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The Holocene vegetational development of Tugtuligssuaq and Qeqertat, Northwest Greenland

Bent Fredskild

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Holocene pollen- and macrofossil diagrams from three high arctic lakes in Northwest Greenland are presented, and based on these the radiocarbon dated palaeovegetation zones (PV zones) are described. Two of the lakes are situated above the upper marine limit on the peninsula Tugtuligssuaq in Melville Bugt, in a highly maritime climate. The vegetation, invading the deglaciated soil around 8500 B.P., was a species-rich pioneer vegetation, dominated by *Poaceae, Oxyria digyna* and other herbs, including some species not growing on the peninsula today. The first dwarf-shrubs, *Empetrum hermaphroditum* and *Vaccinium uliginosum,* immigrated in the coming centuries, followed by *Cassiope tetragona.* By 6700 B.P. *Salix arctica* and *S. herbacea* immigrated. These species together with *Cyperaceae,* later on *Cassiope,* dominate the pollen spectra until *c.* 2300 B.P. The influx of long-distance pollen, indicating more frequent south-westerly winds, increased around 5000 B.P. and remained at a high level until a marked decrease is seen *c.* 2300 B.P. Since then the influx was very low. *Cassiope* dominates in the recent PV zone. The lakes were fairly rich in the first millennia with high production of *Pediastrum* and *Botryococcus. Colymbetes dolabratus* and *Gasterosteus aculeatus,* both north of their present distribution limit, lived in the lakes at an early stage.

Qeqertat at the head of Inglefield Bredning has a more continental climate. The cored lake was not isolated from the sea until 6800 B.P., just prior to the immigration of *Salix arctica. Cyperaceae* dominate the pollen diagram until around 3500 B.P. when *Cassiope* and especially *Salix arctica* become more frequent. At the same time marked changes in the microflora in the lake indicate increased frost boil activity around the lake as a result of a climatic change. Open soil plants are more frequent in the present PV zone.

Pollen influx is low in these high arctic lakes, viz. *c.* 6 in the recent PV zone in Langesø and *c.* 1 in the Qeqertat lake. Melt water washes down pollen and other plant material from the surrounding slopes into Rundesø, thus causing too high influx values.

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The centennary of the birth of Knud Rasmussen on June 7, 1879 was celebrated by the "Knud Rasmussen Foundation" by a renewed cooperative Danish-Greenlandic scientific venture, the "Knud Rasmussen Memorial Expedition" to Melville Bugt, Northwest Greenland. After a preliminary expedition in 1978, during which a hut was built on Tugtuligssuaq, a multidisciplinary expedition investigated the peninsula during the summer of 1979, with a team sledging down from Dundas in the late spring, followed by the main team, brought in on the Admiralty's "Ingolf" on July 15 and taken off by "Beskytteren" August 24. During this period I made botanical studies, assisted by Christian Bay, M. Sc., and cored two lakes named Langesø and Rundesø because of their outline. These unofficial names have been used in four previous publications (Fredskild 1983a, b, 1985, Fredskild & Bay 1980). The local names are however Taherhiaq and Igdluminerhît tahiat respectively.

In 1980 a short final expedition, again transported by "Ingolf", enabled me to carry out similar investigations on the isle of Qeqertat, Inglefield Bredning, August 6–15, and besides to pay brief visits to Tugtuligssuaq on August 4 and 17.

Tugtuligssuaq

Geography

The Greenland ice sheet reaches the sea in the major part of Melville Bugt, only interrupted by a number of semi-nunataks and some peninsulas, of which the 20 km long NE-SW running Tugtuligssuaq is the largest ice-free area on the *c.* 500 km long coast between Holm Ø and the land northwest of Pitugfik Gletscher, Fig. 1. It is built up of gneissic bedrock, most of its surface covered by cobble- and boulder-size rock fragments. Only on gently sloping or horizontal ground can solifluction lobes and sorted stripes and circles be seen, and here the soil development can be studied (Jakobsen et al. 1980). On well-drained ground Arctic Brown soil with an acid (pH 5.2) A-horizon and more neutral (pH 5.6–6.3) B- and C-horizons can be met with, whereas Meadow Tundra and Upland Tundra soils occur on poorly drained ground with a high permafrost table.

Perched boulders were seen down to a dozen metres a.s.l., but no definite former shore lines were found. The minerogenous sediment below the gyttja in the cored lakes, *c.* 15 and 14 m a.s.l., contained neither shell fragments nor marine diatoms.

The climate is high arctic, maritime. An automatic recording station (UGO) worked in the period August 1978 – April 1979, and synoptical studies were undertaken during the field season of 1979 (Jakobsen et al. 1980, Thingvad 1981). The two nearest meteorological stations are Dundas and Upernavik, *c.* 350 km to the northwest and south respectively (Fig. 1). Tugtuligssuaq had a greater precipitation, in the period mentioned *c.* 500 mm as compared to 167 and 288 mm for the respective stations. From the beginning of June until the middle of July temperatures oscillated around 0°C, followed by a little more than one month with positive temperatures throughout the day (mean *c.* 6°) and little precipitation, mainly rain. The autumn, with several days of rain and slush, began on August 13. It lasted till *c.* Sept. 10, when the ground was covered by a lasting snow-cover, judging from the soil temperatures without diurnal oscillations. Prevailing wind directions throughout the year were NE through E to SE. At our arrival on July 15 roughly half of the surface of the western end of the peninsula was still covered with snow.

Further details on the climate of the Melville Bugt area can be seen in Table 1. March was the coldest month in the period 1961–70, whereas February has been colder in recent years except at Thule Air Base in 1983, when January was even colder.

Vegetation

The usually very sparse vegetation has adjusted to the long-lasting snow-cover, and by mid-July 1979 only a few plants on S-facing slopes had come into flower. Snow-patch vegetations dominate. No phanerogams grow in the last patches to melt, only mosses like *Cynodontium tenellum* and *Andraea rupestris,* whereas *Luzula arctica, L. confusa, Huperzia selago* and sterile *Silene acaulis* grow with *Anthelia juratzkana,* often forming a carpet, and with *Solorina crocea* and *Racomitrium lanuginosum* in not too late-melting snow-patches (Fredskild & Bay 1980). On top of the many E-W running, low ridges 0–50 m a.s.l. and on early snow-free, south-facing slopes elsewhere in the lowland an open, poor dwarf-shrub heath can be seen, dominated by usually sterile *Vaccinium uliginosum* ssp. *microphyllum,* rich in *Salix arctica* and *Empetrum hermaphroditum* and sometimes with *Dryas integrifolia.* With a little longer snow-cover *Dryas* disappears and *Cassiope* takes over to become dominant on sites with an even longer snow-cover. Here *Salix herbacea* grows, whereas first *Empetrum,* then *Vaccinium* disappear. *Salix arctica* is subdominant in these snow-protected heaths. *Luzula confusa, Pedicularis hirsuta* and *Carex bigelowii* are most frequent among the few herb species. On level ground snow-patch vegetation dominates.

Almost every slope and plateau above the upper marine limit is covered with blocks, boulders and felsenmeer, with only lichens and mosses, and *Luzula confusa* in between. The few sandy-gravelly, south-facing slopes harbour dry soil species like *Carex nardina, Poa glauca, Antennaria ekmaniana, Campanula uniflora* and *Saxifraga tricuspidata.* Herb-slope vegetation was only met with once, covering a few m² in the eastern end of the peninsula at Itivdlipaluk. Furthermore, a *Carex stans* fen with *Eriophorum scheuchzeri, E. angustifolium, Deschampsia pumila, Juncus biglumis* and *J. castaneus* covered an area *c.* 1 × 0.5 km wide, but otherwise only a few m² here and there along brooks and at the two lakes cored were covered by fen-like vegetations.

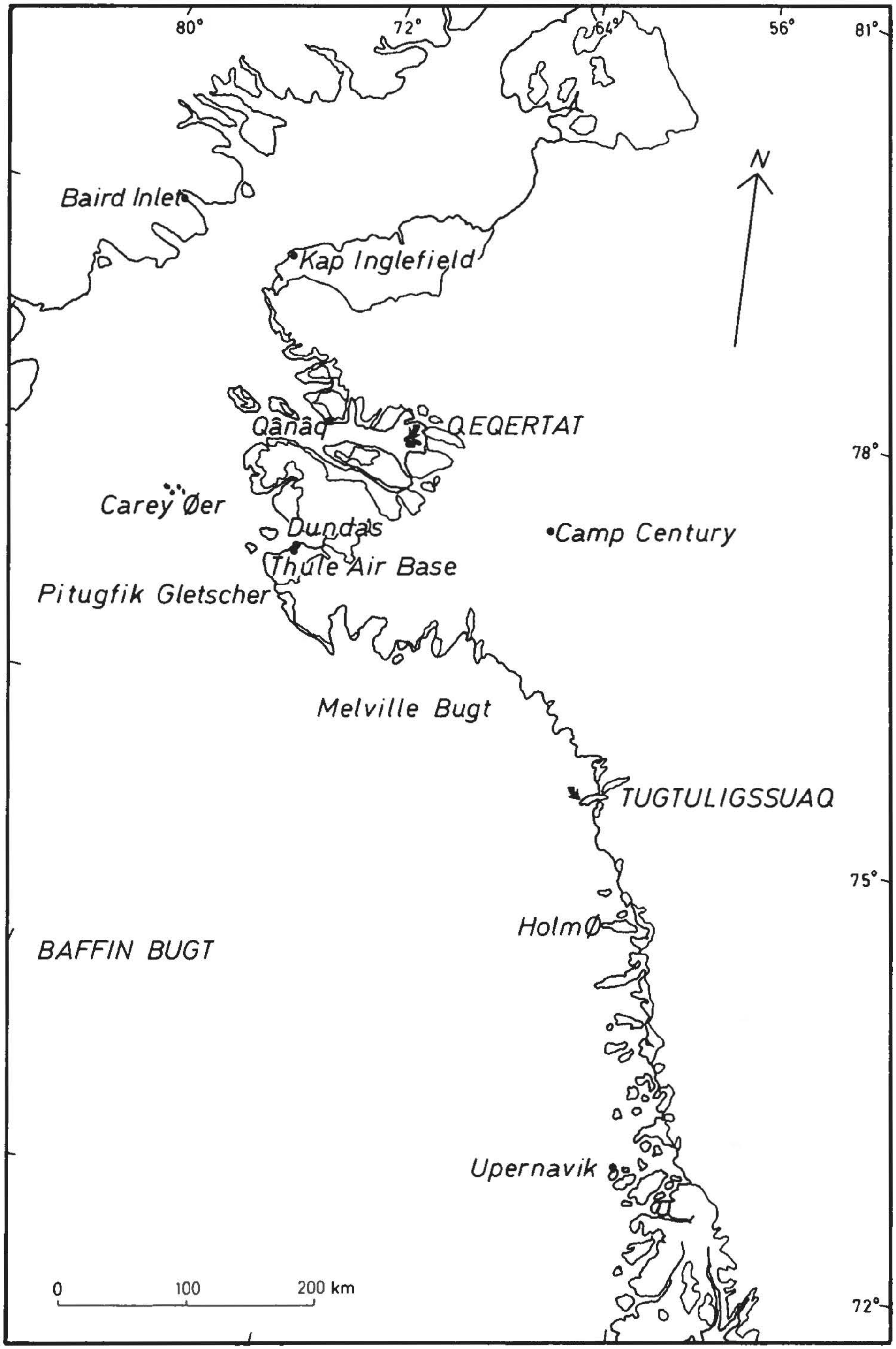
A total of only 83 taxa of phanerogams was found. The nomenclature of these plants follows Böcher et al. (1978). The flora of NW Greenland between 72° and 79° N has been mapped by Bay (1983).

Methods

The methods used in the field and in the laboratory have been described by Fredskild (1973, 1983a). In short they include corings with a piston-sampler with tubes 130 cm long, 3.4 cm wide inside, followed by the taking of one-ml microfossil samples every second cm, and of 1.5–4 cm thick macrofossil and radiocarbon samples, accumulated from many cores within a few m² of the lake bottom. Pollen samples are treated by cold HF before acetolysing, and embedded in glycerol. Absolute pollen counts have been used throughout, following a slight modification of the method described by Jørgensen (1967).

After 1½ years' storage pH and specific conductivity were measured in the sediment water after centrifuging. The conductivity has been corrected for pH (H^+). Likewise, the loss of water at 105°C, the loss on ignition, and the content of sand were measured in almost all the macrofossil samples. The content of sand was also measured in the pollen samples by weighing the sand decanted after the acetolysing. Although the latter method is rather inaccurate, a comparison of the two curves (Plate 1 and 2) shows good agreement. The

Fig. 1.
Map of Northwest Greenland.



combustible matter is expressed as percentage of dry weight.

Langesø

This 800 m long, shallow lake, *c.* 15 m a.s.l., is situated in a depression between a system of low, E-W ridges (Fig. 2,3). It receives only melt water from these low ridges, and by the middle of August the tiny, *c.* 75 m long brooklet to Rundesø had almost dried out. No phanerogams were seen in the lake, but wherever observed, the bottom was covered with a loose carpet of *Drepanocladus exannulatus* and *Marsupella arctica* (K.

Table 1. Meteorological observations at Qânâq, Dundas and Upernavik.

Mean temperature C°	J	F	M	A	M	J	J	A	S	O	N	D	yr
Qânâq													
month	−21.0	−22.7	−23.0	−17.1	−6.0	+1.1	+4.3	+4.6	−1.3	−8.0	−15.6	−21.2	−10.5
minimum	−24.7	−27.5	−27.6	−22.0	−10.3	−2.0	+0.9	+1.9	−3.8	−10.5	−18.9	−25.0	−14.1
maximum	−17.3	−17.9	−18.5	−12.3	−1.8	+4.2	+7.7	+7.2	+1.1	−5.6	−12.3	−17.4	−6.9
Dundas													
month	−22.3	−23.5	−22.9	−16.6	−5.7	+1.1	+4.1	+3.9	−1.3	−8.3	−15.5	−20.3	−10.6
minimum	−26.9	−27.9	−27.3	−21.2	−9.3	−1.7	+1.0	+1.2	−3.8	−11.2	−19.1	−23.5	−14.1
maximum	−17.7	−19.1	−18.4	−11.9	−2.1	+3.9	+7.1	+6.6	+1.3	−5.5	−11.8	−17.1	−7.1
Upernavik													
month	−16.9	−19.0	−18.7	−12.3	−3.7	+1.6	+5.5	+5.3	+1.3	−3.8	−8.6	−13.4	−6.7
minimum	−20.4	−22.1	−21.9	−15.4	−6.2	−0.8	+2.8	+2.8	−0.7	−5.6	−10.5	−15.7	−9.5
maximum	−13.4	−15.8	−15.5	−9.2	−1.2	+3.9	+8.2	+7.8	+3.2	−1.9	−6.6	−11.2	−4.3
Precipitation, mm													
Qânâq	4.9	6.0	3.2	4.4	4.6	7.1	24.3	29.2	11.7	5.4	4.8	2.8	108.4
Dundas	6.7	4.6	5.0	4.9	6.6	6.9	18.2	22.7	11.2	12.3	7.5	8.9	108.6
Upernavik	12.2	11.9	8.8	11.6	11.3	13.9	31.5	30.7	40.4	31.9	37.7	22.4	246.3

Source: Provisional mean temperatures and total amount of precipitation in mm. Greenland. Publikationer fra Det Danske Meteorologiske Institut. Copenhagen 1967–1982.

	Frequency of surface winds from S through W in %				Frequency of observations with calm weather in %			
	April	May	June	July	April	May	June	July
Qânâq	1.4	3.8	14.3	14.9	62.4	48.3	38.4	49.6
Dundas	2.1	11.8	25.1	19.6	79.2	59.1	48.7	48.8
Upernavik	19.2	20.1	24.1	20.5	38.4	36.4	36.6	43.7

Source: Summaries of Weather Observations at Weather Stations in Greenland 1966–1970. Publikationer fra Det Danske Meteorologiske Institut. Copenhagen 1978.

Damsholt det.), with numerous larval houses of Chironomids and a few of Tricoptera. Conductivity is 12 μmho, pH 5.6–6.3 (samples measured 3 times the year after they were brought home). Not until August 17 did an ice floe, until then covering most of the lake surface, allow the coring from a raft in the eastern end at a depth of *c.* 4 m. The ice disappeared during a storm on August 19. The exact depth was difficult to determine because of moss. A total of 33 cores was taken. The following layers were distinguished in the core used for pollen analyses (cm below the lake bottom):

6. 0–87 cm: Bright olive, slightly clayey gyttja with first many (0–20 cm), then few (20–87 cm), mosses. Very watery, especially towards top.
5. 87–100: Laminated, more or less clayey gyttjas, olive, with a greyish tone, especially at 90 cm. Olive-brown at 98.5–100 cm. No mosses but for a few fragments at 92 cm. Many remains of Cladocera.
4. 100–102: Laminated clay-gyttja, olive-grey. Jelly-like, with moss and Cladocera.
3. 102–104: Laminated, grey clay with a little gyttja.
2. 104–108: Violet clay, mostly without sand.
1. 108–125: Grey sand, unsorted, sharp-edged, clayey upwards, coarser and more or less stony downwards.

Common to all cores were the layers above the boundary at 100 cm whereas the thickness of the layers below varied somewhat. At the 108 cm boundary some gravel-size particles were often found, consisting of dried-up clay, washed out into the early lake. Similar particles occur in the sand, which varies in thickness from a few to more than 40 cm. A little deeper than the violet clay the coring was sometimes stopped by a stone.

A careful measuring of the depth below the lake surface and of the 100 cm boundary indicates that the Early Holocene sandy-stony lake bottom had been levelled by the violet clay before gyttja sedimentation started, and consequently the contemporaneity of the 4 cm subsamples in the single cores, accumulated to mostly *c.* 600 ml large radiocarbon and macrofossil samples, seems established.

Five samples have been radiocarbon dated (Table 2).

By means of a best-fit curve through the dates, calibrated according to Clark (1975) and Stuiver (1971), the sedimentation rate has been calculated (Plate 2).

Besides the microfossils shown in the diagram (Plate I), the following were found: *Alopecurus alpinus* type in sample 6, *Melandrium* 3, 20, *Sagina* 17, *Saxifraga caes-*

Fig. 2. Map of the western part of Tugtuligssuaq, drawn by N. Gylling Mortensen. Equidistance 25 m. L = Langesø, R = Rundesø.

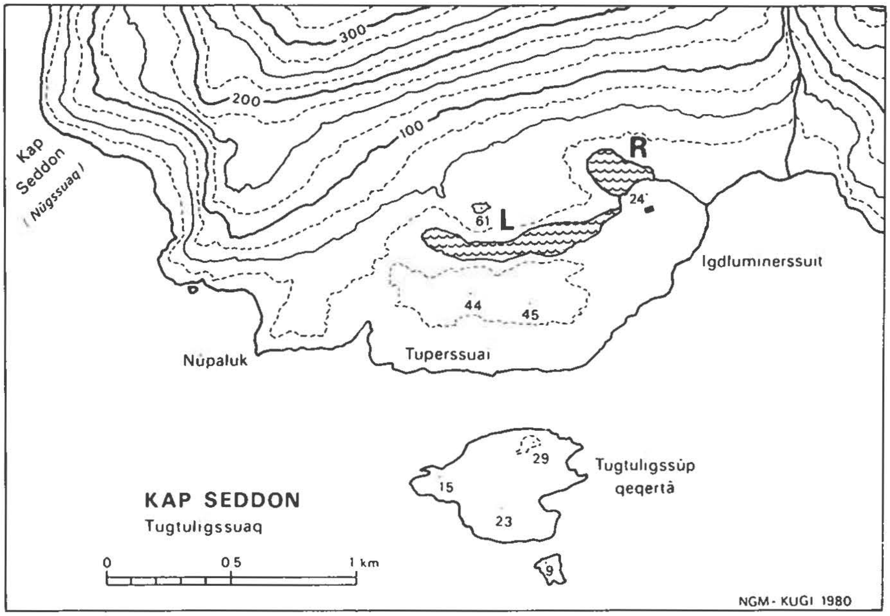


Table 2. Radiocarbon dates and δ^{13}C ‰ values, Langesø.

cm below lake bottom	laboratory no.	^{14}C age before 1950	δ^{13}C ‰	combustible matter, %
18–22	K-3690	2270±75	−19.2	14
38–42	K-3689	4150±90	−20.5	13
62–66	K-3688	4990±90	−19.6	19
82–86	K-3300	6710±105	−19.2	15
98.5–100	K-3276	8540±120	−17.4	8

pitosa type 17, *S. nivalis* type 4, *Tilletia sphagnii* 17, 18, *Equisetum* 10, *Pedicularis* 22, *Chamaenerion latifolium* 23. Only some of the curves of exotic pollen and spores are given. Thus, among Greenland taxa, *Diphasium* (present northern limit of *D. alpinum* is 72°) occurred in sample 8, 12, 15, 18, 23, 24, *Gymnocarpium dryopteris* (to 69° N) in 4, 6, and *Thalictrum alpinum* (to 71°33′ N) in 8, 21. Besides *Conifers* and *Ambrosia*, a few other non-Greenland taxa occurred in half of the samples. "Hystrix" was found in 1, 2 and 7, *Assulina* in 15, 17, 22, 23. Values less than 10 pollen/ml are not marked in the histogram; percentages less than 1% are given as 1%.

Fig. 3. Looking southwards over Rundesø (foreground) and Langesø. Aug. 15, 1979.

Rundesø

The 100–200 m wide, shallow lake, *c.* 14 m a.s.l., receives melt water from part of the 400 m high slope to the north and west, and furthermore Langesø drains through it. No phanerogams were seen , but as in Langesø the bottom is covered by a loose carpet of mosses. pH is 5.5–6.1, conductivity 16 μmho. There is a fairly broad shelf of washed-in sand, but in the southern half the depth reaches a maximum of 505 cm. Because of the many melt water streams to the lake, the melting of the winter ice was faster than in Langesø, and the corings were started in the beginning of August. 26 cores were taken with the 34 mm sampler under 425 cm of water. Because of friction it was only possible to press the tubes a few (4–15) cm down into the clay and sand below the gyttja, but with a smaller piston sampler, with brass tubes only 20 mm wide, 65 cm of the minerogenous sediment were cored.

The following layers were separated in the cores used for pollen analyses (cm below the lake bottom):

4. 0–120 cm:	Bright olive, clayey gyttja, with gradually downwards increasing content of clay with a slightly greyish tone. The upper 30–40 cm extremely watery and difficult to handle when extruded. Some moss fragments occur throughout, a good many in the deepest 12 cm.
3. 120–126:	Greyish, slightly sandy clay with a touch of gyttja and a few moss fragments.
2. 126–131:	Sand with clayey layers. The thickness of the layer varies from core to core.
1. 131–185:	Sand, rather coarse, angular, not water-worn. Because of the narrow core it was impossible to see any lamination.

Besides the microfossils shown in Plate 3, the following were found: *Alopecurus alpinus* type in sample 5 and 27, *Erigeron/Gnaphalium* 6, *Melandrium* 4 (3 pollen), 5, *Polygonum viviparum* 36, *Sagina* 17, *Saxifraga caespitosa* type 5, *Taraxacum* 5, 17, *Cystopteris fragilis* ssp. *dickieana* 10, *Equisetum* 4. Among exotics *Thalictrum alpinum* was found in sample 2, 7, 16, 35, *Botrychium* (N limit 73°) 1, 20, 24, *Chenopodiaceae* 9, 12, *Carya* 1. Furthermore, *Assulina* 6, 36, *Microthyrium* 11, 15, 34, "Hystrix" 1 (4), 2 (3), 3, 4, 7, 8. Values less than 100 pollen/ml are not marked in the histogram.

Because of the loose, very watery upper sediment, no macrofossil samples were taken in the uppermost 16 cm. All the macrofossils found are shown in the diagram Plate 4. The volume of the samples is 726 ml with the exception of the uppermost one (472 ml).

Zonation of the diagrams

As the zonation is not entirely based on the changes in the pollen diagrams, the term palaeovegetation zones (PV zones) will be used instead of pollen assemblage zones (Fredskild 1983a).

PV zone A: *Poaceae-Minuartia rubella* pioneer zone

Following the deglaciation a number of pioneer plants settled on the fresh soil: *Minuartia rubella, Saxifraga oppositifolia* and other Saxifragas, *Silene acaulis, Papaver radicatum, Koenigia islandica, Armeria scabra, Potentilla* and among monocotyledons *Poaceae*, of which seeds of *Poa pratensis/arctica* were found, *Luzula* and a number of *Carex* species, e.g. *C. nardina, C. misandra, C. capillaris* and *C. bigelowii.* Another distigmate *Carex* achene has the stipitate basis, characterizing sectio Heleonastes. It is most likely of *C. glareosa,* growing on or very near to seashores. If so, this would indicate that Langesø was not far above sea level, but as no marine diatoms were found in the minerogenous sediment of either of the lakes, they must be situated above the upper marine limit. *Armeria scabra,* five pollen of which were found in Rundesø and a fruit with attached sepals in Langesø, was not met with during the almost six weeks' stay on Tugtuligssuaq. It grows in dwarf-shrub heaths and fell-fields and in mossy fens that dry out during the summer. It is rare in the northernmost as well as the southernmost part of Greenland, towards the south being found only at higher elevations. The size and shape of the achenes of *Potentilla* species vary, rendering a determination impossible as to species. However, all achenes found throughout the cores resemble mostly those of *P. pulchella.* This species is fairly common on open, clayey-gravelly soil near the sea, on raised marine beds and at bird cliffs, southwards to 67° N in W Greenland, but it was not found on Tugtuligssuaq. *P. hyparctica* is fairly common here, whereas *P. chamissonis* and *P. nivea* were met with only once.

The clay is rich in rebedded pollen and spores, especially in Rundesø, where 3200 exotics per ml (64% of the pollen counted) are found in sample 1. Beyond doubt also the pollen of *Salix, Vaccinium uliginosum, Empetrum, Cassiope* and *Ericales* indet., all of which have thick exines and are known to be fairly resistent to corrosion, must be considered rebedded, the more so as they are missing in one or more of the overlying samples. A comparison between the *Dryopteris*-type curves from the two lakes, and between these curves and the curves of the exotics, reveals that some of these spores also are rebedded, whereas this is hardly or only to a minor extent the case with *Huperzia.*

Four soil samples were analysed to investigate a possible content of rebedded pollen (Table 3). Sample "a" is from a thin, dark, organic layer *c.* 0.5 m below the soil surface in an otherwise sandy-clayey soil. Judging from the pollen spectrum a humus layer under a former *Cassiope* heath has been buried by solifluction.

Sample "b" is from pure clay in a *Salix herbacea* snow-patch, "c" from clay with thin, darker solifluction layers under a *Salix arctica-Cassiope-Anthelia* vegetation and "d" from similar soil under a *Cassiope-Racomitrium-Salix arctica* vegetation. The pollen content varies greatly, as also does the content of exotic pollen.

Table 3. Number of pollen and spores from soil samples.

	a	b	c	d
Cassiope tetragona	340	70	12	36
Empetrum				2
Ericales sp. indet.		2	6	26
Cyperaceae	22	55		4
Gramineae		1		
Minuartia/Silene			1	2
Oxyria digyna		4		1
Salix arctica	7	40	1	6
Salix herbacea	2	20	2	
Dryopteris		2	2	16
Huperzia selago		48		6
Diphasium				1
Lycopodium dubium		2	1	3
Alnus		1		
Betula			1	29
Σ pollen counted	371	245	26	132
Σ pollen per slide	15600	490	26	264
Charcoal		2		
Wood fragm., exotic				6
Chironomidae		1		

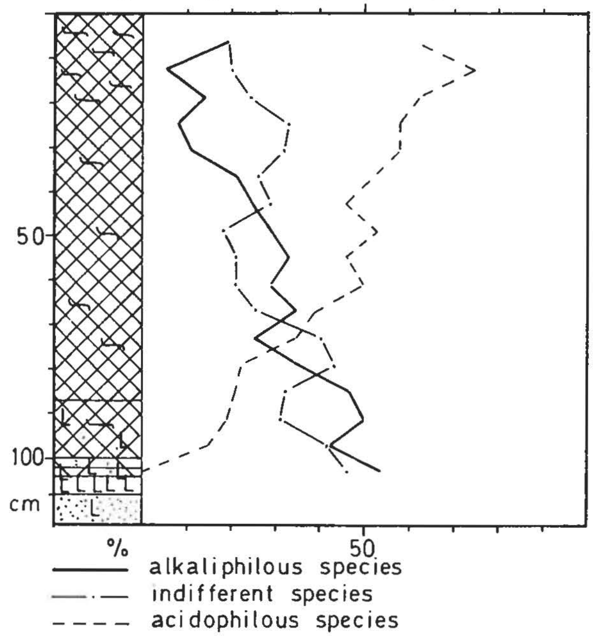


Fig. 4. pH spectra of diatoms, Langesø (after Foged, in press).

Especially sample "d" confirms that the major part of the exotic pollen and spores, and also of the *Dryopteris* spores in the gyttja samples, originates from clay washed out into the lakes.

In the beginning the lakes were so rich in suspended clay that neither plants nor animals could thrive. As soon as the water became clear enough, *Botryococcus* flourished, approaching 200 000/ml, a concentration only exceeded once in the Greenland lakes investigated so far, viz. in Johs. Iversen Sø (Fredskild 1983b). Shortly after, *Pediastrum boryanum* began to flourish, and *Daphnia pulex*, Chironomids, Tricoptera and *Lepidurus arcticus* were frequent, the last reaching its maximum at the transition to zone B. Likewise, the diatoms found indicate a rich lake, in which alkaliphilous and indifferent species dominate (Fig. 4). The terrestric plants as well as the organisms in the lake reflect primarily the physical properties, the fresh, minerogenous soil and the clayey, later on fairly rich water, rather than the climate. No hint of climatic conditions differing significantly from those of today can be deduced.

PV zone B: *Oxyria-Empetrum* pioneer zone

The pioneer plants dominate the vegetation, with the anemophilous *Oxyria digyna* dominating the pollen spectra. At least part of the soil surface is still comparatively rich, as indicated for example by *Carex capillaris* and *Juncus biglumis/triglumis*, typical of the fresh soil in frost boils, the first two species being extremely rare on Tugtuligssuaq today, the last not seen at all. Three *Ranunculus* pollen were found in Rundesø. Today only two species of *Ranunculus* occur, viz. *R. hyperboreus*, of which sterile specimens were found twice, and *R. pygmaeus*, met with at three sites growing in moist soil. Three other species, occurring south as well as north of Tugtuligssuaq, could have grown in the area, viz. *R. nivalis* and *R. sulphureus*, both growing today on moist, often mossy ground near snowbeds and in fens, and *R. confervoides*, which together with *Hippuris* is the most widespread of the Greenland hydrophytes, geographically as well as ecologically.

A certain stabilization and possibly an initial leaching of the soil is indicated by the immigration and flourishing of *Empetrum hermaphroditum*. In the second half of the zone also *Vaccinium uliginosum* and *Cassiope* immigrate. Pollen of other genera not represented on the peninsula today have been found in one or both lakes, viz. *Tofieldia*, *Taraxacum*, *Erigeron/Gnaphalium* and *Hippuris*. *Tofieldia pusilla* is a southern species, reaching only 74°30′ N in W Greenland, whereas *T. coccinea* is growing in *Cassiope*- and *Diapensia*-heaths and fellfields between 67° and 72° N and at a few sites in the Thule area northwest of Tugtuligssuaq (76°–78° N). The only *Taraxacum* known from this part of Greenland is *T. phymatocarpum*, growing on clayey or stony, fairly dry ground. *Erigeron/Gnaphalium* pollen, found in both lakes, most likely originate from *E. compositus*, growing on dry slopes and rocks in the continental parts of Greenland, yet only exceptionally south of 66° N. The rare *E. eriocephalus* occurs north and south of the peninsula, whereas the other *Erigeron* species as well as *Gnaphalium* are southern species. A single, unmistakable pollen of *Hippuris vulgaris* occurs in L5. This aquatic plant occurs in poor as well as rich waters all over Greenland, but is extremely rare in the farthest north.

The phytoplankton production in the lakes is high, dominated by *Pediastrum*, primarily *P. boryanum*, followed by *P. integrum/muticum*. A maximum is reached at 5 000 000 *P. boryanum* coenobia per ml in the beginning of the zone in Rundesø. Even considering the slow sedimentation rate, this must reflect an extremely high annual production, of the order of 50 000/cm^2/yr, if the sedimentation rate is 1 cm/100 yr. Values of this order have only been found twice in Greenland lakes, viz. in early Holocene sediments in the low arctic Johs. Iversen Sø (Fredskild 1983a,b) and Spongilla Sø (Fredskild 1973). Alkaliphilous diatoms dominate (Fig. 4).

Not only phytoplankton but also Cladocera and insects flourished. Of special climatic significance is the finding in both lakes of a pronotium of the beetle *Colymbetes dolabratus* (U. Røen det.). Its northern limit today at c. 73° N is controlled by the duration of the ice-cover on lakes (Røen 1963). Its occurrence in zone B seems to indicate longer and milder summers, which is also supported by the finding of a bone from the sternal armature of the stickleback *Gasterosteus aculeatus* (U. Røen det.), the northern limit of which today is at 74° N.

On the assumption that the radiocarbon dates are reliable, the two pioneer zones lasted about one and a half millennia. As in the S and W Greenland diagrams, *Empetrum* and *Vaccinium uliginosum* were among the first dwarf-shrubs to immigrate, after a couple of centuries. It seems as if *Empetrum* was more frequent in zone B than later on, yet it did not cover large areas around the lake. However, the ratio between seeds and leaves in Rundesø (Plate 4) indicates a higher fertility, with which the higher pollen frequencies in zone B, as compared to zone C and D, may be connected. *Cassiope* immigrated about one millennium later. Of the total of 83 phanerogams, found to be growing on Tugtuligssuaq today, 31 phanerogams have been proved to occur in the pioneer phases, and in addition five species not found today were growing in or near the lake. Furthermore, 10 species, of which some undoubtedly occurred already during zone A and B, have been demonstrated in later parts of the diagrams. If to these are added the many species that have not been demonstrated, either because of little or no pollen or macrofossil production, e.g. *Saxifraga foliolosa, S. cernua, Antennaria ekmaniana, A. canescens* and *Cardamine bellidifolia,* or because their pollen or spores cannot be determined to species level, e.g. *Poaceae, Luzula, Polypodiaceae* spores without perine, a picture emerges of a fairly diverse vegetation, rich in species. This pioneer vegetation is common to all Greenland corings. Thus in four lakes at Godthåbsfjord no less than 64 species or genera were determined in samples from the first 1.4 millennium. Later on many species were ousted or banished to isolated habitats of unstable soil like frost boils and screes.

Exotic pollen show a minimum in both lakes in zone B. This is partly coincident with the decrease in content of clay with rebedded pollen, partly because very few pollen-carrying winds from south of the Laurentide Ice reached Melville Bugt (Fredskild 1984).

PV zone C: *Salix-Cyperaceae-Cassiope* zone

Cassiope reaches a first maximum at the beginning of the zone, followed by a decrease in percentages. The only slight decrease in *Cassiope* pollen per ml in Langesø, combined with a seemingly increasing sedimentation rate (Fig. 5), indicate an almost constant influx of

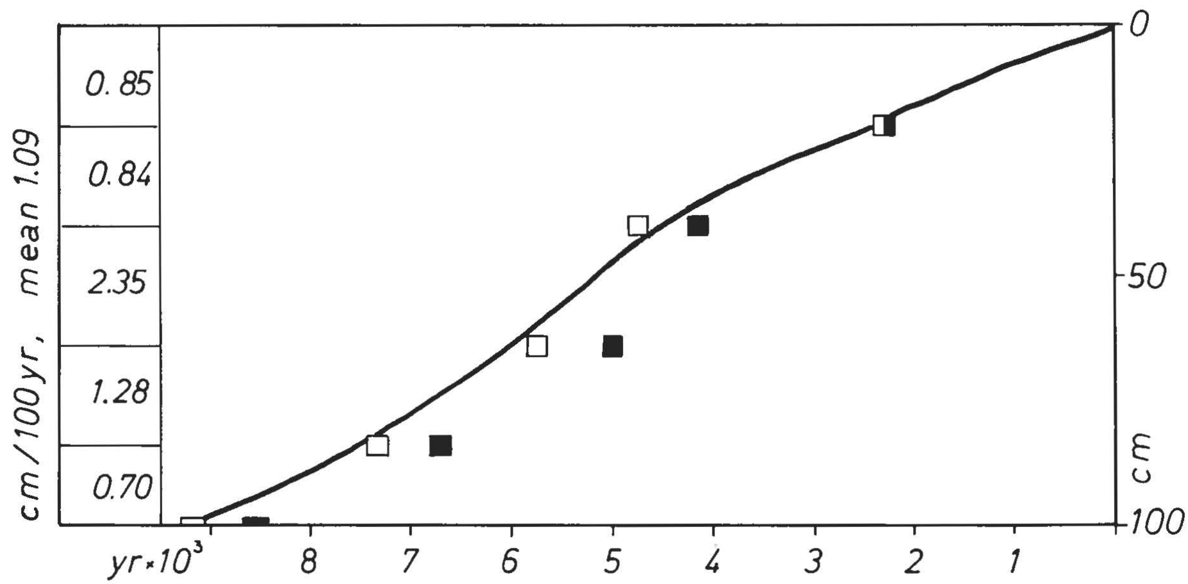


Fig. 5. ^{14}C ages versus depth, Langesø. Black boxes are ^{14}C dates, open boxes calibrated dates.

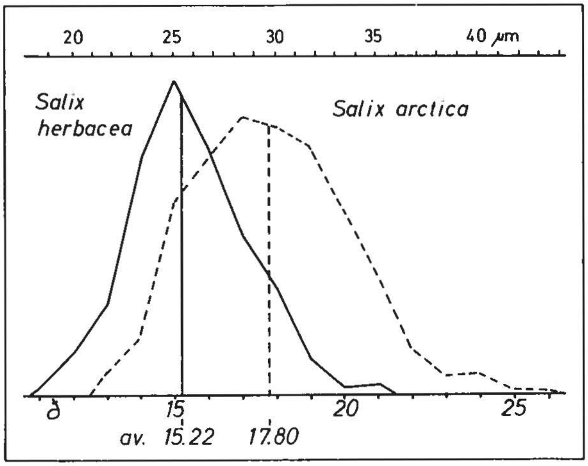


Fig. 6. Length measurements of fossil *Salix* pollen in Langesø. Unit = 1.67 µm.

Cassiope pollen in the first part of the zone. *Salix arctica* immigrates, followed shortly after by *S. herbacea*. Usually the separation of the pollen of these two species causes no trouble. Funder (1978, table 5) has shown that the pollen of *S. arctica* are bigger than those of *S. herbacea* (22.1 and 18.0 µm resp.). As a matter of precaution, the *Salix* pollen in the Langesø core were measured (Fig. 6). The greater sizes (29.7 and 25.4 µm) are due to different embeddings, but the ratios are much alike: 1.17 for the Langesø material, 1.23 for the recent material.

Cyperaceae are increasing, making up 50% of the pollen in the middle of the zone. Among the macrofossils, achenes of *Carex bigelowii*, 50 in all, are by far the most important in the two lakes. Today it is the most frequent *Carex* species, occurring in the widespread *Cassiope-Salix arctica* dwarf-shrub heaths and in the not too late-melting snow-patches. It grows on moist ground between boulders on the east side of Rundesø. Other possible sources of the *Cyperaceae* maximum could be *Carex stans, Eriophorum scheuchzeri* and *E. angustifolium*, respresented by 3, 1 and 0 achenes. A fragmentary fen with these three species was found at the western end of Langesø, and a few, mostly sterile *Carex stans* grow at Rundesø.

Shortly after their immigration the curves of both *Salix* species reach a level that remains almost unchanged up to the present day. By the beginning of the zone, however, several species are severely reduced: *Empetrum, Oxyria,* and especially the grasses, which in most samples make up only 0.5–2%. Low percentages like these have not been found previously in any pollen diagram from Greenland lakes, and only one recent gyttja sample has percentages of the same order, a sample from a pond on the S Greenland outer coast in surroundings totally dominated by *Empetrum* heaths (Fredskild 1973, table 22). Likewise, many open ground herbs become rarer or disappear during zone C: *Papaver, Tofieldia, Cerastium, Stellaria, Minuartia/Silene, Armeria, Campanula* and *Potentilla*. The pollen influx increases.

In the Langesø diagram, with very few rebedded pollen, the *Dryopteris* curve decreases in the beginning of zone C. Three ferns grow on Tugtuligssuaq: *Cystopteris fragilis* and *Woodsia glabella* (both found only once on rocks at Itivdlipaluk), and *W. alpina* (found twice). As the bedrock disintegrates easily, the rocks near the lakes may well have offered more habitats for ferns in Early Holocene than today. At least it is difficult to see any climatic cause for the decline, nor can it be a question of competition with other plants. Moreover, decreasing fern values, also in influx, is seen in the four Godthåbsfjord lakes (Fredskild 1983a) and in some of the S Greenland lakes (Fredskild 1973, Kelly & Funder 1974).

From the middle of the zone, a gradual increase in *Cassiope* pollen corresponds with a decrease in *Cyperaceae,* whereas most other curves continue unchanged. The only difference between the lakes, apart from the *Dryopteris* spores, which will be discussed below, is seen in *Salix*. In Langesø, surrounded by many *S. herbacea* snow-patches, the two *Salix* curves remain at the same level, whereas in Rundesø *S. herbacea* decreases while *S. arctica* increases.

In all S and SW Greenland lakes a marked increase in long-distance *Alnus* pollen is seen *c.* 7000 B.P. (Fredskild 1983a, 1984), but not until between 6500 and 6000 B.P. did the low pressures with pollen-carrying winds from Labrador regularly reach as far north as Melville Bugt and Inglefield Bredning. Whether the *Betula* pollen came from N America or from Greenland is uncertain, but the increase in *Betula* later than that of *Alnus* suggests the latter. *B. glandulosa* did not immigrate to S Greenland until shortly before 4000 B.P., whereas *B. nana* arrived at Godthåbsfjord *c.* 6300 B.P. Its spreading to more northern parts of the west coast has not yet been dated, but its spreading to the Disko Bugt area was later than 6750±105 (K-3505), which is the date of a sample without *Betula* pollen from a lake at Diskofjord. By *c.* 2300 B.P. a marked decrease in *Alnus* as well as in *Betula* is seen, undoubtedly caused by a reduction in the number of southerly winds reaching Tugtuligssuaq in spring. There is no self-evident explanation of the *Cassiope* increase and the *Cyperaceae* decrease from the middle of the zone. The spreading of *Cassiope* heaths and, as seen in Rundesø, of *Salix arctica,* doing well on sites with a snow-cover lasting too long for *Cassiope,* may indicate higher precipitation and/or later melting of snow.

The phytoplankton production in the lakes decreases drastically in the beginning of the zone. Thus, in Langesø *Botryococcus* is reduced by a factor 10, *Pediastrum boryanum* decreases from 442 000/ml to less than 50 in the upper half of the zone, and *P. integrum/muticum,* with 500 000/ml in zone B, is totally missing from the middle of the zone upwards. A similar trend is seen in Rundesø. In both lakes *P. braunii* immigrates contemporaneously with the extinction of *P. integrum/muticum* but never becomes frequent. Acidophilous diatoms increase throughout at the expense of alkaliphilous and indifferent species, thus confirming the picture of a progressive oligotrophication, common to all Greenland lakes in gneissic areas (Fredskild 1983b) – with however the exception of Qeqertat, see p. 16.

The reduction in phytoplankton is also reflected in the animals living in the lakes: *Lepidurus arcticus* and *Daphnia pulex* appear in the middle of the zone, whereas the number of Chironomids and Tricoptera (probably all *Apatania zonella*) remains unchanged in Langesø. In Rundesø Chironomids decrease while Tricoptera increase upwards. A few *Alona* occur throughout the zone in Langesø. *A. costata,* known from NW Greenland and Ellesmere Island (Røen 1981), is the most likely, but *A. guttata,* with a N limit at 73° in W Greenland (Røen 1962) cannot be excluded, the more so as it has been proved as far north as Vølvedal, N Greenland, (83°02′, Bennike 1983) in three peat samples, slightly younger than 5000 B.P. *Acroperus harpae* (N limit at Dundas, 76°34′, Røen 1981) increases in number towards the end of the zone in Langesø. Also the content of sand in Langesø (Plate 1 and 2) increases upwards. This need not be a result of greater washing of sand into the lake, but may be a result of decreasing sedimentation rates, connected with a smaller production of organic matter in the lake itself.

PV zone D: *Cassiope-Salix-Cyperaceae* zone

In the Langesø diagram an upper zone is separated, mainly because of the significant decrease in long-distance *Alnus* and *Betula. Cassiope* reaches its Holocene maximum in the beginning of the zone. In sample 22 *Cassiope* pollen make up 77% of the pollen, but this is obviously caused by macroscopic supply. Because of this, the percentage is estimated intermediate between sample 21 and 23, and the ΣP/ml and influx have been calculated on this basis. Six *Juncaceae* pollen, most likely of *Luzula arctica* or *L. confusa,* both very common around the lake, occur in the four uppermost samples, as compared to five pollen in the rest of the diagram. The increase in *Poaceae* in the uppermost sample may be fortuitous. It is not seen in Rundesø. Here the curves of *Cyperaceae* and *Cassiope* parallel those in Langesø, but it has been impossible to place the border between zone C and D in this diagram.

Pollen influx, long-distance and rebedded pollen

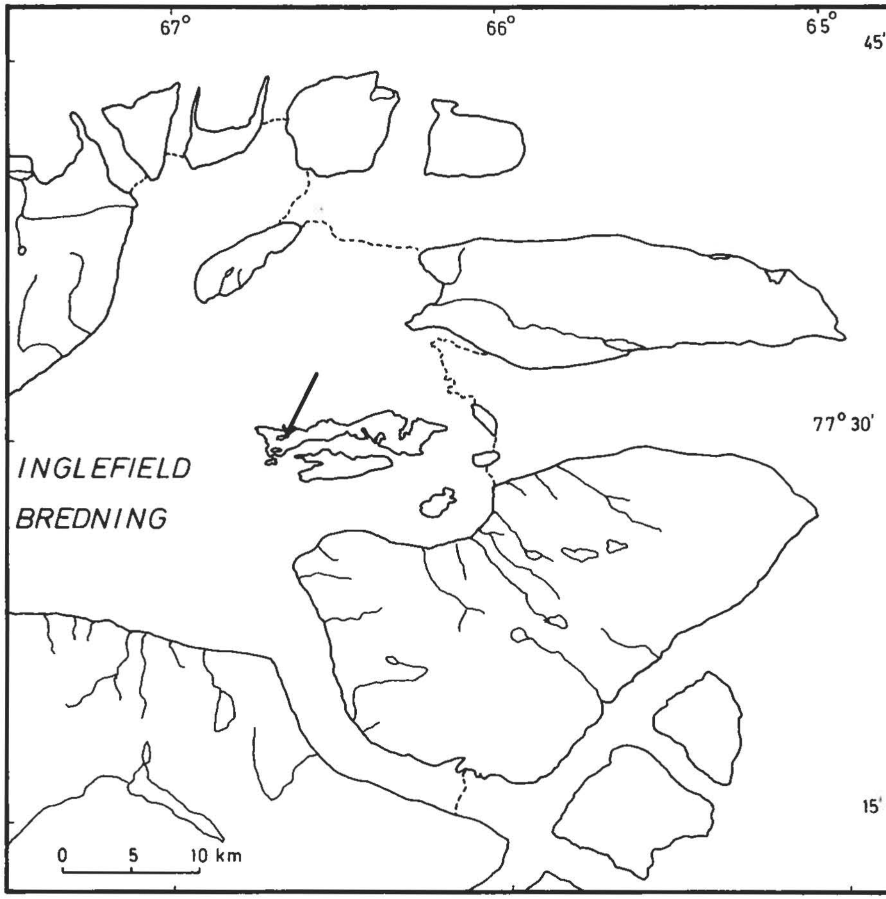
As mentioned above, Langesø receives very little melt water from its surroundings, and the supply of washed-in pollen must be very low. Therefore the influx is believed to reflect the pollen production in this high arctic area very well. For the whole core the average influx (excluding exotics) is 15.8 pollen/cm²/yr. Supposing that the best-fit curve (Fig. 5) is reliable, the influx was 6–10 in sample 1–4, increasing to 20–30 in the middle of zone C and then decreasing to 5–7 in the uppermost samples. This is in accordance with the results from other high arctic lakes: Qeqertat (Plate 5) with an average of 7 during Hypsithermal, decreasing to 1 in the recent pollen zone; Kap Inglefield further north (78°32′) with a Hypsithermal average of 7, decreasing to *c.* 0.5 (Fredskild unpublished); Baird Inlet, Ellesmere Island, where Hyvärinen (1985) estimates the maximum Holocene influx to be closer to 5 than 15, decreasing to *c.* 1 in the recent pollen zone. In low arctic areas the influx is much higher (150–3000, Fredskild 1985).

The influx to Rundesø is significantly higher, on an average *c.* 160 cm²/yr for the whole core. This is caused by melt water running down to the lake in numerous small streams, washing the preceding year's pollen deposition away from the soil surface, stones and vegetation. In well-vegetated areas such washing down of pollen from surrounding slopes can give odd results, e.g. the S Greenland Drepanocladus Dam and Galium Kær with 25–60 000 pollen/cm²/yr in the older sediments (Fredskild 1973).

Like in Langesø the *Alnus* increase in the Rundesø diagram is contemporaneous with the immigration of *Salix herbacea,* and higher up in the diagram the *Alnus* curve declines. The increase in *Betula* comes a little later, but unlike in Langesø, the *Betula* curve does not fall, showing rather a slightly increasing trend upwards. This must be explained by an increasing supply of rebedded pollen from the clay, which contains very few *Alnus* pollen but many *Betula,* as illustrated by sample 1 and 2 in Rundesø (482 *Betula* against 25 *Alnus*). This would indicate an increase in melt water, and thereby precipitation, eroding the surrounding till deposits, and maybe also an increase in frost boil activity on the level ground just around the lake on the W, S and E side. The *Dryopteris* curve also increases in the upper half of the diagram, in contrast to the marked decrease in Langesø. Likewise, the number of pollen/ml increases upwards. Radiocarbon dating has not been carried out in Rundesø because of the risk of contamination with older humic substances washed down from the surroundings, as seen in the reversed date-sequence in the upper part of a core from a Faroe Islands lake surrounded by steep slopes (Jóhansen 1977). If the *Alnus* decline at *c.* 60 cm is contemporaneous with the decline at *c.* 2300 B.P. in Langesø, then the sedimentation rate in the upper half of the Rundesø diagram is *c.* 1 cm in 40 yrs, with an average deposition of 440 pollen cm²/yr on the lake bottom. So the average influx would be *c.* 50 in the deeper 60 cm of the core, and the sedimentation rate 1.06 cm/100 yr.

The dominating role of washed-down pollen, contemporary as well as rebedded, in the upper part of the

Fig. 7. Sketch map of the head of Inglefield Bredning. The dashed line indicates the margin of the ice cap towards the sea. The cored lake is shown by the arrow.



Rundesø diagram, contrasting with the very few in the Langesø diagram, is also illustrated by the higher percentages of long distance Conifer, *Ambrosia* and especially *Artemisia* pollen in Langesø (the north limit of *Artemisia* in W Greenland is 72°).

Qeqertat

Geography

Some low, gneissic roche moutonné islands, with hillocks rarely more than 100 m high, are situated at the head of Inglefield Bredning (Fig. 7). I spent August 6–16, 1980, in the western half of the biggest island. The highest point, 78 m a.s.l. (hand-level), is on a little plateau, covered above 73 m with sand, stones and boulders, which is considered the upper marine limit. Below this level, ridges and level ground are free of till-like material, and frost boils, showing marine clay with shell fragments, are frequent. Two shell samples, consisting of equal amounts of *Hiatella arctica* and *Mya truncata,* from frost boils at 43 m and 22.5 m a.s.l. (hand-level), the latter next to the lake cored, have been dated (Table 4). By means of these and the dating of the basal limnic gyttja in the lake, an emergence curve has been constructed (Fig. 8). According to this, the island became free of ice 9500–9000 B.P. Apart from the two species

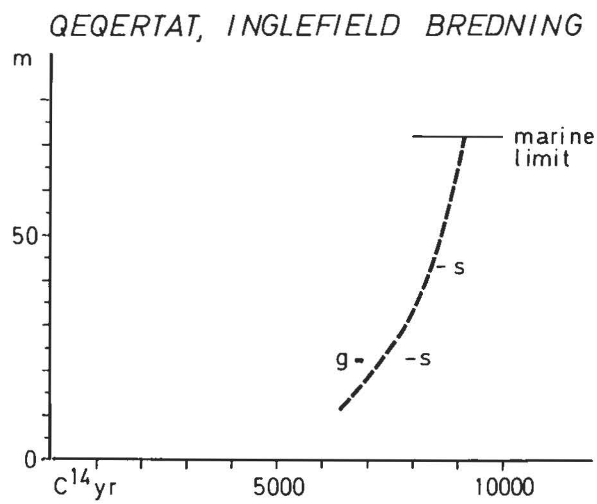


Fig. 8. Emergence curve, Qeqertat. Radiocarbon datings: see Table 4.

Table 4. Radiocarbon dates and $\delta^{13}C$ ‰ values, Qeqertat.

cm below lake bottom	Laboratory no.	^{14}C age before 1950	$\delta^{13}C$ ‰	combustible matter, % of dry weight
43–51	K-3740	3610±80	−18.5	28
71–75	K-3739	4370±85	−20.7	37
103–107	K-3738	5370±95	−19.9	32
131–135	K-3502	6800±85	−22.6	10
shells, 22.5 m a.s.l.	K-3503	7930±120	0.5	
shells, 43 m a.s.l.	K-3504	8620±125	1.3	

mentioned, a single fragment of *Cardium ciliatum* was found in the 22.5 m sample (K. Strand Petersen det.).

The nearest meteorological station is Qânâq/Thule, *c.* 60 km to the west at the entrance of the fjord, more exposed to winds from Baffin Bay. Here, 3 months have a positive mean temperature, with July and August between 4 and 5°C (Table 1). The climate at Qeqertat was said to be more sunny, and judging from the vegetation, the climate is intermediate between the high arctic, maritime climate of Tugtuligssuaq and the high arctic, continental, desert-like climate in central Peary Land.

Vegetation

The landscape is characterized by low, E-W running ridges of polished gneiss without or with only a thin veneer of sandy soil. The shallow depressions between the ridges contain hummocky fens, sometimes with small ponds. Scattered *Carex nardina* grow on the driest rocks, whereas *Carex rupestris* dominates the dry rocks with shallow soil. *Dryas integrifolia* is often subdominant here; accompanying plants include *Saxifraga tricuspidata, Hierochloë alpina* and *Melandrium triflorum. Vaccinium uliginosum,* not fruiting, and *Empetrum hermaphroditum* are common on not too dry rocks and on top of the hummocks in the mossy *Cassiope* heaths. Such were seen on N-facing slopes and moist, level ground around the fens. *Salix arctica* is the species with the widest ecological range, growing frequently from the driest rocks to the fens. Likewise, *Dryas* shows great tolerance, yet in the fens it is only seen in the "microheaths" on top of the highest hummocks. *Carex bigelowii* is very common in the heaths and on not too dry rocks.

Cyperaceae dominate the fens. Around ponds and lakes a zone is dominated by *Carex stans,* with some *Eriophorum scheuchzeri* and scattered *E. triste, Carex marina* and *C. maritima.* On slightly higher ground the fens become hummocky, with heath-like vegetation on top of the highest hummocks and with *Carex misandra, C. atrofusca, Kobresia simpliciuscula* and *Arctagrostis latifolia* on the lower ones. Between the hummocks the soil is bare or has a blackish cover of algae. *Juncus biglumis, J. triglumis* and *Carex capillaris* dominate the many frost boils. Ponds and lakes are fairly rich (pH 7.7–8.1, conductivity 110–322 µmho). The only hydrophyte, *Hippuris vulgaris,* is rare, growing in only two ponds.

The widespread *Cassiope-Salix herbacea-Anthelia* snow-patches characterizing Tugtuligssuaq were not met with on Qeqertat. *Salix herbacea,* close to its northern limit, was seen only once. In all, 91 species of phanerogams were found, as against 83 on Tugtuligssuaq, an indication of a greater diversity of biotopes.

Corings

The only lake which could be cored is *c.* 1000 × 1–200 m (Fig. 9), with a threshold slightly above the surface at 22 m a.s.l. (hand-level). The coring was hampered and sometimes made impossible by very big ice floes drifting around. 26 cores were taken under 3 m of water. No hydrophytes were seen in the lake, but loose carpets of *Scorpidium scorpioides* and *Calliergon* cf. *stramineum* and pea-size *Nostoc* balls were lying on the bottom. Because of this and the extremely watery gyttja, the exact depth could not be fixed. Two widely overlapping cores were used for pollen analysis, samples 1–29 from one, 30–36 from another. In these the following layers were distinguished (cm below lake bottom):

10. 0–27 cm:	Very watery, gritty gyttja with *Nostoc* balls, colour bright olive, slightly greyish.
9. 27–47:	Bright olive, slightly laminated, very watery gyttja with *Nostoc.*
8. 47–51:	Like layer 9, but with a greyish tone.
7. 51–55:	Reddish gyttja, slightly more firm.
6. 55–74:	Slightly laminated, bright, brownish-olive gyttja with only a few *Nostoc.*
5. 74–77:	Bright olive gyttja, with a reddish tone.
4. 77–129.5:	Laminated, bright, brownish-olive gyttja. 102–129.5 with many, still green *Nostoc* decreasing in size and number upwards in the layer.
3. 129.5–133.5:	Finely laminated, firm gyttjas, mostly brownish. At 133.5 a 3 mm thick, blackish-olive layer.
2. 133.5–135:	Very finely laminated. Olive and dark olive gyttja layers alternate with paper-thin clay layers.
1. 135–140:	Marine clay and sand.

Most remarkable are the many *Nostoc* balls throughout the cores. They were still green, and a microscopic in-

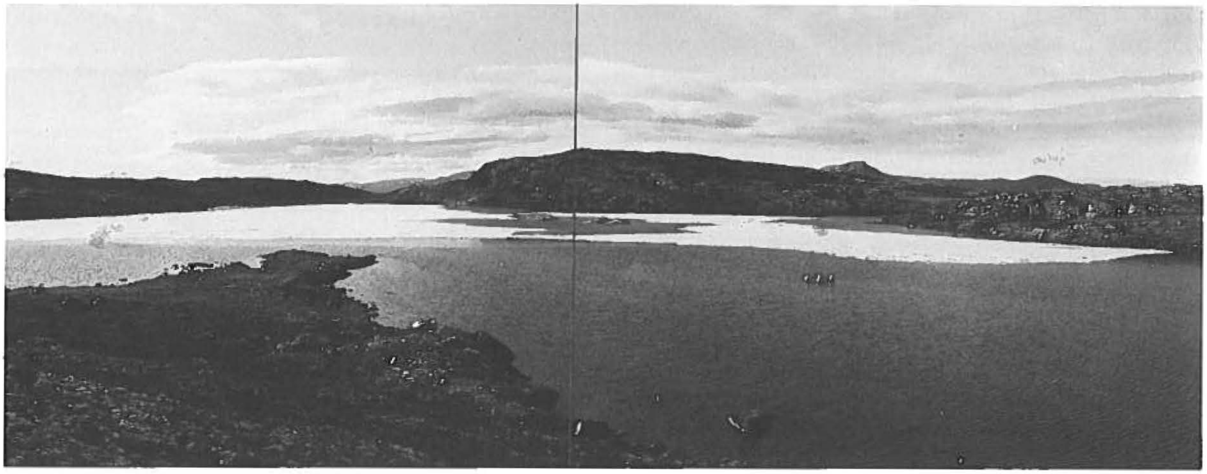


Fig. 9. Qeqertat, looking northwestwards over the cored lake. Aug. 9, 1980.

vestigation revealed the green content of some of the cells still in contact with the wall. Similar well-preserved *Nostoc* balls were found in the earliest layers of Johs. Iversen Sø at Godthåbsfjord (Fredskild 1983a). A contamination with recent material is out of the question.

When the plexiglass tubes were placed next to each other, it became evident, thanks to the different colours in the laminated gyttja, that all layers were equally thick below *c.* 63 cm. Above this level they varied a great deal. The accumulated macrofossil and radiocarbon samples from layer 1 till the middle of layer 6 were cut according to the depth, with the black 3 mm layer at 133.5 cm as reference level. Above the middle of layer 6 some of the cores were "stretched" or "pressed" a little. Thus, for example, the distance of the reddish layer, easily visible in all 26 cores and beyond doubt reflecting a synchronous but unknown event, varied up to 7 cm from the reference level. The extremely watery character of the gyttja is shown by the total weight of organic plus minerogenic material after drying at 105°C (Plate 6), ranging from 2.5 to 4.3% of the wet weight in the samples from 5–127 cm.

Six gyttja and two shell samples have been radiocarbon dated (Table 4).

Zonation of the diagram

Besides the microfossils, shown in the diagram (Plate 5), the following were found; *Salix herbacea* in sample 8, 29, *Alopecurus alpinus* type 30, *Juncus/Luzula* 7, 9, *Diapensia* 8, *Saxifraga caespitosa* type 8, 19, 28, *Saxifraga nivalis* type 13, 24, *Vaccinium* 15, *Sphagnum* 22, 24, *Ambrosia* 5 (4 pollen). Values less than 100/ml are not marked in the histograms of *Pediastrum,* but a few coenobia occur in almost every sample.

PV zone A: *Dryopteris-Cyperaceae* zone

This zone is distinguished mainly by the high frequencies of spores of *Dryopteris* type. Contrary to the till material in the deepest samples in Langesø and Rundesø, the marine clay in sample 2 and 3 contains very few exotic pollen (1.7 and 3.8%), and two samples from the marine clay (136 and 138 cm) were almost without pollen. It is therefore concluded that most of the spores are contemporary. The perine was intact on four out of 46 spores in sample 2, showing that these four are of *Cystopteris fragilis* ssp. *dickieana,* which today is growing here and there on the rocks on Qeqertat. Two spores of the same species were found in sample 14, one in 18. *Woodsia glabella* occurs also but is rare. Considering how loosely the perine fits to the spore, it is hard to believe that it would not be lost if embedded in till. Single *Cystopteris* spores also occur in the diagrams from Langesø, Rundesø and Kap Inglefield. Hyvärinen (1985) has a similar *Polypodiaceae* maximum in the deepest samples of the Baird Inlet diagram, and assumes a local production. An early *Polypodiaceae* maximum is far from being a specific high arctic phenomenon. A number of S and W Greenland pollen diagrams show early and/or mid Holocene maxima, relatively as well as absolutely, which are connected neither with rebedded nor with long-distance pollen.

Salix arctica immigrates in the beginning of the zone: 20 pollen in sample 2, none in sample 1. To be sure of this, a sample from layer 2 in another core was analysed, and the immigration around 6800 B.P. was confirmed. The following were found in this sample (same order as in the diagram): *Dryopteris* 48, *Equisetum* 1, *Tofieldia* 1, *Cyperaceae* 33, *Oxyria* 2, *Cassiope* 7, *Poaceae* 9, *Papaver* 1, *Dryas* 1, *Salix arctica* 0, *Ranunculus* 1, ΣP 105, ΣP/ml 577, *Artemisia* 1, wood fragments 2, charcoal 3. *Botryococcus* 9700, *Pediastrum integrum/*

muticum 8800, *P. boryanum* 1100, Chironomidae 6 and "Hystrix" 45 600 per ml. In addition one pollen of *Taraxacum* and one of *Chenopodium* type were found.

As more than two millennia had passed since deglaciation of the more elevated parts of Qeqertat, all or most other plants had immigrated, and the vegetation had been consolidated, with *Cassiope* heaths, fens and other vegetation types like those of today. Fragments of *Equisetum variegatum* rhizomes and achenes of *Carex capillaris*, both growing in frost boils beside the lake today, are found, as are achenes of *Carex bigelowii* and other Carices, but remains of dwarf-shrubs dominate the samples.

When the lake is isolated from the sea, the diatoms indicate a highly alkaline water (Fig. 10). This may well be a result of washing-in of clay from the surrounding marine beds, as shown by the many "Hystrix" in sample 2. Chironomids, *Alona* and *Daphnia* immigrate, shortly after followed by *Lepidurus* and Tricoptera.

PV zone B: *Cyperaceae-Cassiope* zone

This zone, covering most of the diagram, is dominated by *Cyperaceae*, as far as pollen are concerned. Judging from the macrofossils, *Carex bigelowii*, which is very common in heaths, especially *Cassiope* heaths, and on not too dry rocks, is the main supplier. This, however, most likely is a distorted picture. South and east of the lake there are fairly large areas with fen vegetations as described above, partly separated by very low ice ramparts which will prevent macrofossils, but not pollen, from reaching the lake. Part of the shore is made up of few m high, rocky slopes covered by *Cassiope-Racomitrium* heaths with *Carex bigelowii* and *Salix arctica* in protected places, *Vaccinium* and *Dryas* heaths in drier places. Macrofossils from these communities are easily washed down to the lake, thereby being overrepresented. However, macro- and microfossils supplement each other. In the more than 4000 pollen of local taxa in the diagram, only one certain pollen of *Vaccinium* – which is very common on Qeqertat today – was found (a few atypical grains may be hidden in the curve of *Ericaceae* sp. indet.). However, in almost every sample there are *Vaccinium* leaves, and even a seed and two well preserved anthers, still with the Bicornes appendage, were found in the deeper part of the zone. This can be taken as an indication of warmer conditions, since not a single berry was found in 1980, in spite of searching. Apart from this, the curves and histograms of local taxa are not very informative about the palaeoclimate. Most pollen curves keep their level for about three millennia. However, the long-distance pollen point to more frequent southerly winds reaching the area: 124 *Alnus* pollen were found in samples 6–22 ($\Sigma P = 2538$) but only 16 in samples 23–25 ($\Sigma P = 1267$). Corresponding numbers for *Betula* are 46 and 10. The peak in exotics in sample 20 may be caused by contamination of the sample during preparation, as the 35 pollen include 21 *Juglans*, 6 *Fagus* and 1 *Aesculus*, none of which were met

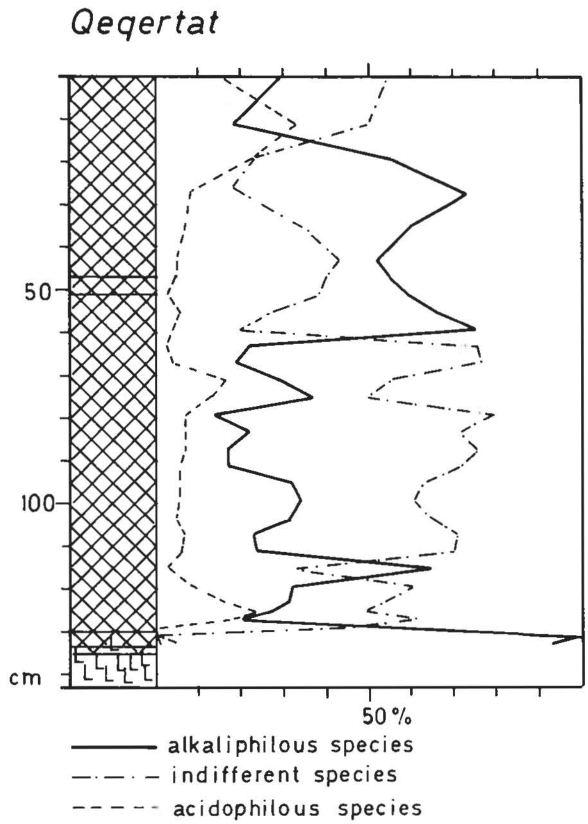


Fig. 10. pH spectra of diatoms, Qeqertat (after Foged, in press).

with in the other samples. Lumps of *Salix* pollen were found in sample 12 and 19, indicating macroscopic supply. The percentages therefore have been interpolated from the neighbouring samples, and the huge amount disregarded in the calculation of influx and content per ml (dashed lines in Plate 5).

Indifferent and alkaliphilous diatoms indicate chemical conditions like today's up to the 60 cm level (Fig. 10). *Botryococcus* dominates in the beginning, followed by *Pediastrum integrum/muticum* and, to a smaller extent, *P. tetras*. The water beetle *Hydroporus melanocephalus*, known from the area today, was living in the lake. The Rotatorie *Filinia* immigrates and Tanypodinae become more frequent.

Roughly 4000 B.P., at the 60 cm level, a drastic change is recorded in the diatoms: alkaliphilous diatoms increase threefold at the expense of the indifferent and the few acidophilous species, and marine diatoms occur in samples at 55 and 59 cm. *Pediastrum integrum/muticum*, being more demanding than *P. tetras*, increase. Three "Hystrix", characteristic of marine sediments, are found in sample 20, two in sample 22. This can only be explained by some washing-in of marine material, which may also account for the change in the otherwise uniform sediment. As the lake is not fed by any eroding water courses, erosion of marine sediments at the lake shore and/or increasing frost boil activity in the fens and moist dwarf-shrub heaths next to the lake are likely explanations. Common to both is a climatic change, most likely decreasing temperature which would thicken the ice-cover and raise the permafrost level. The thickness of the ice in arctic lakes depends not only on temperature but also on the thickness of the insulating snow-cover on the ice. A decrease in precipitation during winter will cause a thicker ice-cover. The drop in *Alnus* and *Betula* pollen shortly after could be another consequence of the same climatic change.

PV zone C: *Cyperaceae-Salix arctica-Cassiope* zone

The most pronounced change is the doubling of *Salix arctica* percentages, mainly at the expense of *Cyperaceae*. An explanation in terms of change in vegetation types is most difficult to give, as *Salix* has a very wide ecological range, and *Cyperaceae* include *Carex nardina* and *C. rupestris* as well as *Eriophorum*. The low ΣP does not permit conclusions as to the rarer pollen types; only the increase in *Ranunculus* in the middle of the zone seems significant. One species only of *Ranunculus* was found on Qeqertat, *R. hyperboreus*, which grows in moss at every pond and lake, but flowering plants were only met with once. The flowering of this plant calls for a warmer microclimate at its habitat, not necessarily a warmer macroclimate but more sunshine, i.e. a more continental climate. Thus it can be seen flowering vigorously in the sunny central Peary Land. An achene was found in the 35–39 cm sample. *Hippuris*, today growing only in two small ponds, grew in the lake in the later part of the zone. No less than seven of its characteristic stephanocolpate pollen were found in sample 30, four in 31, one in 32 and 34. *Pediastrum* flourished in the lake, the diatom flora of which was still dominated by alkaliphilous species. *Lepidurus* disappears. Neither "Hystrix" nor marine diatoms were found above the beginning of the zone, indicating more stable conditions around the lake. At the beginning of the zone, the pollen influx decreases. This is caused partly by the decreasing number of pollen per ml, roughly to the half, partly by the decreasing slope of the best-fit curve (Fig. 11). A slightly younger age of the 43–51 cm sample would make the fall in influx more gradual and more parallel to the fall in the pollen content, but even so the influx decreases.

PV zone D: *Cyperaceae-Cassiope* zone

This zone is characterized by a decrease in *Salix arctica* and a corresponding increase in *Cyperaceae*. Pollen of *Potentilla*, *Saxifraga oppositifolia* type and, especially, of *Papaver* are comparatively frequent in the sediment, which is otherwise extremely poor in pollen. *Papaver* is common around the lake, especially in dwarf-shrub heaths but also in *Racomitrium* heaths. Three species of *Potentilla* grow on dry rocks: *P. hookeriana* ssp. *hookeriana*, *P. hookeriana* ssp. *chamissonis* and *P. nivea*, whereas P. *hyparctica* prefers moist, mossy N-facing rocks. The curves of alkaliphilous diatoms and of *Pediastrum boryanum* decrease, whereas the content of sand increases, but none of the changes from zone C to D can be unambiguously explained in terms of a climatic change.

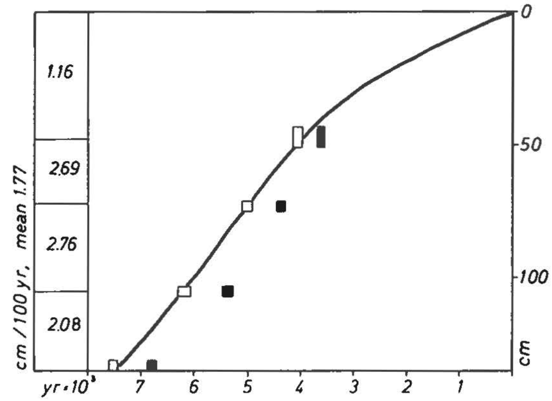


Fig. 11. ^{14}C ages versus depth, Qeqertat. Black boxes are ^{14}C dates, open boxes calibrated dates.

Discussion

Deglaciation of the area dealt with in this paper occurred *c.* 9000–8500 B.P. In the Canadian high arctic, remnants of the Innuitian ice sheet did not cover all the country, and refugia may have been available for the hardy, high arctic flora and fauna (Brassard 1971, Kelly & Bennike 1985). The oldest Holocene dates indicating climatic conditions not differing much from today's are those of the basal gyttjas in the Baird Inlet core, Ellesmere Island (8970±160 B.P., Hyvärinen & Blake 1981) and in Langesø (8540±120 B.P., this paper), besides the date of the basal organic material from a core on Nordvestø, Carey Islands (8940±90 B.P., Brassard & Blake 1978). On northern Ellesmere Island the firm grip of the sea ice and ice shelves was loosened, and driftwood stranded on the beaches. The oldest date so far is 8915±115 B.P. from Clemens Markham Inlet (Stewart & England 1983), contemporary with the dating of shells indicating more or less open waters at the coasts of Baffin Island (Miller et al. 1977) and Greenland (Kelly 1985). At a lake on Kap Inglefield, cored in 1980 (Blake 1981), the beginning of the pioneer vegetation cannot be dated, but around 7500 B.P. this vegetation changed to a *Salix arctica* dominated community (Blake et al. 1985).

The vegetation settling on the fresh soil was as everywhere in Greenland and northern Canada the usual, species-rich, pioneer vegetation, consisting exclusively of herbs and Pteridophytes. The somewhat delayed occurrence of dwarf-shrubs may be caused by one or more

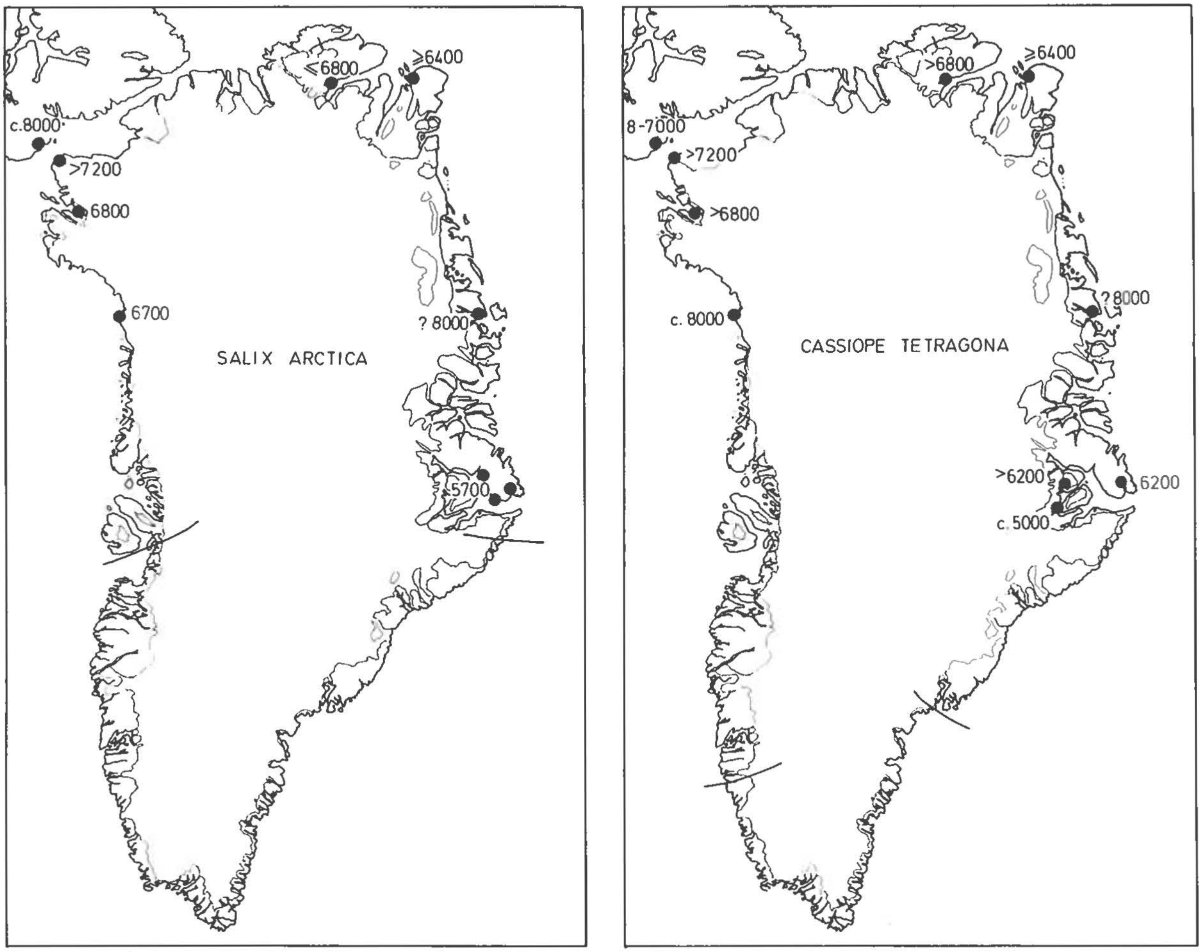


Fig. 12. Immigration of *Salix arctica* and *Cassiope tetragona*. Present southern limit marked.

of the following factors: a) dispersal capacity, b) failure to adapt to growing in unstable soil, and c) – less likely in these latitudes – maturation of the soil. Edlund (1983) divides the high arctic vegetation into four zones, of which zones 1 and 2, representing the most impoverished flora, include herbs. The mean daily July temperature is less than 3°C. The "mini-treeline" forms the border to the next zone, in which single dwarf-shrubs like *Salix arctica* grow on favourable sites. Here, the July temperature is between 3.0 and 3.5°C, whereas in the "mini-forest zone", with temperatures exceeding 3.5°C, dwarf-shrub heaths dominate on mesic and xeric sites. However, this classification is relevant only when describing climax vegetations.

Empetrum hermaphroditum and *Vaccinium uliginosum*, coming from the south, were the first immigrants among dwarf-shrubs, arriving only a couple of centuries after the beginning of gyttja sedimentation, whereas the high arctic *Cassiope tetragona* and *Salix arctica* were a little later (Fig. 12).

The existence of *Colymbetes dolabratus* in Langesø about 8000 B.P., and of this species and *Gasterosteus aculeatus* at the transition between PV zone B and C (about 6700 B.P.) in Rundesø and Langesø respectively, indicates limnic conditions warmer than today, undoubtedly connected with a longer ice-free period. This will increase the primary production in the lake (Smol 1983), yet the extremely high *Pediastrum* and *Botryococcus* production in these lakes is also connected with the supply of nutrients, which, as illustrated by the higher minerogenic content, was greater before the dwarf-shrub heaths spread into the surroundings. An obvious explanation would be more sunny summers. The higher fertility of *Empetrum* and *Vaccinium uliginosum*, as indicated in the high ratio of pollen (and seeds of *Empetrum*) versus leaves in PV zone B on Tugtuligssuaq, also points to higher summer temperatures.

Around 6000 B.P. (Kap Inglefield), or shortly before, the increase in *Alnus* pollen indicates higher frequency of southerly winds (Fredskild 1984) which may well have caused greater precipitation, and which may also be responsible for the initial formation of the several metres thick moss mounds on Carey Islands (Brassard & Blake 1978). Numerous datings of driftwood in the NE Canada – N Greenland sector prove a reduced summer fjord ice at this time (Stewart & England 1983, Blake 1975). In N Peary Land, Lapland buntings were living before, and *Alona guttata* around 4800 B.P., both species well north of their present northern limit (Bennike 1983). In W Greenland a number of extinct thermophilous molluscs occur during the Hypsithermal (Kelly 1980).

The post-Hypsithermal cooling, indicated by a change in oxygen isotope ratios between 5000 and 4500 B.P. in the Devon Island ice core (Koerner & Fischer 1981), and in the Camp Century core (Dansgaard et al. 1971), is reflected in a number of different features, e.g. increasing cover of ice in the fjords and later on formation of ice shelves (Hattersley-Smith 1972), a permanent ice-cover on Kap Inglefield Sø, cessation of peat growth on Carey Islands, the extinction of thermophilous fauna elements, decreasing number of pollen-carrying winds reaching NW Greenland, formation of moraines in W Greenland, decrease in pollen influx, and increased frost boil activity on Qeqertat. Most of these events can be dated at around 4500–3500 B.P. A second cooling around 2000 B.P., traceable in almost any S and W Greenland lake and bog, is only weakly reflected in the diagrams from Tugtuligssuaq and Qeqertat, the main indications being a further decrease in influx of long-distance pollen as well as of local pollen, and a slower sedimentation rate in those lakes not supported by downwashed material.

Finally it should be mentioned that Hyvärinen (1972) and Vasari (1972) each presents two pollen diagrams from peat monoliths from four sites between northernmost Melville Bugt and Inglefield Land. Three diagrams are highly influenced by manuring from bird cliffs or former Inuit settlements, and only the fourth one, from Etah on the SW corner of Inglefield Land (Vasari 1972), seems to have been deposited under normal conditions. The peat formation here began on a raised beach at 1860±150 B.P. The plant community was dominated by grasses with some *Salix arctica, Cassiope* and *Cerastium/Stellaria.* A fast peat formation, roughly 1 cm in 10 years for the major part of the monolith, ends with a 12–15 cm sample dated at 1200 B.P. The vegetation changes towards a more dry *Salix arctica* heath, still with many grasses, but also with *Potentilla* and *Saxifraga. Cassiope* becomes rarer. Peat formation under this type of vegetation is slow, as illustrated by the dates of samples 12–9 and 9–6 cm below the surface (330 B.P. and 175 B.P. respectively). This points to a climatic change, the date of which is rather uncertain.

Acknowledgements

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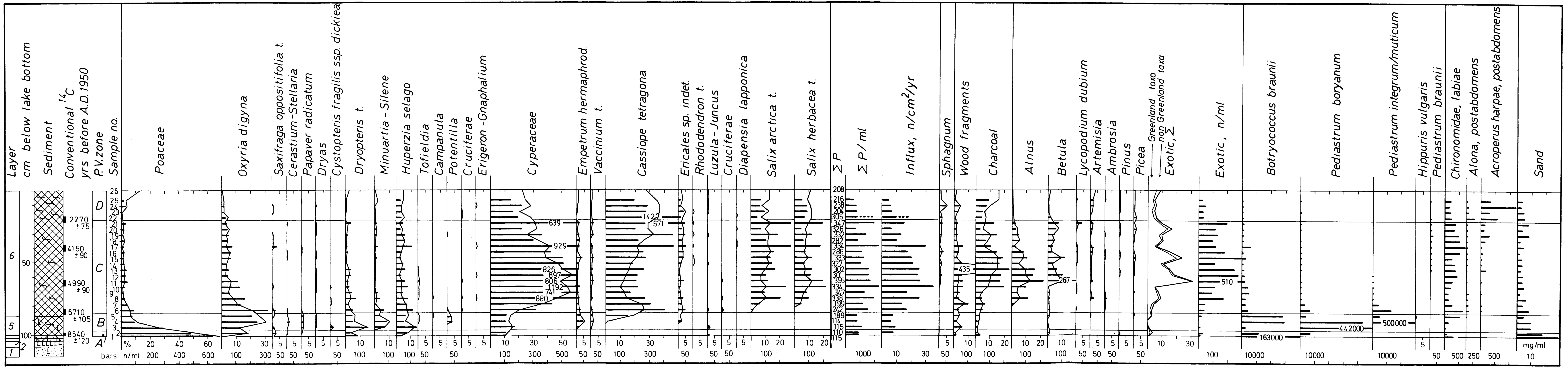
Plates

1. Langesø, microfossils
2. Langesø, macrofossils
3. Rundesø, microfossils
4. Rundesø, macrofossils
5. Qeqertat, microfossils
6. Qeqertat, macrofossils

TUGTULIGSSUAQ Langesø (75°22'N 58°36'W)

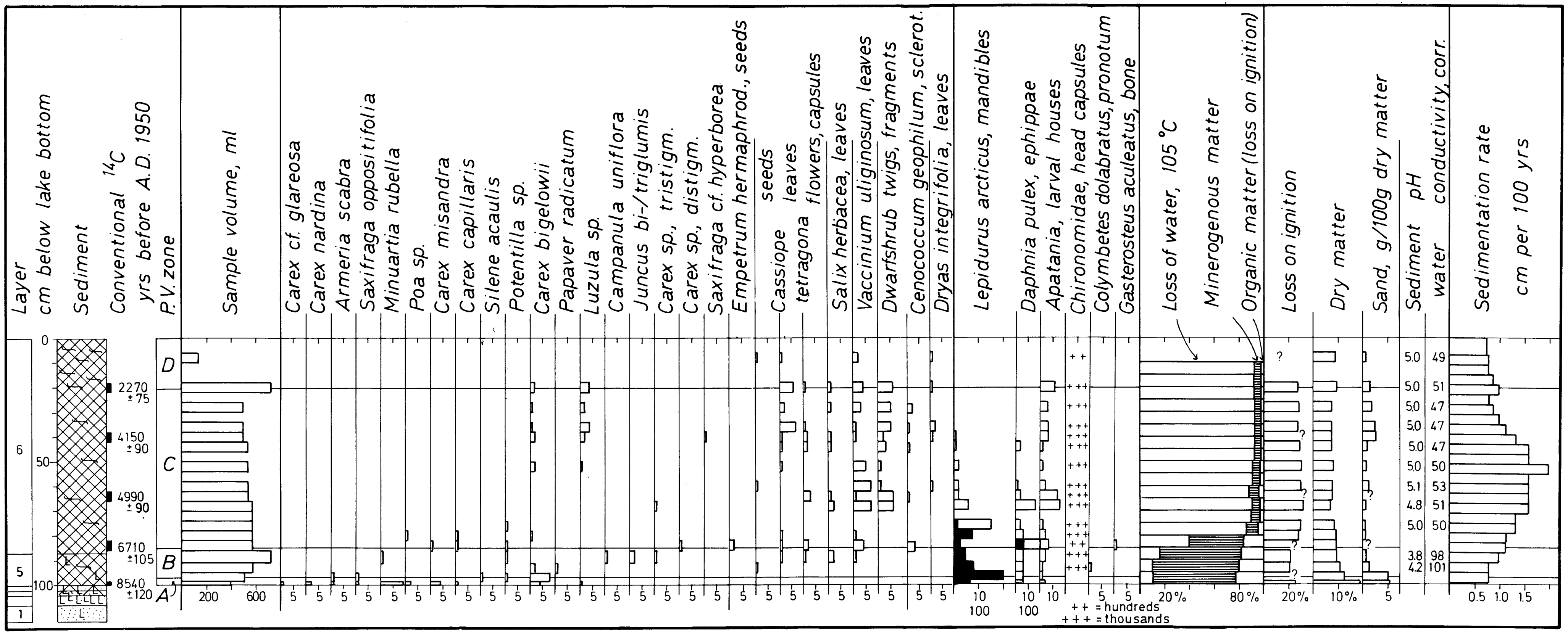
Melville Bugt W Greenland (Microfossils)



Bent Fredskild 1979 - 80

TUGTULIGSSUAQ Langesø (75°22'N 58°36'W)

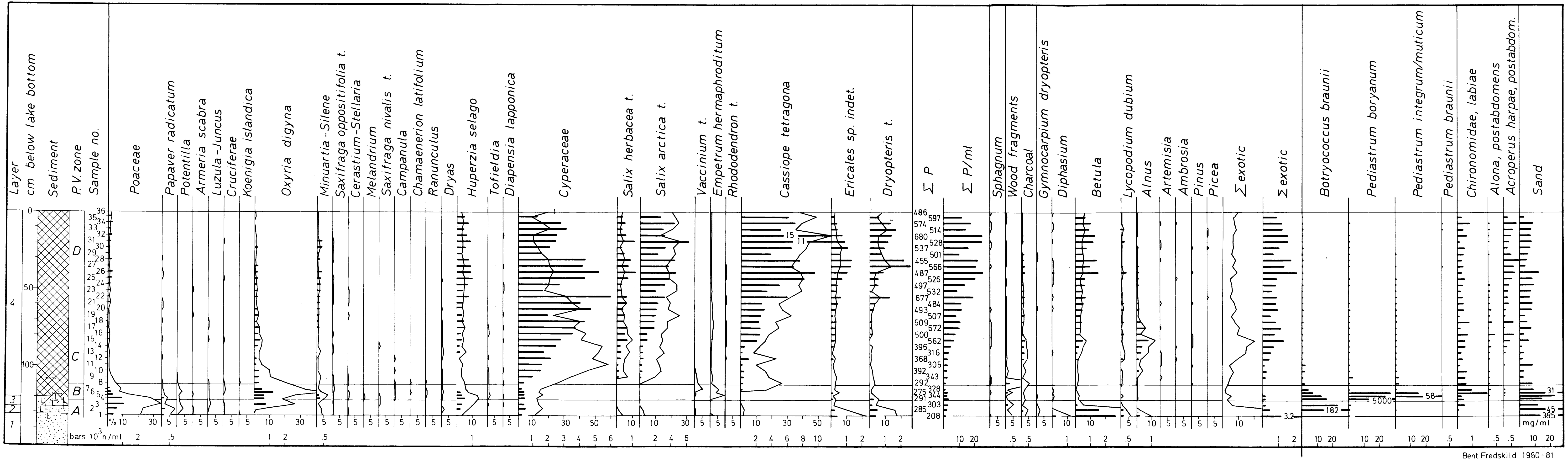
W Greenland (Macrofossils, sediment analyses)



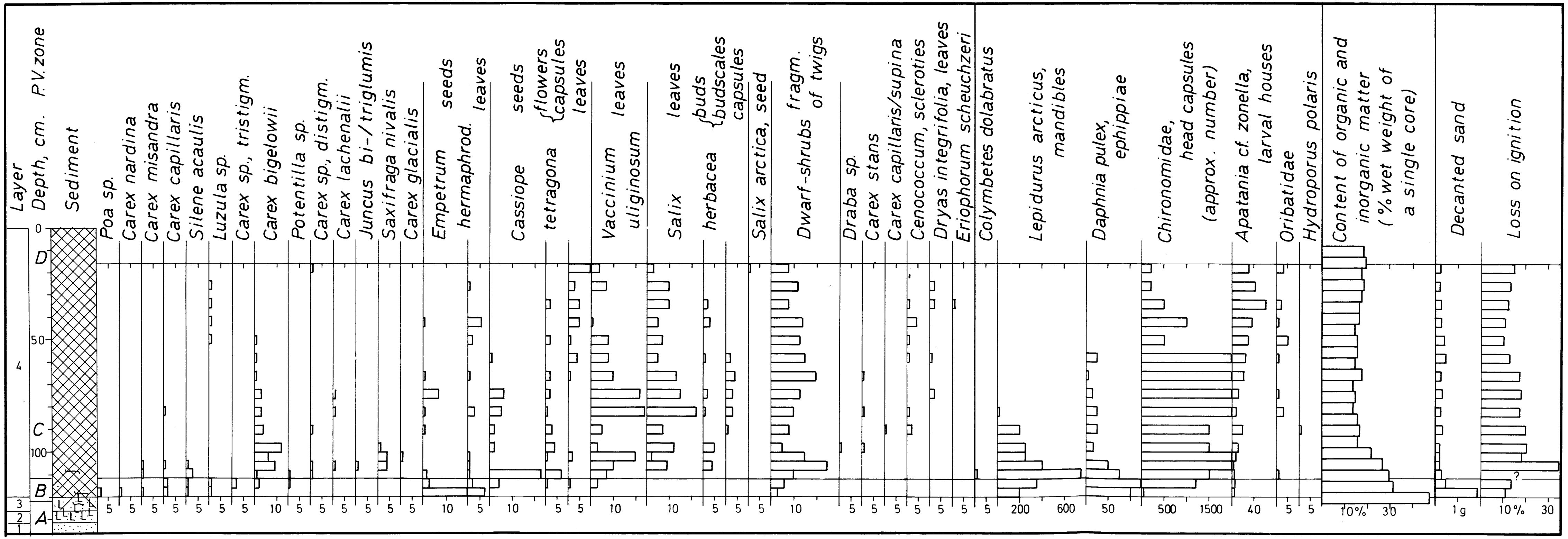
Bent Fredskild 1979-82

TUGTULIGSSUAQ Rundesø (75°22'N 58°36'W)

Melville Bugt W Greenland (Microfossils)



TUGTULIGSSUAQ Rundesø (75°22'N 58°36'W)
W Greenland (Macrofossils, sediment analyses)



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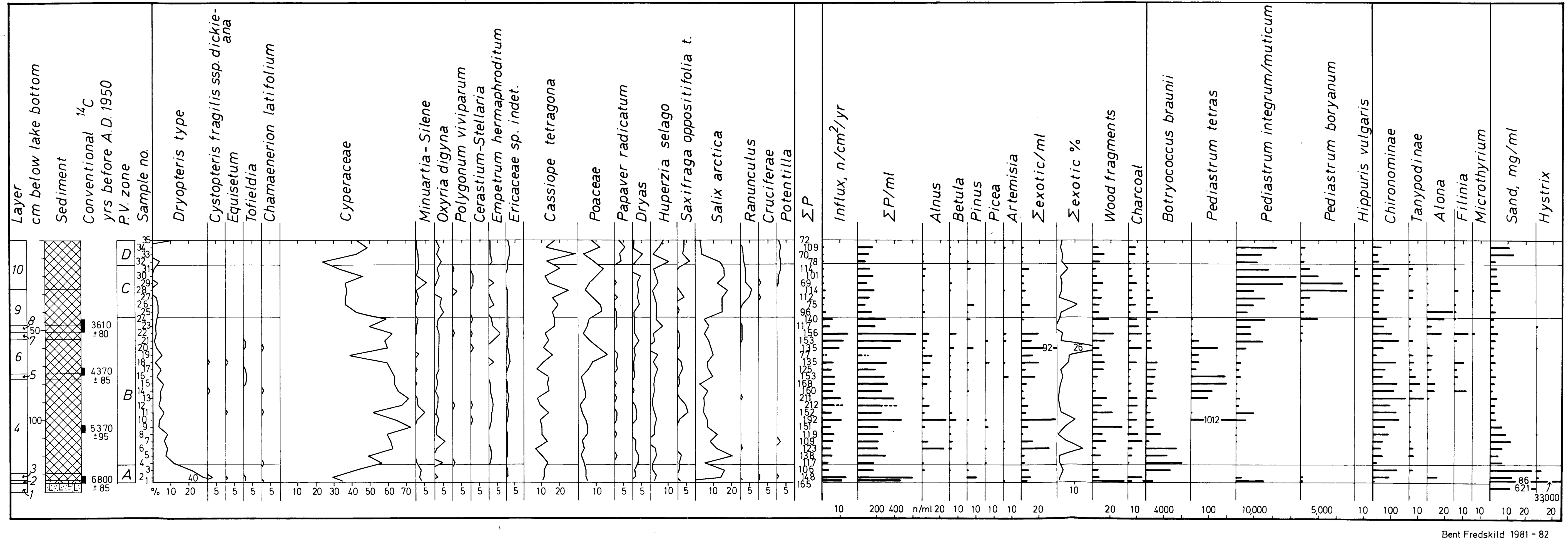
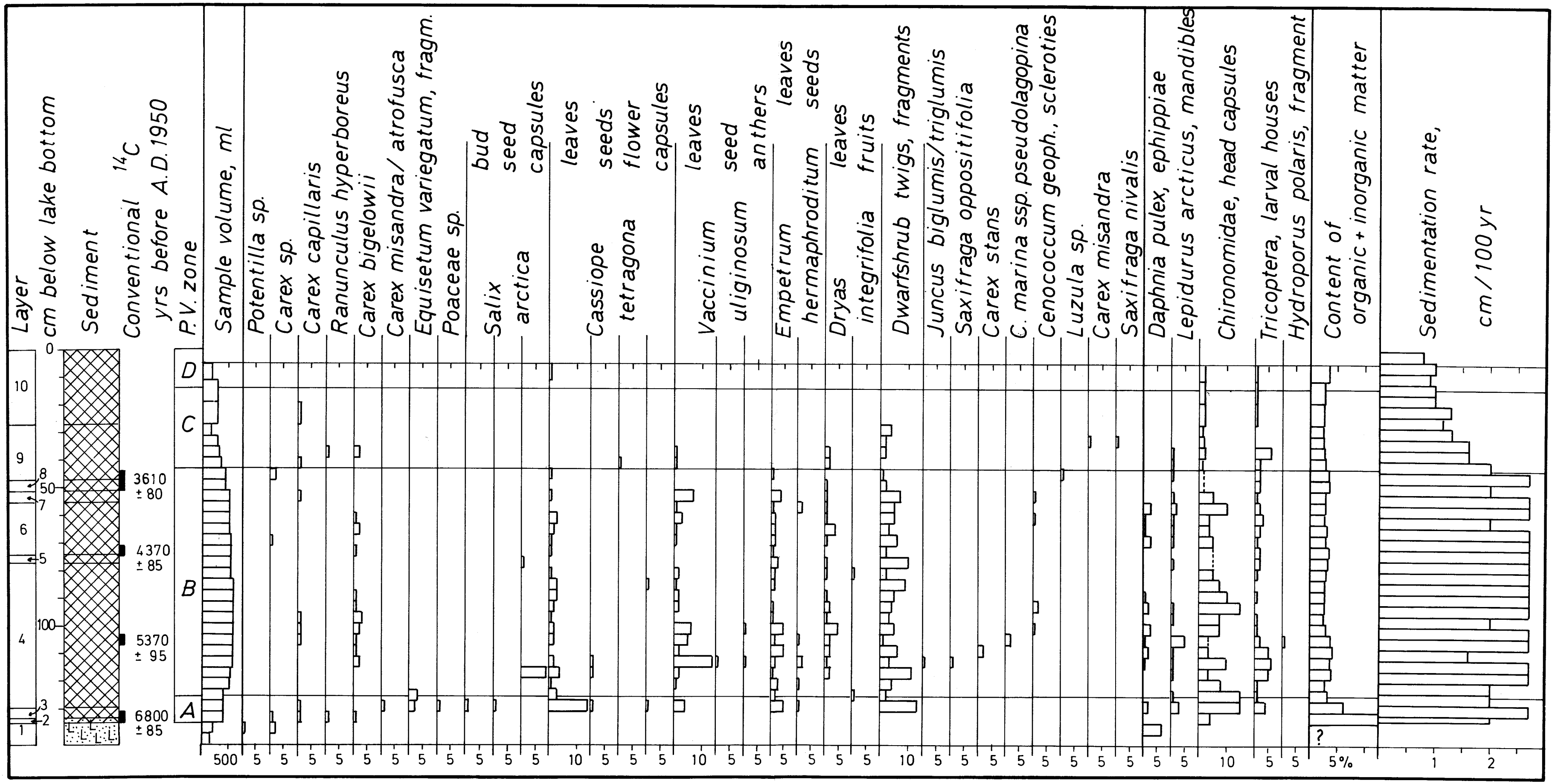
QEQERTAT (77°30'N 66°39'W)
Inglefield Bredning NW Greenland



QEQERTAT (77°30'N 66°39'W)

NW Greenland, Inglefield Bredning (Macrofossils)



Bent Fredskild 1982

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Typescript. – Page 1 should contain: (1) title, (2) name(s) of author(s), (3) abstract, and (4) author's full postal address(es). Large mss. should be accompanied by a Table of Contents, typed on separate sheet(s). The text should start on p. 2. Consult a recent issue of the series for general lay-out.

Double space throughout and leave a 4 cm left margin. Footnotes should be avoided. Desired position of illustrations and tables should be indicated with pencil in left margin.

Underlining should only be used in generic and species names. The use of italics in other connections is indicated by wavy line in pencil under appropriate words. The editor undertakes all other type selection.

Use three or fewer grades of headings, but do not underline. Avoid long headings.

References. – Reference to figures and tables in the text should have this form: Fig. 1; Figs 2–4, Table 3. Bibliographic references in the text are given as: Shergold (1975: 16) and (Jago & Daily 1974b).

In the list of references the following usage is adopted:

Journal: Tarling, D. H. 1967. The palaeomagnetic properties of some Tertiary lavas from East Greenland. – Earth planet. Sci. Lett. 3: 81–88.

Book: Boucot, A. J. 1975. Evolution and extinction rate controls. – Elsevier, Amsterdam: 427 pp.

Chapter (part): Wolfe, J. A. & Hopkins, D. M. 1967. Climatic changes recorded by Tertiary landfloras in northwestern North America. – In: Hatai, K. (ed.), Tertiary correlations and climatic changes in the Pacific. – 11th Pacific Sci. Congr. Tokyo 1966, Symp.: 67–76.

Title of journals should be abbreviated according to the last (4th) edition of the World List of Scientific Periodicals (1960) and supplementary lists issued by BUCOP (British Union-Catalogue of Periodicals). If in doubt, give the title in full.

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Illustrations

General. – Submit two copies of each graph, map, photograph, etc., all marked with number and author's name. Normally all illustrations will be placed within the text; this also applies to composite figures.

All figures (incl. line drawings) must be submitted as glossy photographic prints suitable for direct reproduction, i.e. having the format of the final figure. Do not submit original artwork. Where appropriate the scale should be indicated in the caption or in the illustration.

The size of the smallest letters in illustrations should not be less than 1.5 mm. Intricate tables are often more easily reproduced from line drawings than by type-setting.

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Size. – The width of figures must be that of a column (77 mm), 1½ column (117 mm) or of a page (157 mm). Remember to allow space for captions below full page figures. Maximum height of figures (incl. captions) is 217 mm. Horizontal figures are preferred.

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Caption. – Captions (two copies) to figures should be typed on separate sheets.

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