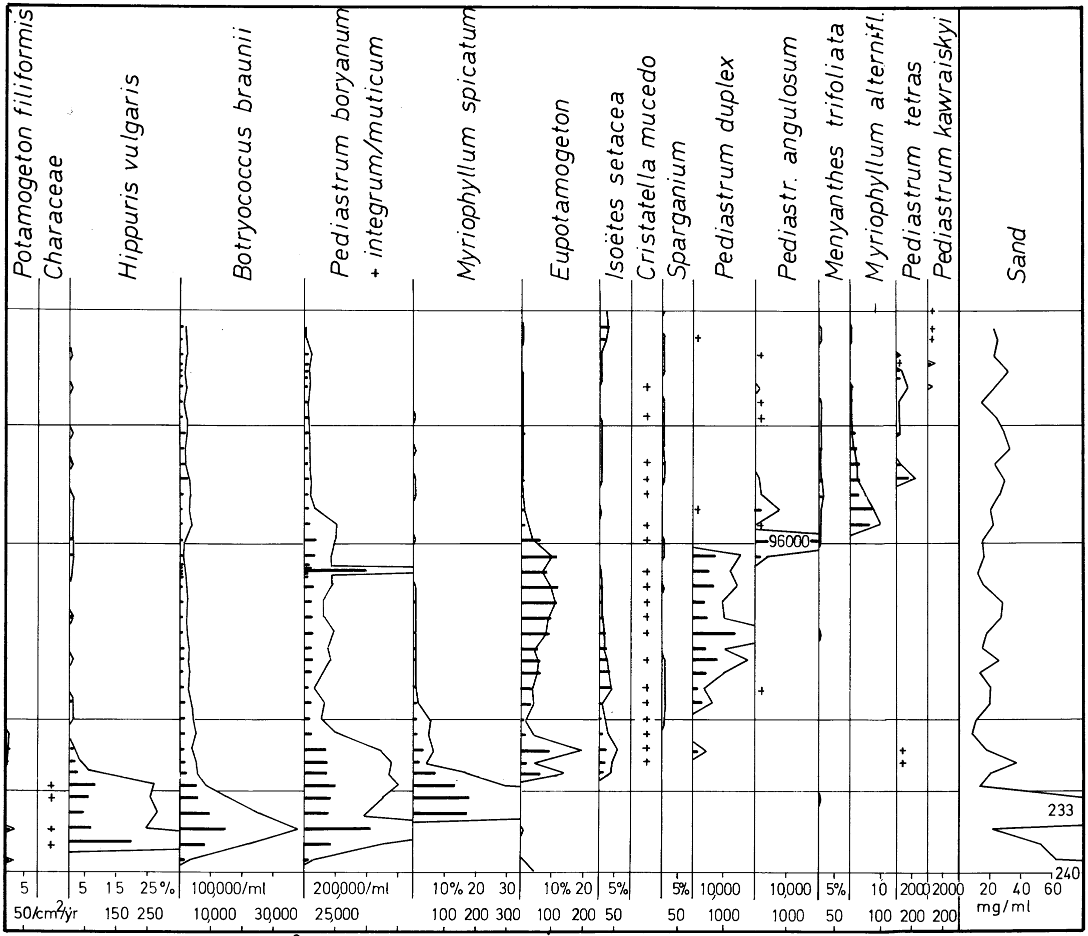
1. Johannes Iversen Sø, terrestrial microfossil diagram
2. Johannes Iversen Sø, limnic microfossil diagram
3. Johannes Iversen Sø, macrofossil diagram
4. Karra, microfossil diagram
5. Karra, macrofossil diagram
6. Terte, Lake A, terrestrial microfossil diagram
7. Terte, Lake A, limnic microfossil diagram
8. Terte, Lake A, macrofossil diagram
9. Sârdlup qáqâ, terrestrial microfossil diagram
10. Sârdlup qáqâ, limnic microfossil diagram
11. Sârdlup qáqâ, macrofossil diagram

JOHS. IVERSEN SØ (64°24'N 50°12'W)
Godthåbsfjord W. Greenland Microfossils



Bent Fredskild 1974 - 75

JOHS. IVERSEN SØ (64°24'N 50°12'W)
Godthåbsfjord W. Greenland Microfossils

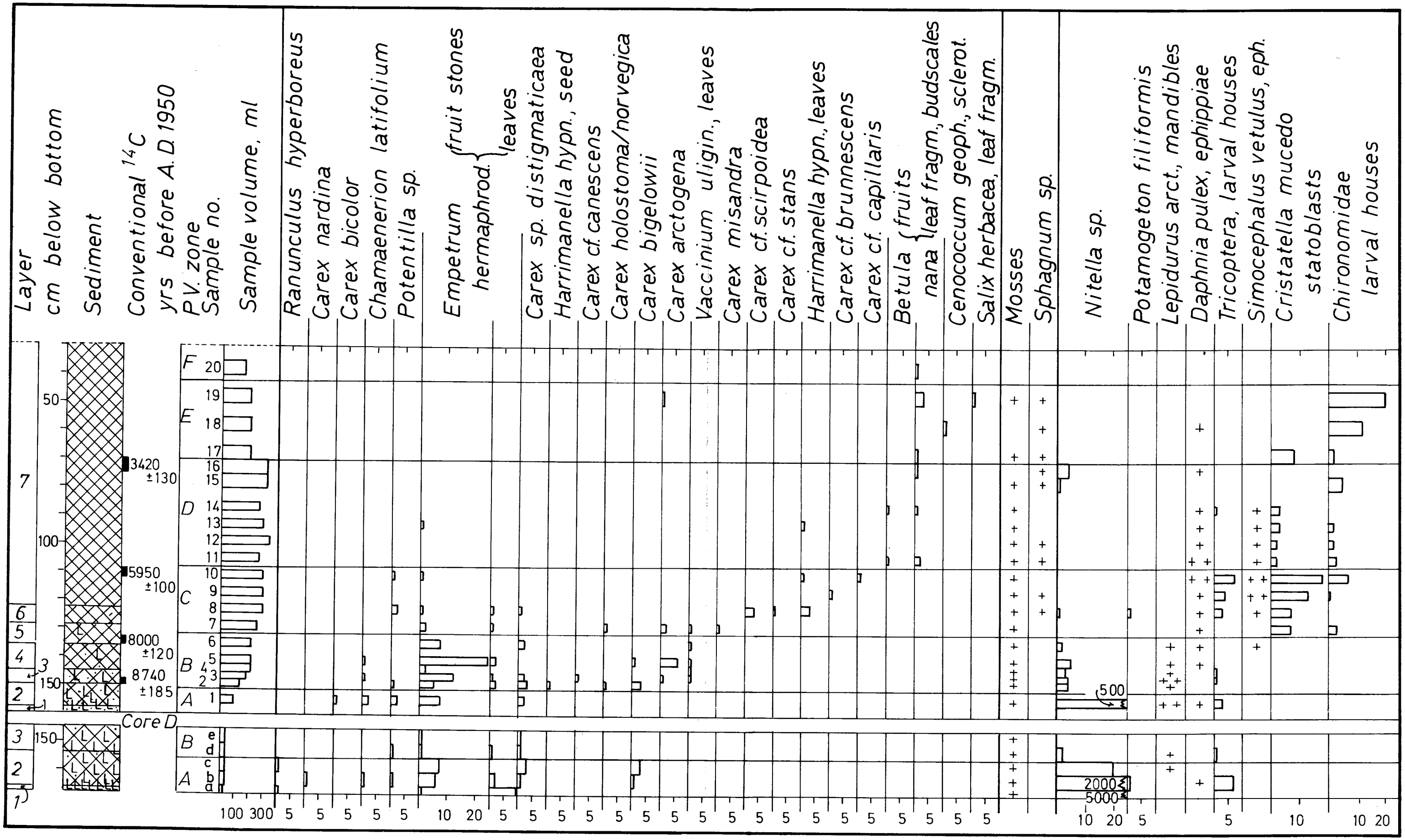


Curve = % or n/ml, bar = n/cm²/yr

Bent Fredskild 1974 -75

KARRA (64°46'N 50°35'W)

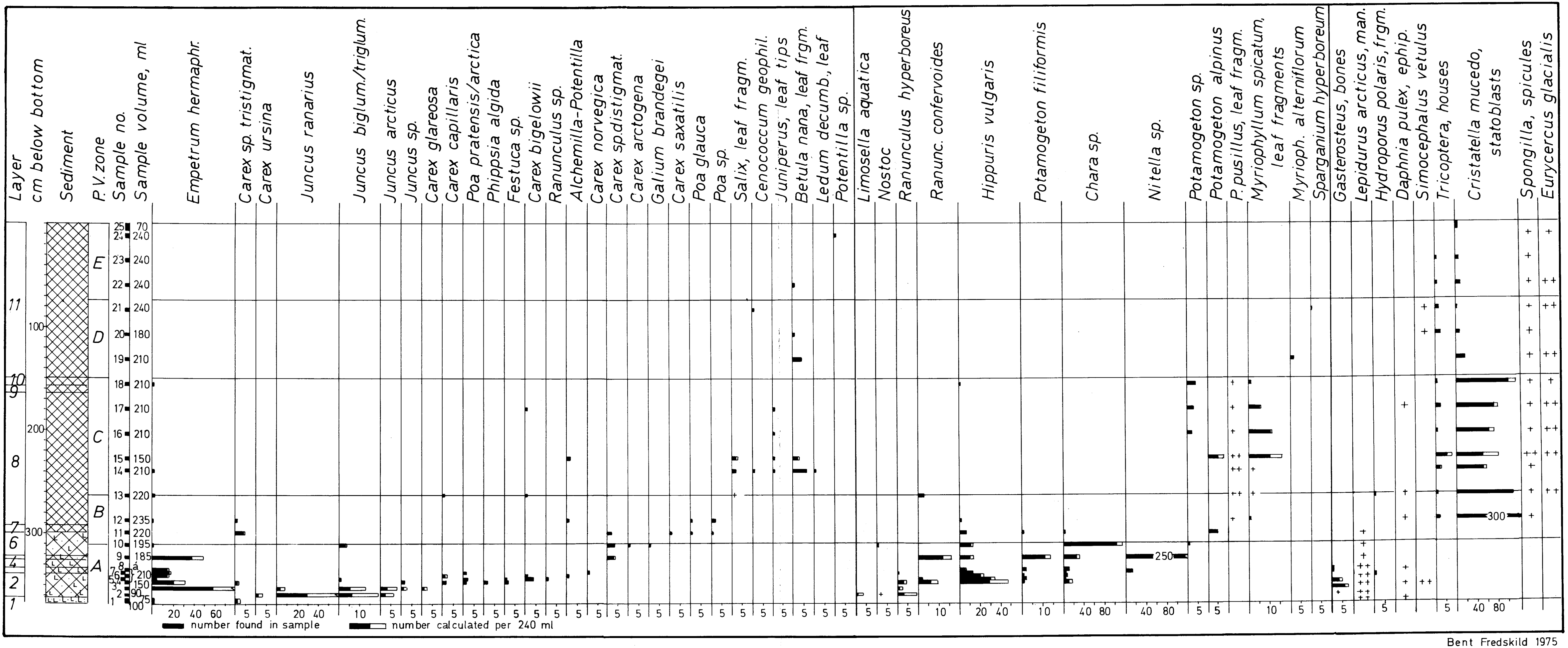
Godthåbsfjord W. Greenland Macrofossils



Bent Fredskild 1977

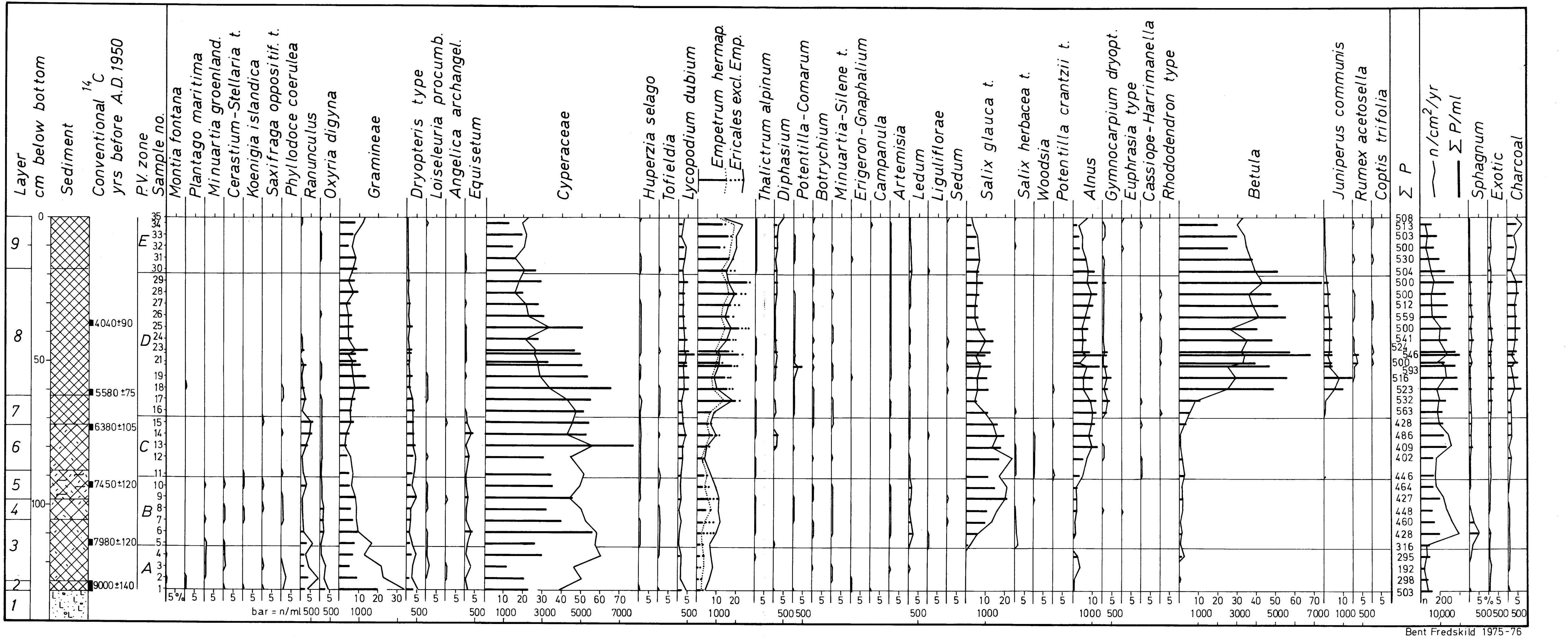
JOHS. IVERSEN SØ (64°24'N 50°12'W)

Godthåbsfjord W. Greenland Macrofossils



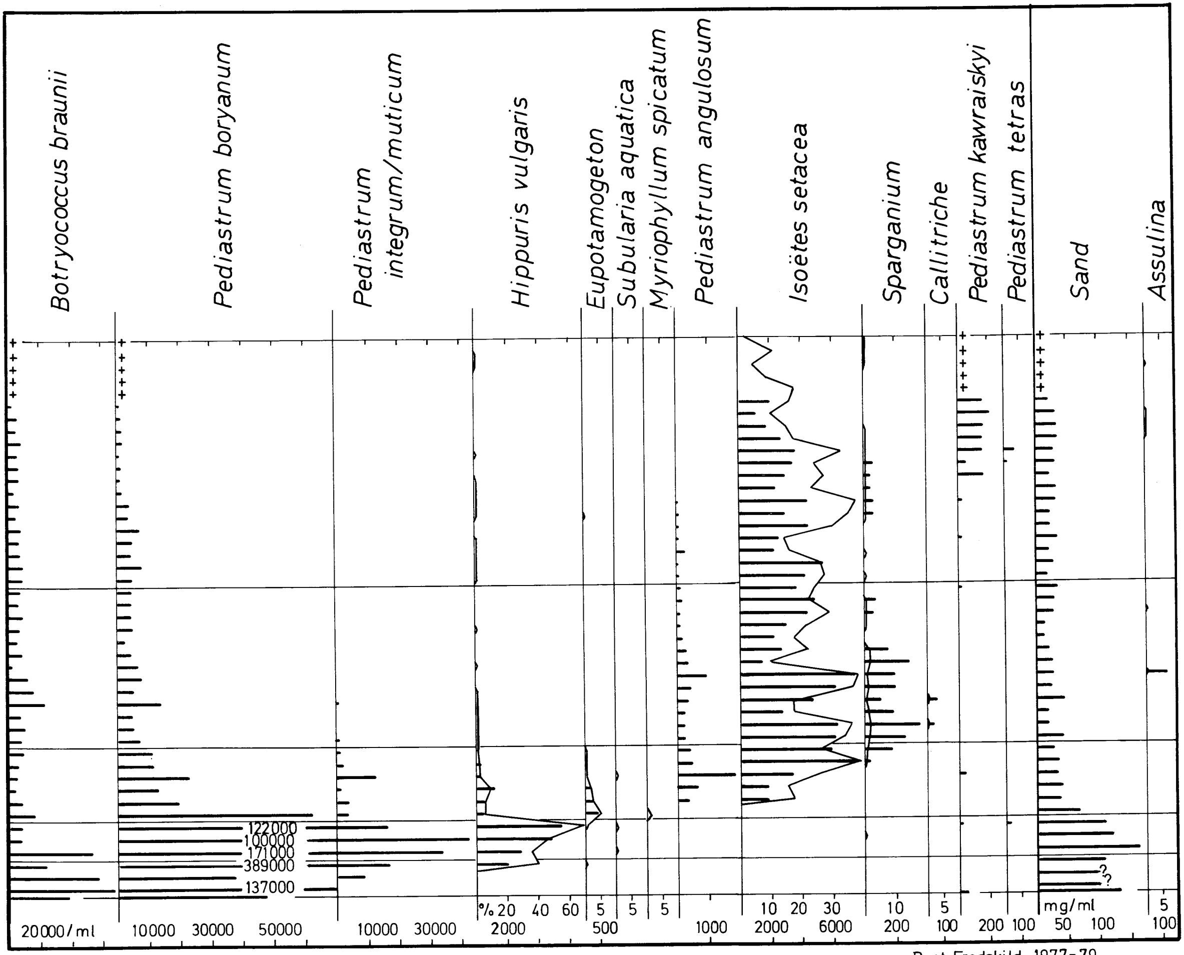
Bent Fredskild 1975

TERTE Lake A (64°28'N 51°35'W)
Nordlandet W. Greenland Microfossils



Bent Fredskild 1975-76

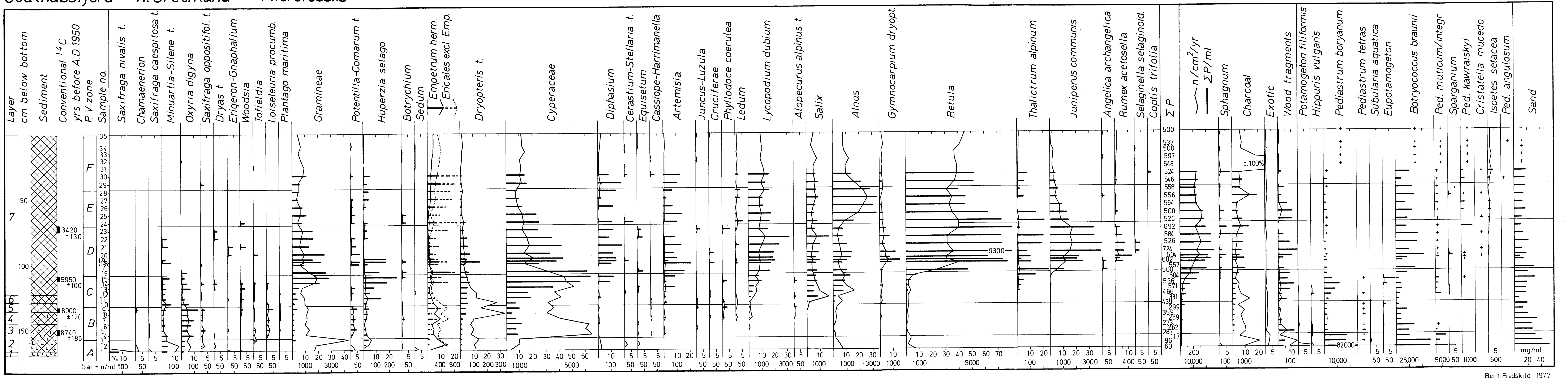
SÂRDLUP QÁQÂ (64°24'N 51°41'W)
Nordlandet W. Greenland Microfossils



Bent Fredskild 1977-79

KARRA (64°46'N 50°35'W)

Godthåbsfjord W.Greenland Microfossils



Bent Fredskild 1977

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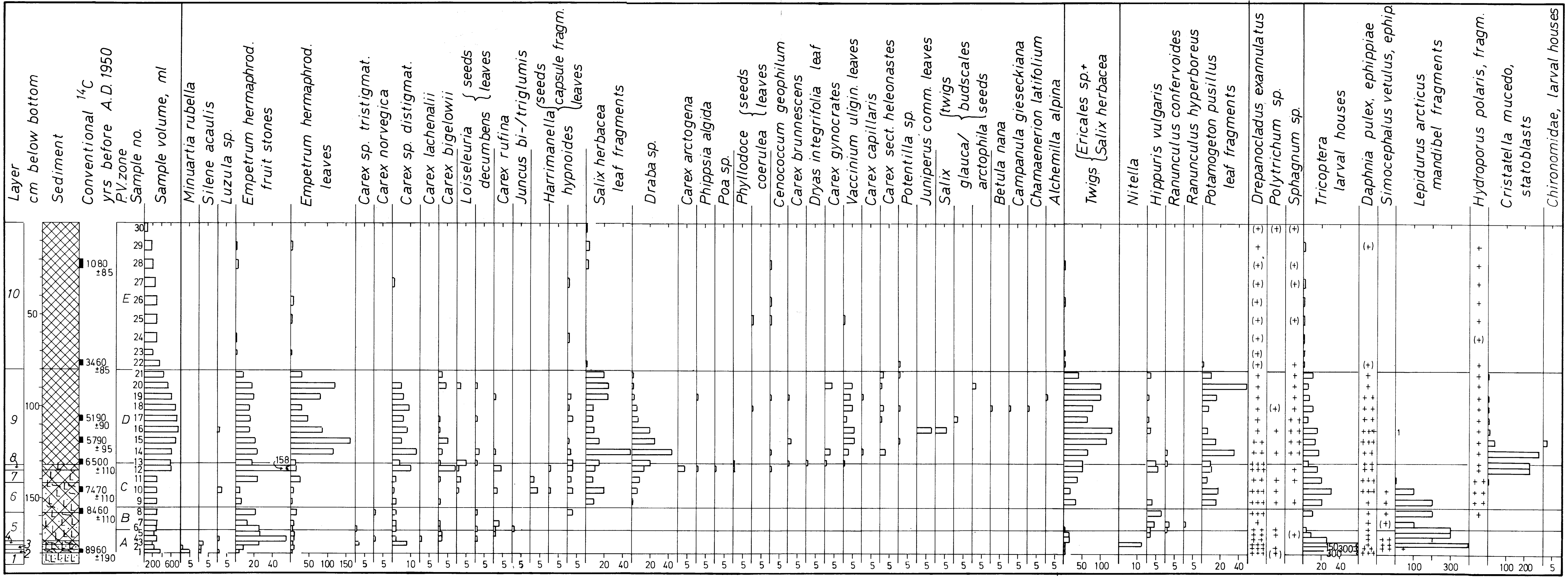
Nordlandet W. Greenland Macrofossils



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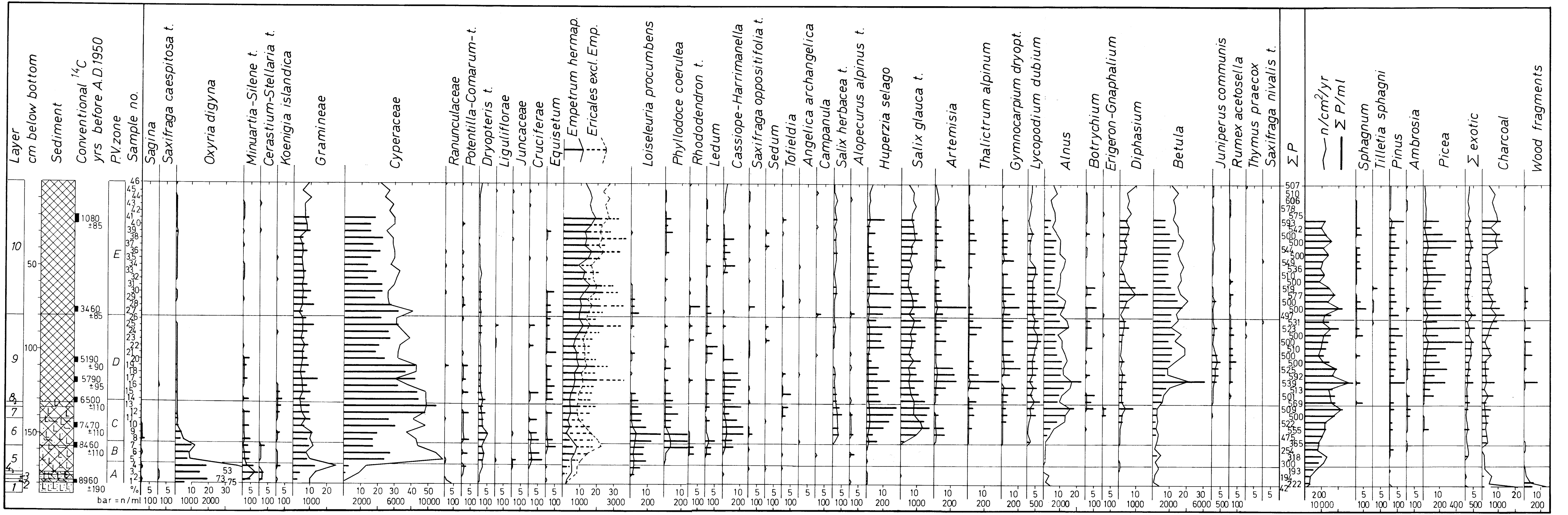
Nordlandet W. Greenland Microfossils



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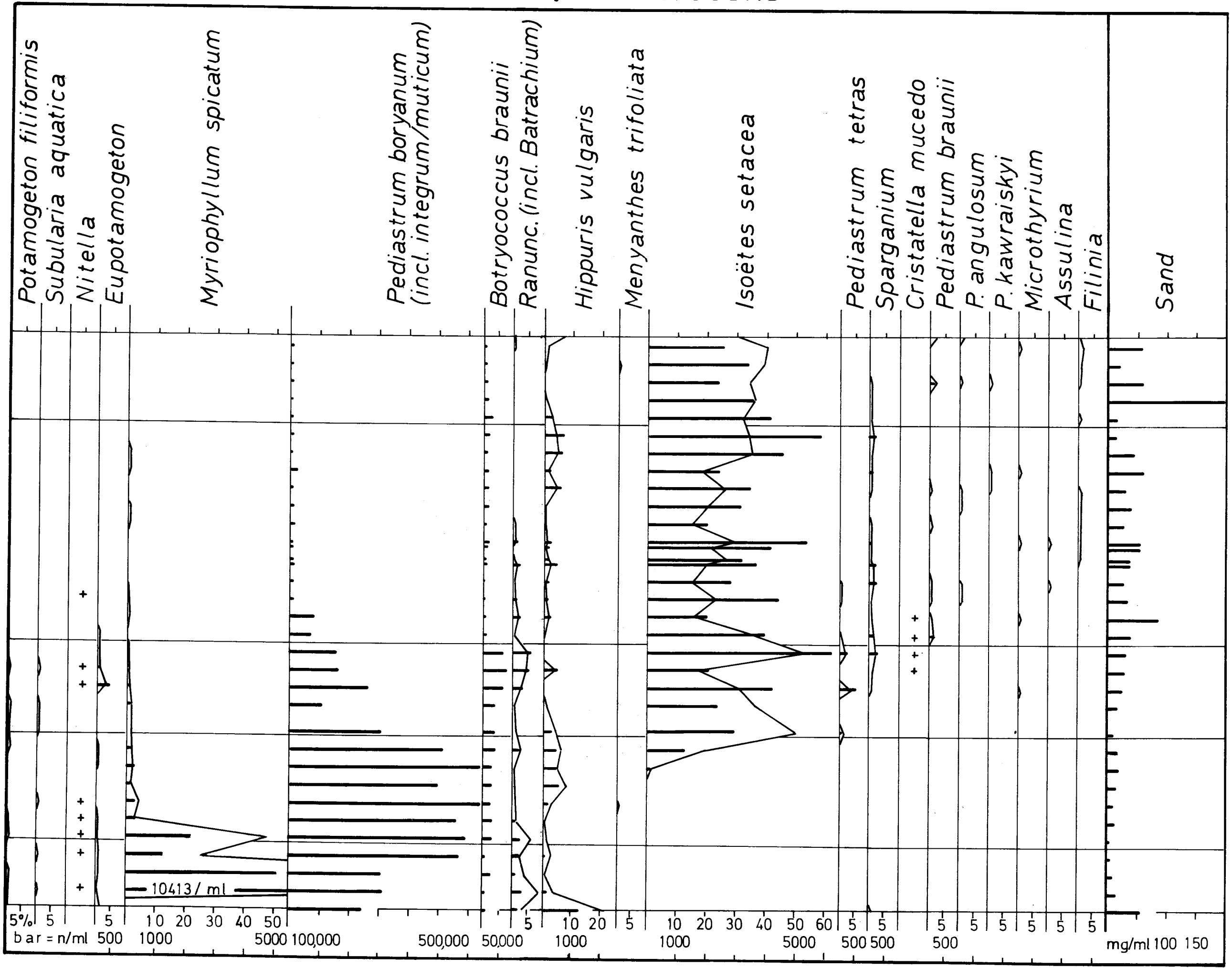
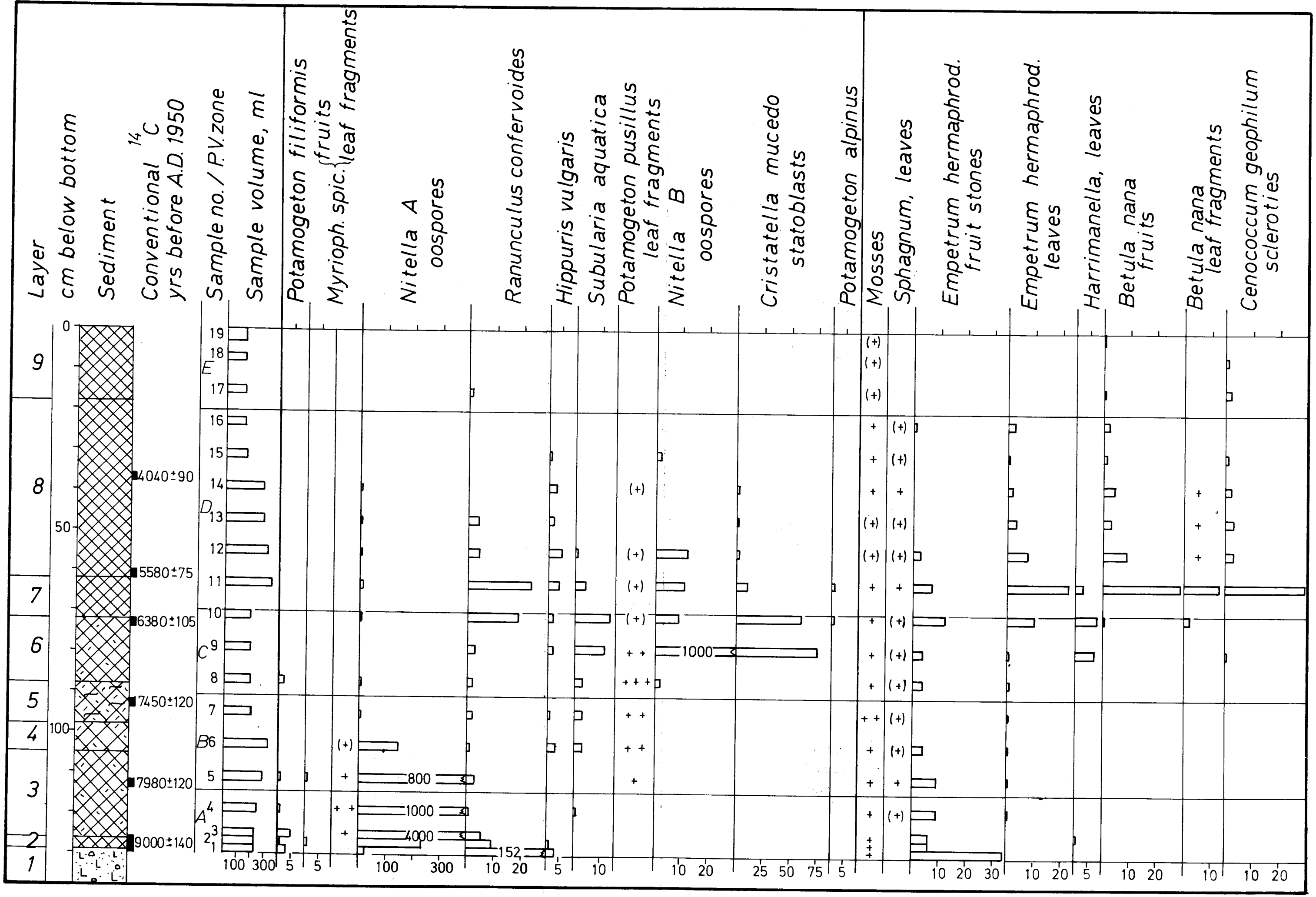
TERTE Lake A
W. Greenland (64°28'N 51°35'W) Microfossils



Bent Fredskild 1975-76

TERTE Lake A
W. Greenland (64°28'N 51°35' W) Macrofossils



Bent Fredskild 1976

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