GRØNLANDS GEOLOGISKE UNDERSØGELSE
Bulletin No. 129

Holocene stratigraphy and vegetation history in the Scoresby Sund area, East Greenland

by

Svend Funder

Seven plates in pocket

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Abstract

The Holocene stratigraphy in Scoresby Sund is based on climatic change as reflected by fluctuations in fjord and valley glaciers, immigration and extinction of marine molluscs, and the vegetation history recorded in pollen diagrams from five lakes. The histories are dated by C-14, and indirectly by emergence curves showing the patterns of isostatic uplift.

From *c.* 10100–10400 to 9400 yr BP the major fjord glaciers showed oscillatory retreat with abundant moraine formation, the period of the Milne Land Moraines. The vegetation in the ice free areas was a sparse type of fell field vegetation but with thermophilous elements indicating temperatures similar to the present.

From 9400 yr BP the fjord glaciers retreated rapidly in the narrow fjords, the few moraines formed are referred to the Rødefjord stages and indicate topographically conditioned stillstands.

At 8000 yr BP the low arctic *Betula nana* imigrated into the area, and in the period until 5000 yr BP dense dwarf shrub heath grew in areas where it is now absent. In the fjords the subarctic *Mytilus edulis* and *Pecten islandica* lived, suggesting a climate warmer than the present.

From *c.* 5000 yr BP the dense dwarf shrub heath began to disappear in the coastal areas, and a 'poor' heath dominated by the high arctic *Salix Arctica* and *Cassiope tetragona* expanded. These two species, which are now extremely common, apparently did not grow in the area until *c.* 6000 yr BP. In lakes in the coastal area minerogenic sedimentation at *c.* 2800 yr BP, reflecting the general climatic deterioration.

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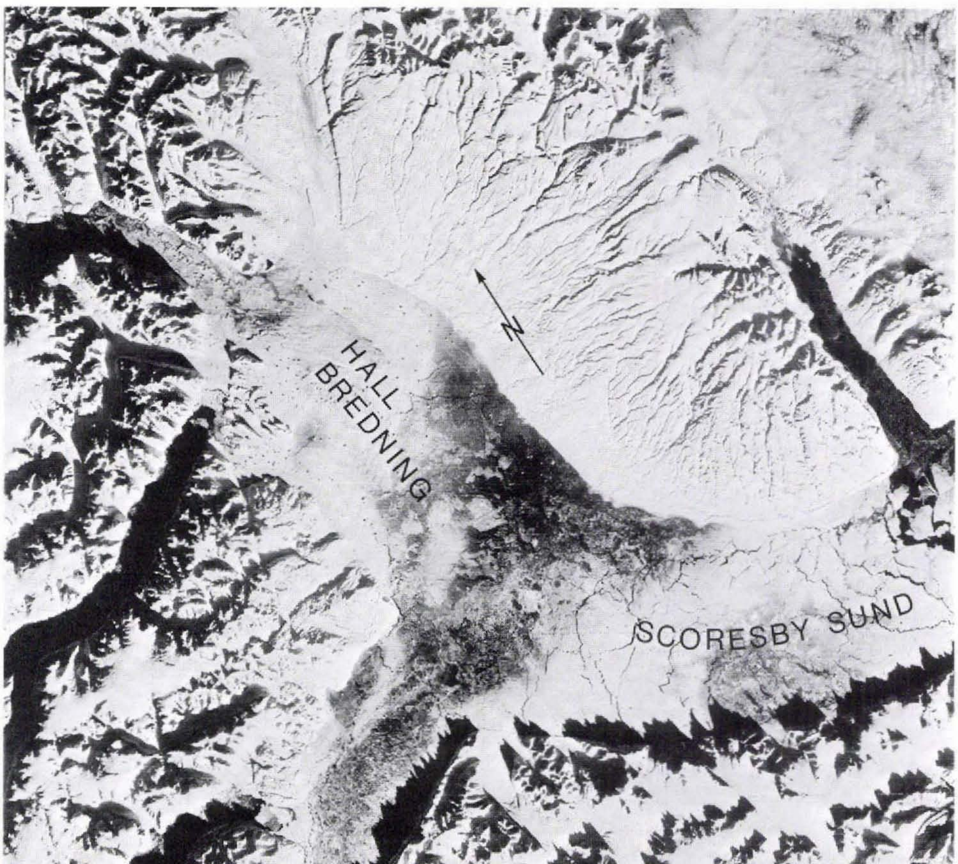
Fig. 1. ERTS-1 imagery of Scoresby Sund and map of Greenland with Scoresby Sund area framed. The satellite photograph is taken after the first winter snowfall on October 21, 1973 at noon, and shows the contrasting landscapes on either side of Hall Bredning. The mouths of the steep fjords appear to the left while the outer coast at the Greenland Sea to the right is covered by clouds. ERTS-1 imagery 1455–13071, by courtesy of NASA.



INTRODUCTION

The Scoresby Sund region in East Greenland comprises the land area that drains into the wide Scoresby Sund – Hall Bredning basin (fig. 1). The area extends from 70° to 72°N., and constitutes the southernmost part of the East Greenland fjord zone, an area noted for its long steep-sided fjords. In the Scoresby Sund region the fjords penetrate the land to a distance af 300 km from the outer coast of the Greenland Sea.

In 1968 systematic mapping of the geology of this area was begun by the Geological Survey of Greenland (GGU); the Quaternary part of the mapping was carried out by the author in the summers of 1969, 1970 and 1971. Some results of this work have been included in the 1:100 000 geological map sheets which are being published by the Survey.

The present work deals with the stratigraphical aspects of this work, and with the Holocene stratigraphy in particular, – the pre-Holocene having been dealt with earlier (Funder & Hjort, 1973). The stratigraphy is based on climatic change, as reflected by changes in ice coverage, isostatic upheaval, immigration and extinction of marine organisms, and changes in the vegetation. For the dating and correlation of these different types of evidence C-14 dating has been an essential tool.

The GGU expeditions provided very good facilities for transport, by helicopter and boat, in the otherwise inaccessible area. To take advantage of this an attempt was made to work on a 'regional scale' and cover as much as much area as possible, although this meant that some problems requiring detailed study on the localities had to be left unsolved.

TOPOGRAPHY AND HYDROGRAPHY

The very varied bedrock geology of the area has given rise to some distinctly different types of topography (fig. 1 and plate 11). The types are:

(a) High mountain plateaux which dominate the western part of the area, to the west of Hall Bredning. The plateaux occur with elevations up to 2000 m and are generally covered by local ice caps, but where exposed their surface is smoothly undulating with few traces of glacial erosion. The plateaux are now separated from each other by narrow, deep fjords (fig.7), but Ahlmann (1941) showed that they are remnants of a Tertiary peneplain that extended over the entire East Greenland fjord zone, which was raised to the present altitude in Late Tertiary times. In the

Scoresby Sund area the plateaux are composed of granite, gneiss, and schists of Precambrian and Palaeozoic age and of Tertiary basalt.

(b) The same types of crystalline rocks occur in some areas of alpine topography, Liverpool Land at the outer coast and Stauning Alper to the north of Hall Bredning. Here isolated mountain peaks and ridges, up to 2500 m, are surrounded by a network of glacier filled valleys.

(c) Areas of smooth and gently sloping terrain occur where sandstone and shale of Late Palaeozoic and Mesozoic age form the bedrock. Jameson Land is an outstanding example of this type of topography, from the coast at Hall Bredning the land rises evenly to altitudes of 1100 m 50 km from the coast (figs 1 and 8). The same type of topography occurs also in areas of southern Milne Land and along Rødefjord and Rypefjord in the interior parts.

From their morphology and depth the fjords in Scoresby Sund fall in two groups: the narrow and greatly overdeepened fjords which trend E–W, and the wider and shallower fjords with a N–S course.

The first group includes Nordvestfjord, Øfjord and Fønfjord, all with maximum depths exceeding 1200 m according to recent soundings. They all seem to consist of only one basin with a smooth long profile and a general depth of *c.* 1000 m along the greater part of their course. Adding the height of the exposed mountain sides the total depth of the troughs is 2000–3000 m, the width is 5–10 km, and the length 100–150 km. At the head of the fjords the depth decreases gradually, and they all end in broad valleys filled by calving glaciers. At their mouths, where the fjords join the shallower Hall Bredning – Scoresby Sund basin the presence of islands and skerries indicate the existence of thresholds.

The second group of fjords includes Hurry Inlet, the Hall Bredning – Scoresby Sund basin, and Rødefjord–Rypefjord. In these fjords the depths scarcely exceed 600 m, and they are wider and their sides less steep.

The origin of the East Greenland fjords has been extensively discussed by geologists working in the area. This early debate has been summarized by Ahlmann (1941) who held the view that the fjords in their present form had been gouged out by glaciers which often followed an existing drainage system in the area, which again to some extent had developed along lines of tectonically determined weakness.

CLIMATE, GLACIATION, PERMAFROST

Regular measurements of temperature and precipitation have been made only at Kap Tobin near the Scoresbysund settlement (fig. 2). The mean annual temperature here is −8°C, and the average annual precipitation is 476 mm.

The climate at Kap Tobin and in the areas near the outer coast is highly influenced by the cold East Greenland Polar Current, the main outlet of water from the

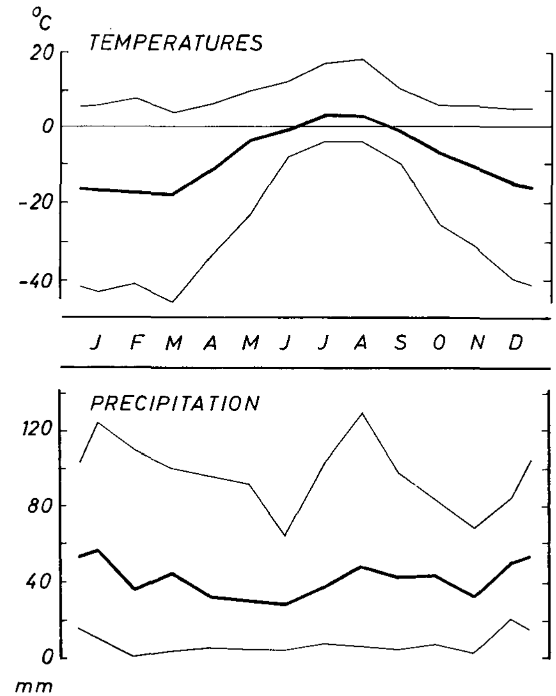


Fig. 2. Temperatures and precipitation at Kap Tobin (Scoresbysund) in the period 1964–1973. Thick lines: average values; thin lines: absolute maximum and minimum values. From *Publikationer fra det danske Meteorologiske Institut.*

Arctic Ocean. In years with a strong Polar Current, and a dense belt of drift ice along the coast, the climate is stable and dry, dominated by radiation, whereas little drift ice means moist, cyclonic weather.

The wide mouth of Scoresby Sund acts as an entrance to the area for oceanic air masses, giving a cool and moist coastal type of climate over the southern and western coasts of Jameson Land; however, the effect of these air masses decreases with the distance from the Greenland Sea, and they rarely penetrate the narrow fjords in the interior parts of the region, where the climate is generally stable with warm dry summers.

The climatic gradient from the outer coast to the interior is a well known feature in all parts of Greenland, and may be exemplified by temperature observations at two stations in King Oscars Fjord to the north of Scoresby Sund (quoted by Washburn, 1965) which show that the annual mean temperature and the mean temperature for the warmest month is 2–3° higher in the interior.

The climatic gradient is also reflected in the altitudes of the glaciation limits, i.e. the lowest altitude at which glaciers can develop under the present climatic conditions. In a compilation made by Weidick (1975, fig. 1) this limit can be seen to rise from *c.* 500 m above sea level at the coast to *c.* 1500 m in the interior.

An impression of the present glaciation in the area can be obtained from plate 11. The type of glaciation is dictated by the local topography. In areas of alpine topography mountain and valley glaciers form a network, leaving only isolated mountain peaks ice free, this type of glaciation is especially conspicuous in Liverpool Land and Stauning Alper. The highland plateaux support local ice caps with valley glaciers and small piedmont glaciers as their outlet, at an earlier stage these ice caps were connected with the Greenland ice sheet.

The area of the Greenland ice sheet that drains into the East Greenland fjord zone is small compared with that draining into areas in West Greenland, the ice divide is only 100–200 km west of the present ice margin in the Scoresby Sund region (e.g. Holtzscherer & Bauer, 1954). The main outlets from the Greenland ice sheet are the large valley glaciers whose calving fronts appear at the head of the fjords; they are remnants of the powerful fjord glaciers whose development and decay will be discussed below. Calving production and rates of movement have been measured for two of these glaciers in the region (Olesen & Reeh, 1969, 1973).

The Scoresby Sund area lies in the area of continuous permafrost (e.g. Weidick, 1968, fig. 25). Borings have shown thicknesses of 80–220 m for the permafrost layer in areas immediately to the north of the Scoresby Sund region (Kirchner, 1963; Washburn, 1965).

The terms 'high arctic', 'low arctic', and 'subarctic' are important biogeographical concepts, and will be used frequently in the text to describe different types of climate and distributions of organisms. In the terrestrial environment the boundary between low arctic and high arctic is defined by the northernmost occurrence of copse type vegetation which seems to coincide more or less with a mean temperature of the warmest month of 5°C (Böcher, 1933a). In the marine shallow water environment the boundary between subarctic and arctic is marked by the northernmost occurrence of a littoral fauna (Madsen, 1936). From all criteria the Scoresby Sund area lies in the high arctic/arctic zone, but low arctic/subarctic conditions are approached in the interior parts.

NOTES ON THE SCIENTIFIC EXPLORATION OF THE AREA

In his whaling ship William Scoresby visited the area for four days during a voyage in 1822. He gave a short description of the natural history of the area (Scoresby, 1823), and named the 'sound' – after his father.

In 1891–1892 a surveying and scientific expedition stayed in the area. Observations on the geology, including the Quaternary, were published by Bay (1896), and the vegetation was described by Hartz (1895a, b). In 1899 the Swedish geologist A.G. Nathorst visited the area briefly on his way north (Nathorst, 1901). The area was again investigated by a scientific and surveying expedition in 1898–1900, and the observations on the geology, physiography and vegetation were published by Nordenskiöld (1907) and Kruuse (1905).

In 1925 the Scoresbysund settlement was founded in the area, which had until then been uninhabited, and in the following years the activity of scientific expeditions increased. Systematic geological mapping was started on the initiative of Lauge Koch, but after a few years the centre of the work was moved north from Scoresby Sund. During these expeditions the Quaternary geology was ignored or referred to only sporadically (Rosenkrantz, 1929, p. 150; 1942, p. 54; Aldinger, 1935, p. 28; Stauber, 1940, p. 22; Kempter, 1961, p. 86). The hydrography and biology of the fjords were investigated by Thorson (1944).

In recent years a number of university expeditions have visited the area and produced descriptions of the geomorphology and Quaternary geology (Sugden & John, 1965; Cruikshank & Colhoun, 1965; O'Brien, 1971; Street, 1977).

SEA LEVEL CHANGES

C-14 dates on shell material, corrections and errors

The C-14 ages obtained for marine bivalve shells in the area appear from table 1, which also includes dates obtained by other workers. The location of the dated samples appear from fig. 3.

Since the early work of Washburn & Stuiver (1962) a large number of shell dates from the East Greenland fjord zone have been accumulated. Unfortunately the C-14 laboratories involved have not calculated their ages in the same way, and the published dates cannot be correlated directly. The difference between the calculation methods lies in the varying usage of corrections for isotopic fractionation and for the apparent age of sea water.

Fractionation of the carbon isotopes takes place especially during assimilation in terrestrial plants which are depleted in the heavy isotopes relative to the atmosphere. The concentration of the stable isotope ^{13}C gives a measure of this fractionation. In terrestrial organisms the concentration of ^{13}C normally amounts to *c.* – 25 per mille of the arbitrary PDB standard, while in marine organisms it is normally *c.* 0.0 per mille (Olsson & Osadebe, 1974). Consequently marine shells will have a higher ^{14}C activity than terrestrial plants of the same age. In order to provide consistent dates most laboratories normalize shell dates to $\delta^{13}C = 0.0$ ‰ PDB; some laboratories, however, normalize shell dates, like those for terrestrial organisms, to $\delta^{13}C = -25$ ‰ PDB. The two methods will give shell dates with a difference of 410 years for identical material.

The apparent age of sea water, and of organisms acquiring their carbon from it, is due to impeded exchange of carbon at the ocean surface and to slow turn over of the water masses (Mangerud, 1972). The apparent age may vary on a regional scale; in the East Greenland fjord zone it has been tested by dating shells which were collected alive in the period 1900 – 1935, i.e. before nuclear experiments upset the balance of ^{14}C in the atmosphere. The results from all parts of the area are similar suggesting an apparent age of 150 years, or 550 years if normalized to $\delta^{13}C = -25$ ‰ PDB. (Washburn & Stuiver, 1962; Hjort, 1973; Tauber & Funder, 1975). This age is slightly higher than that observed in adjacent parts of the North Atlantic (Mangerud, 1972; Krog & Tauber, 1974; Mangerud & Gulliksen, 1975).

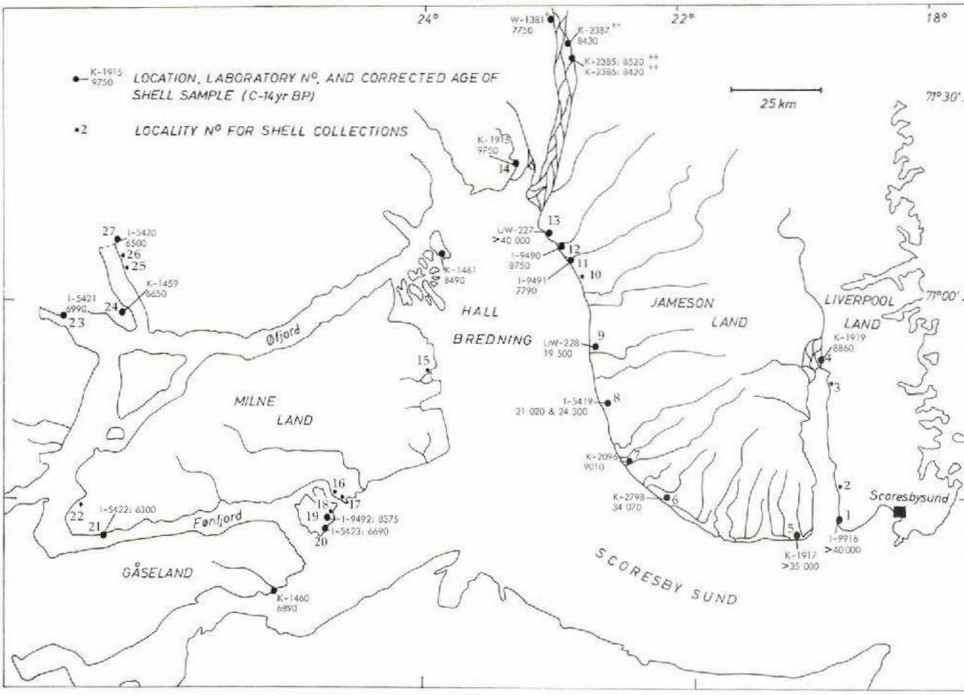


Fig. 3. Shell dates and sites for collection of shell faunas in the Scoresby Sund area. Locality numbers refer to the fauna list, table 3.* from Schafer (in Levin *et al.*, 1965).** from Street (1977).

The shell dates from the East Greenland fjord zone represent three different combinations of laboratory corrections; in order to make them comparable and to approximate the true ages as closely as possible the dates must be corrected, each group in its own way.

(1) Shell dates normalized to $\delta^{13}C = 0.0$ ‰ PDB must be corrected by subtracting an equally normalized apparent age of 150 yr.

In the area this applies to the dates from the following laboratories: the Copenhagen laboratory (dates marked K, Tauber, 1968), Isotopes Inc. (dates marked I, Walton *et al.*, 1961), the laboratory at the University of Washington (dates marked UW, Fairhall *et al.*, 1966), the laboratory of the Geological Survey of America (dates marked W), and the laboratory at the University of Michigan (dates marked M, J.B. Griffin, personal communication).

(2) Shell dates normalized to $\delta^{13}C = -25$ ‰ PBD must be corrected by subtracting an equally corrected apparent age of 550 yr.

In the area this applies to the dates from the laboratory at Lund University (dates marked Lu, Håkansson, 1969).

(3) Shell dates normalized to $\delta^{13}C = -25$ ‰ PDB but published with a correction for apparent age of 550 yr should not be corrected further.

Table 1. C-14 dates of marine bivalve shells from the Scoresby Sund area

GGU No	Lab. No	LOCALITY	FIELD ALTI-TUDE	CORRE-SPOND-ING SEA LEVEL	HOLOCENE MARINE LIMIT	AGE	CORRECTED AGE[1]	DATED SPECIES
			m above sea level			C-14 yr BP		
106510	UW-227	Gurreholm, Jameson Land	44	?	92-100	> 40,000		*Hiatella arctica*
146508	I-9916	Hurry Inlet, near Kap Hope	19-22	?	44	> 40,000		*Astarte borealis*
146503	K-1917	Kap Stewart, Jameson Land	33-36	?	?	> 35,000		*Hiatella arctica, Mya truncata, Astarte borealis*
146514	K-2798	Langelandselv, Jameson Land	53-56	60	?	$34{,}070^{+1980}_{-1620}$		*Hiatella arctica, Mya truncata, Astarte borealis, A. elliptica, Cardium ciliatum, Serripes groenlandica*
106524	I-5419	Heden, Jameson Land	42-45	?	?	a) 21,020 ± 430 b) 24,300 ± 700		*Hiatella arctica, Mya truncata*
106518	UW-228	Lollandselv, Jameson Land	36	?	?	19,500 ± 250		*Hiatella arctica, Mya truncata*
146510	K-1915	Konglomeratelv, Kjove Land	97-100	107-110	110	9,900 ± 120	9750	*Hiatella arctica, Mya truncata*
146515	K-2096	Blokelv, Jameson Land	22-25	> 25	?	9,010 ± 130	8860	*Hiatella arctica, Mya truncata, Astarte elliptica*
146506	K-1919	Ryders Elv, Klitdal	30-33	30-41	41	9,010 ± 140	8860	*Mya truncata*
106511	I-9490[2]	Lodins Elv, Jameson Land	50	> 50	90	8,900 ± 135	8750	*Hiatella arctica*
	K-2385[3]	Schuchert Dal	50-51	> 58	60-70[4]	8,670 ± 130	8520	*Hiatella arctica, Mya truncata, Macoma calcaria, Nucula tenuis*[3]
119020	K-1461	Bjørneøer	65	> 65	c. 90	8,640 ± 140	8490	*Hiatella arctica, Mya truncata*
	K-2387[3]	Schuchert Dal	50	pingo	60-70[4]	8,580 ± 130	8430	*Hiatella arctica, Mya truncata, Pecten islandica*[3]
	K-2386[3]	Schuchert Dal	58	58?	60-70[4]	8,570 ± 130	8420	*Hiatella arctica, Mya truncata, Macoma calcaria, Nucula tenuis*[3]
134014	I-9492[2]	Danmark Ø	44-46	> 50	c. 90	8,525 ± 140	8375	*Mya truncata*
106517	I-9491[2]	Fegins Elv, Jameson Land	25-29	> 29	?	7,940 ± 130	7790	*Astarte elliptica*
	W-1381[5]	Roslin Gletscher, Schuchert Dal	50	?	60-70[4]	7,900 ± 350	7750	*(Mya truncata)*
134011	I-5421	Harefjord	42-46	46	50	7,140 ± 130	6990	*Mya truncata*
96108	K-1460	Gåseland	5-6	?	c. 90	7,040 ± 130	6890	*Hiatella arctica, Mya truncata*
134015	I-5423	Danmark Ø	3-4	3-6?	c. 90	6,840 ± 125	6690	*Hiatella arctica, Mya truncata, Astarte borealis, A. elliptica*
96048	K-1459	Rypenæs, Rypefjord	17-25	17-58	58	6,800 ± 130	6650	*(Mya truncata)*
134008	I-5420	Eielson Gletscher, Rypefjord	10-20	20-36	36	6,650 ± 125	6500	*Hiatella arctica, Mya truncata, Macoma calcaria*
134013	I-5422	Morænepynt, Fønfjord	21-22	25	42	6,450 ± 120	6300	*Hiatella arctica, Mya truncata*

1: Corrected for apparent age of sea water, see text

2: Other dates obtained for the same samples are: *I-9490* (= I-8891): 7,900 ± 130; *I-9492* (= I-8893): 6,890 ± 110; *I-9491* (= I-8892): 7,885 ± 130. See text and Funder (1977).

3: From Street (1977)

4: From Cruikshank & Colhoun, 1965.

5: From J.P. Schafer in: Levin *et al.*, 1965

In the area this seems to apply to the dates from the laboratory at Yale University (dates marked Y, Stuiver & Deevey, 1961, 1962).

It should be noted that Lasca (1969) dealing with the isostatic uplift of the Skeldal area to the north of Scoresby Sund erroneously has corrected dates of type 1 with an apparent age of type 2 – making the ages 400 yr too young.

The dates from the East Greenland fjord zone quoted in the text below have all been corrected according to the principles outlined above. No correction of the dates relative to tree ring chronology has been applied (Damon *et al.*, 1972) the reason for not using this correction is that the majority of the East Greenland dates lie in the Early Holocene, beyond the present range of this correction. However, since this correction is not linear it can be expected to affect emergence curves and curves for sedimentation rates in a significant way.

Although the present work is concerned mainly with the Holocene the 'old' dates, i.e. dates older than 15 000 years, have been included in the list because of the indirect evidence they give on the Holocene. The special problems presented by these dates have been discussed earlier (Funder & Hjort, 1973).

Some samples have given ages that seemed inexplicable from their geological setting. A sample of shells collected in a rock fissure 10 m above sea level at Kap Tobin was dated to 380 ± 100 yr BP (uncorrected, sample K–1918). The most likely explanation for this age is that the shells were lifted up by heavy swell which is known to occur along this part of the coast.

Some other samples (I–9490, I–9491, I–9492) also gave ages that seemed too young (table 1). However, on re-dating, new ages were obtained which conformed much better with the expected ones, and this set of dates has been used – although with hesitation since the error has remained unexplained by the laboratory (Funder, 1977).

Marine limits

The marine limit marks the highest altitude of former sea levels at a locality. The altitudes of marine limits recognized in the region are shown on the map (fig. 4). In table 2 the individual observations have been tabulated.

In general, positive signs of former marine activity are easier to define than the negative ones. The positive signs include erosion cliffs, gravel beaches, and low gradient delta terraces preferably with a well developed distal slope – all of these features are often associated with occurrences of fossiliferous silt at a lower level. The negative signs, i.e. evidence that marine activity has not occurred at a locality, are an abundance of perched boulders and an undisturbed appearance of fine grained non-marine sediments such as till.

Ideally all observations on the marine limit should include positive and negative signs, meeting at a well defined altitude. Quite often, however, the marine limit can only be established as a zone between the highest positive and the lowest negative signs. Evidence of this type is included in fig. 4. In some areas only positive signs have been observed, providing a minimum estimate for the altitude of the marine

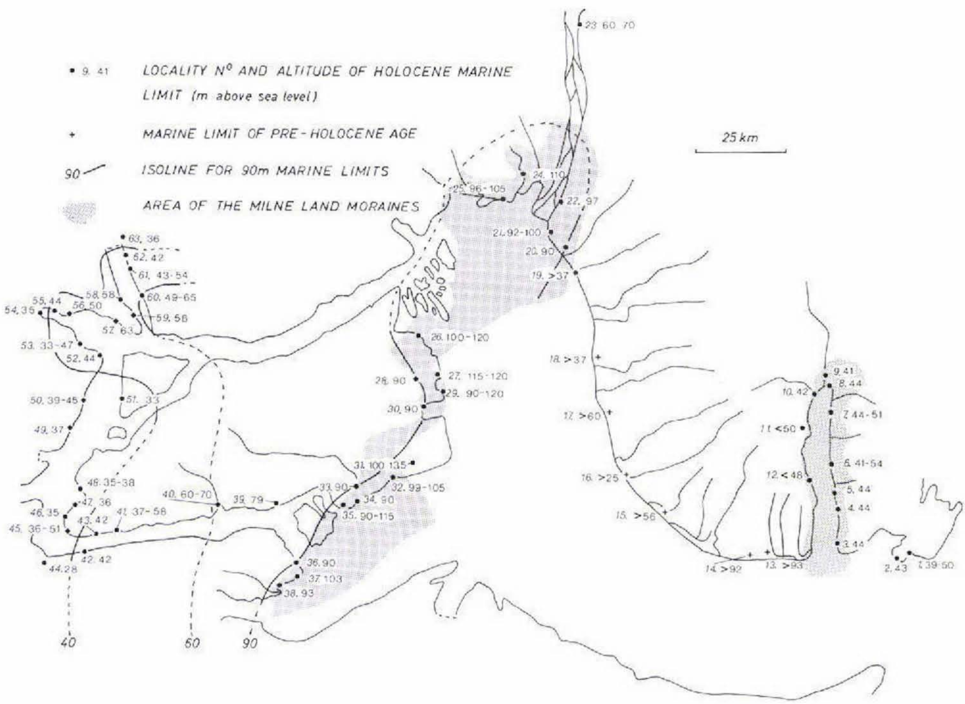


Fig. 4. Marine limits and area of the Milne Land Moraines in the Scoresby Sund region. Locality numbers refer to the list in table 2.

limit. In problematical areas this information may be of some value. In fig. 4 this type of evidence has been included for areas in western and southern Jameson Land, where bedrock consisting of easily disintegrating sandstone and shale, an unfavourable topography and a protracted period of weathering and solifluction have combined to obliterate the traces of former marine activity.

It appears from the C-14 dates that the marine limit in the area is generally of Holocene age, and was formed immediately after the deglaciation of the sites. However, in western and southern Jameson Land the marine deposits at the highest altitudes seem to be associated with 'old' shells, i.e. shells older than 15 000 years, while shells of Holocene age have been found only at lower altitudes. By analogy with observations further north in the fjord zone (Funder & Hjort, 1973) it seems likely that the marine deposits here record at least two separate periods of isostatic adjustment, and a pre-Holocene and a Holocene marine limit must be distinguished in this area. For reasons mentioned above the Holocene marine limit is only imperfectly known, but a sample from 25 m above sea level in southern Jameson Land has been dated to 8860 yr BP, and gives a minimum estimate for this area (fig. 4, locality 16).

From the altitudes of the Holocene marine limits the area can be divided into

Table 2. Observations on the altitudes of marine limits in the Scoresby Sund area

No	LOCALITY	MARINE LIMIT m a.s.l.	MEASURING METHOD*	TYPES OF EVIDENCE	HIGHEST FOSSILS
1	Hartz Vig, Scoresby Sund	39-50	P	Beach/undisturbed till	
2	Kap Tobin, Scoresby Sund	43	P	Beach/undisturbed till	
3	Kap Hope, Hurry Inlet	44	P	Gravel/undisturbed till	22
4	Hulelv S, Hurry Inlet	44	P	Beach cliff/undisturbed till	34
5	Sulugpik, Hurry Inlet	44	P	Gravel/undisturbed till	35
6	Nøkkedal, Hurry Inlet	41-54	P	Delta terrace/undisturbed till	-
7	Kær Elv, Hurry Inlet	44-51	P	Delta terrace/undisturbed kame	15
8	Ulveodde, Hurry Inlet	45	P	Gravel/perched boulders	34
9	Ryders Elv, Hurry Inlet	41	P	Beach cliff	33
10	Ugleelv, Hurry Inlet	42	P	Upper delta terrace surface	-
11	Gåseelv, Hurry Inlet	< 50	P	Upper delta terrace surface	-
12	Astartekløft, Hurry Inlet	< 48	P	Gravel/undisturbed till	-
13	Møns Elv, Jameson Land	> 93	P	Sorted fossiliferous silt	93
14	Hesteelv, Jameson Land	> 92	P	Sorted silt	-
15	Langelandselv N, Jameson Land	> 56	P	Sorted fossiliferous silt	56
16	Blokelv, Jameson Land	> 25	P	Sorted fossiliferous silt	25
17	Huginsø, Jameson Land	> 60	Th	Sorted fossiliferous silt	60
18	Lollandselv N, Jameson Land	> 37	Hl	Sorted fossiliferous silt	37
19	Fegins Elv, Jameson Land	> 30	Al	Boulder shoreline	29
20	Lodins Elv, Jameson Land	90	P	Upper delta terrace	70
21	Gurreholm, Jameson Land	91-100	P	Beach terrace/undisturbed till	65
22	St. Regneelv, Jameson Land	97	P	Upper delta, distal slope	-
23	Roslin Gletscher, Schuchert Dal	60-70**	?	Beach, sorted marine sediment	?58
24	Konglomeratelv, Kjove Land	110	P	Gravel/undisturbed till	97
25	Sydkap, Kjove Land	96-105	P	Beach cliffs/undisturbed till	-
26	Bregnepynt, Milne Land	100-120	Al	Gravel/undisturbed till	-
27	Eastern Milne Land	115-120	Th	Upper delta/undisturbed till	-
28	Eastern Milne Land	90	Al	Beach, delta distal slope	-
29	Eastern Milne Land	90-120	Al	Beach/undisturbed till	-
30	Charcot Havn, Milne Land	90	Al	Beach cliff, upper delta	-
31	Vesterelv W, Milne Land	100-135	P	Gravel/undisturbed till	-
32	Mudderbugt E, Milne Land	99-105	P	Beach/undisturbed moraine	-
33	Sandodden, Milne Land	90	Al	Upper delta surface	-
34	Blanke Bugt, Milne Land	90	Al	Sorted silt/undisturbed till	-
35	Spurvebugt, Milne Land	90-115	Th	Beach, delta surface	-
36	Gåsepynt N, Gåseland	90	P	Sorted silt/undisturbed till	-
37	Gåsepynt, Gåseland	103	P	Beach, cliff/undisturbed till	35
38	Gåsepynt S, Gåseland	93	P	Beach, delta/undisturbed moraine	35
39	Rensund N, Milne Land	79	P	Upper delta, beach	-
40	Fønbugt, Milne Land	60-70	P	Upper delta distal slope	-
41	Fønfjord N, Milne Land	37-58	P	Upper delta/undisturbed till	-
42	Fønfjord S, Gåseland	42	P	Beach, upper delta	-
43	Morænepynt, Milne Land	42	Hl	Upper delta/undisturbed till	22
44	Hjørnedal, Gåseland	28	P	Beach cliff, delta surface	-
45	W Milne Land	36-51	P	Beach/undisturbed till	-
46	Strømbugt S, Milne Land	35	P	Beach, cliff/undisturbed till	-
47	Strømbugt, Milne Land	35	Hl	Beach cliff, delta/undisturbed till	-
48	Strømbugt N, Milne Land	35-38	P	Cliff, delta surface	15
49	Brunedal, Rødefjord	37	P	cliff, delta surface	-
50	Lerelv, Rødefjord	39-45	P	Upper delta/undisturbed till	-
51	Storø, Rødefjord	33	P	Upper delta, distal slope	-
52	Rødepynt, Rødefjord	44	P	Cliff	-
53	Harefjord S	33-47	P	Delta surface/undisturbed till	-
54	Harefjord Gletscher	35	P	Beach terrace	-
55	Harefjord N	44	P	Beach terrace	-
56	Ternevigene, Harefjord	50	P	Beach, delta/undisturbed till	46
57	Kullerne E, Harefjord	53-61	P	Beach, delta/undisturbed till	-
58	Rypenæs N, Rypefjord	58	Hl	Beach, cliff/undisturbed till	35
59	Rypefjord W	58	Hl	Beach, cliff/undisturbed till	35
60	Rypefjord E	49-65	P	Beach, delta surface	-
61	Tappedal S, Rypefjord	43-54	P	Delta surface	10
62	Rypefjord N	42	P	Beach, cliff/undisturbed till	20
63	Eielson Gletscher, Rypefjord	36	P	Beach, cliff/undisturbed moraine	20

* Th theodolite, Hl hand level, P Paulin barometer, Al altimeter

** From Cruikshank & Colhoun, 1965

three zones: (1) a coastal area with low marine limits, decreasing in altitude towards the outer coast (40–?50 m), (2) a central area in Hall Bredning – Scoresby Sund with maximum altitudes for the marine limit (90–?135 m), and (3) an interior fjord area with low marine limits, decreasing in altitude towards the present margin of the ice sheet (70–35 m).

From Kjove Land to the north of Hall Bredning Sugden & John (1965) reported raised beaches at an altitude of 134 m. In the present author's opinion these features are kame terraces since they are not horizontal, bur rise in altitude towards the northwest. The marine limit at the locality seems to be *c.* 110 m above sea level.

Amongst the factors determining the altitude of the marine limit at a locality two can be considered to be of importance: the thickness of the ice load, which decides the total amount of isostatic subsidence, and the rate of removal of this load, which decides how much of the adjustment process will take place after the ice has disappeared, leaving a visible record.

In terms of these factors, and of the alignment of the zones in the area, the zones can be interpreted as representing the following: (1) an area of early and slow deglaciation and/or thin (or no) ice cover, i.e. a situation marginal or peripheral to the former ice load, (2) an area of rapid deglaciation and thick ice cover, i.e. situated at or somewhat behind the margin of the ice load, and (3) an area of thick ice cover and late and slow deglaciation, i.e. situated well behind the margin of the ice load.

The coincidence of the zone of maximum Holocene marine limits with that of the Milne Land Moraines (fig. 4) gives some support to this interpretation; the Milne Land Moraines signify oscillatory retreat of the major glaciers after a period of stillstand or advance, and the implication seems to be that in this area the isostatic readjustment was a response to the rapid unloading of ice at *c.* 10 000 yr BP.

It should finally be mentioned that a dome shaped pattern of marine limits with similarities to that described here from East Greenland has been recorded for areas in West Greenland (Weidick, 1976, fig. 375).

Emergence curves

Emergence curves describe the emergence of the land relative to present sea level at a given locality, i.e. that portion of the post-deglaciation isostatic rebound that has not been nullified by rising sea level. Two emergence curves have been constructed from the Scoresby Sund area to show the different patterns of upheaval in the central area and in the interior fjords (fig. 5). The location of the dated samples on which the curves are based appears from fig. 3. The purpose of the curves is to provide a tool in the dating of the deglaciation history; they also allow some check on the date of the isolation of the lakes that have been utilized for pollen analysis and the commencement of organic sedimentation in them.

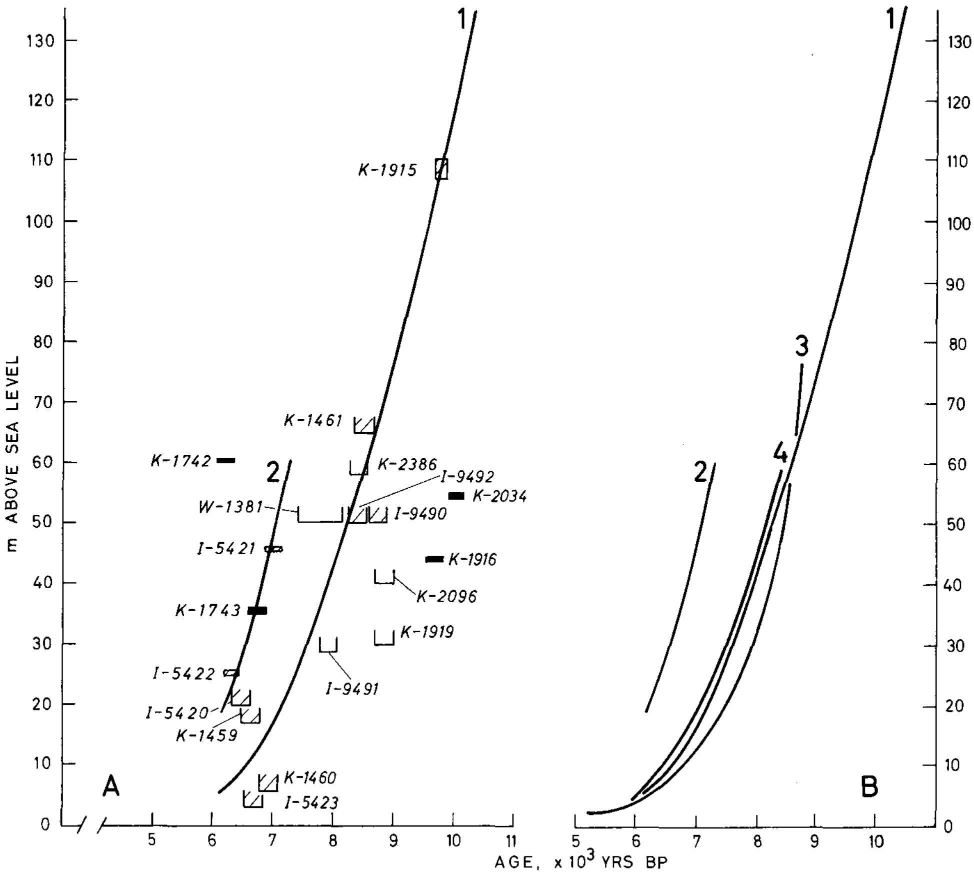


Fig. 5. Emergence curves from the East Greenland fjord zone. *A:* curves from the Scoresby Sund area, 1: central area (marine limits ≥ 90 m), 2: interior fjord area (marine limits ≤ 60 m). C-14 dates plotted with ± one standard deviation. Only hatched samples have been considered in the construction of the curves. Boxes with open tops mark that only minimum values can be determined for corresponding sea level. Black rectangles denote dates on lake sediment, all other dates are on bivalve shells. *B:* comparison with earlier curves from the fjord zone, 1: central Scoresby Sund, 2: interior Scoresby Sund, 3: Mesters Vig (Washburn & Stuiver, 1962), 4: Skeldal (Lasca, 1969, corrected by the present author according to the principles outlined in the text).

Emergence curves have in recent years been constructed for many localities in Greenland, and the problems relating to their construction and significance have been discussed extensively (Weidick, 1972a; Kelly, 1973; Ten Brink, 1974; Donner & Jungner, 1974). From the Scoresby Sund area an emergence curve has been constructed by Street (1977) which is based on some of the same material as curve 1 in fig. 5.

In the evaluation of the Scoresby Sund data two problems are considered to be of major importance; the geographical spread of the data, and the relation between the dated molluscs and former sea levels.

The emergence curve reflects a local isostatic history, and the dates on which it is based should preferably come from a restricted area. This requirement is often hard to meet, and in Greenland only the curves from Mesters Vig (Washburn & Stuiver, 1962) and Skeldal (Lasca, 1969) satisfy this demand. The data from Scoresby Sund show a considerable geographical spread; however, following the interpretation of marine limits given above it is here assumed that localities within the same 'zone of marine limits' should have a similar isostatic history. Thus curve 1 (fig. 5) is based only on samples from the area with marine limits at or above 90 m, while curve 2 represents the interior fjord zone with marine limits at or below 60 m.

Some control of this assumption is afforded by the dates from other parts of the area; these dates should plot in the diagram according to their zone of marine limits, as indeed they seem to do: the dates from the coastal area fall consistently to the right hand side of curve 1, while dates from areas with marine limits between 90 and 60 m fall in the area between curves 1 and 2.

The shells found in the area were all associated with well sorted, low energy sublittoral silt, and reworking and redistribution is thought to be of minor importance (Kelly, 1973; Donner & Jungner, 1974). When found *in situ* the shells were always in life position and even when they were collected from the surface of cryoturbated silt the composition of the faunas indicate that they represent life assemblages (see discussion below). Some notes on the setting of individual samples were given earlier (Funder, 1971a, 1972a, 1973).

However, the problem remains to decide where sea level stood when the animals were alive. For many of the samples there is no evidence which can be used to associate the shells with their sea level, and the samples have been plotted in fig. 5 according to their field altitude which provides only a minimum value for the sea level, as indicated by open boxes. As noted by Thorsen (1933) the littoral zone down to a depth of 3 m is at present almost devoid of bivalves. Where the fossiliferous deposits are directly overlain by a pile of marine sediments, it is assumed that the top of these sediments gives a minimum altitude for sea level at the time when the bivalves lived (samples K–1915, K–2096, I–9491, I–5420). At a few localities the shells were found in silt with a lateral transition into beach sand and gravel at a somewhat higher level; here the shells have been associated with the sea level marked by the beach deposits, and appear as closed boxes in fig. 5 (samples I–5421, I–5422). At a few localities the shells were found so close to the local marine limit that the range of possible sea levels is very restricted (sample K–1915).

It appears that potential errors increase with distance below the local marine limit, and since the tendency is that old shells will appear at too low a level, the effect will be a false steepening of the emergence curves. Dates from low altitudes should therefore be treated with caution. With these considerations in mind the curves from Scoresby Sund have been drawn by visual fitting.

In fig. 5 B the curves have been compared with those obtained earlier from the adjacent areas of Mesters Vig (no. 3) (Washburn & Stuiver, 1962) and Skeldal (no. 4) (Lasca, 1969, corrected by the present author). There seems to be general agreement between the curves, as could be anticipated from the similarities in the general glacial history of the two areas (Funder & Hjort, 1973). The main difference between the curves lies in the very steep upper part of the curve from Mesters Vig; however, as pointed out by Ten Brink (1974), there seems to be reasons for believing that this curve is subject to the 'false steepening' mentioned above.

Finally it should be mentioned that the correction of C-14 dates relative to tree ring chronology can be expected to cause some disturbance to existing emergence curves; however, since the great majority of the dates lie beyond the present range of this correction, it cannot be applied.

MARINE FAUNAS

The species identified in the raised marine deposits are presented in table 3, the sampling localities appear from fig. 3, and some characteristic species are shown on plate 1. Observations on the past marine faunas made during the early expeditions to East Greenland were summarized by Jensen (1905). Apart from *Mytilus edulis* and *Pecten islandica* all the species identified still live in the area at present.

To complete the list of known subfossil species in the area the following species recorded by others should be added to those given in table 1: *Nuclua tenuis, Modiolaria discors, Thyasira gouldi,* and *Axinopsis orbiculata* (Jensen, 1905; Sugden & John, 1965; Street, 1977).

The biology at the bottom of the East Greenland fjords is well known owing to the extensive dredging and bottom sampling carried out in Scoresby Sund and in the fjords to the north by Thorson (1933, 1944), and in the areas to the south by Bertelsen (1937). Results from this work were summarized by Ockelmann (1958) who dealt specifically with the bivalves, while Thorson (1944) surveyed the marine gastropods. The nomenclature here follows the two latter authorities, contrary to the usage in earlier papers by the author.

In order to obtain some first hand knowledge of the present fauna dredgings have been made by the author in shallow water in all parts of the area.

Some general characteristics of the subfossil faunas and observations made in the dredge hauls will be discussed below.

Hiatella arctica and Mya truncata. From the geologist's point of view there is a striking contrast between the inconspicuous role attributed to these two species in the present bottom communities and their dominance of the subfossil faunas.

Table 3. The faunas in the raised marine deposits in Scoresby Sund

LOCALITY No	ALTITUDE, m above sea level	*Leda pernula* Leche	*Yoldia* cfr *hyperborea***	*Portlandia arctica* (Gray)	*Arca glacialis* Gray	*Mytilus edulis* Linné	*Pecten islandica* O.F. Müller	*Propeamussium groenlandicum* (Sowerby)	*Astarte borealis* (Chemnitz)	*Astarte montagui* (Dillwyn)**	*Astarte elliptica* (Brown)	*Astarte crenata* (Gray)	*Serripes groenlandicus* (Bruguière)	*Cardium ciliatum* Fabricius	*Macoma calcaria* (Chemnitz)	*Macoma loveni* (Steenstrup)**	*Hiatella arctica* (Linné)	*Mya truncata* Linné	*Lepeta coeca* (O.F. Müller)	*Natica* sp.**	*Balanus balanus* (Linné)**	*Bryozoa* spp.	*Lithothamnion* sp.	GGU sample No
1A	6-8	-	-	-	-	-	-	-	F	-	-	S	-	-	-	-	F	F	-	-	S	-	-	146509
B	22	-	-	-	-	-	-	-	F	-	F	-	-	S	-	-	F	F	-	S	-	-	-	146508
2	30-34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	F	-	-	-	-	-	146507
3	30-34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	C	-	-	-	-	-	146506
4	8-20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	F	-	-	-	-	-	146501
5A	33-35	-	-	-	-	-	-	-	F	S	S	-	-	-	-	-	S	F	-	S	-	-	-	146502
B	34-36	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	F	F	-	-	-	-	-	146503
6	53-56	-	-	-	-	-	-	-	F	-	F	S	F	F	-	S	C	F	-	S	-	-	-	146514
7	22-25	-	-	-	-	-	-	-	C	-	F	S	-	-	-	-	F	F	-	-	-	-	-	146515
8	42-45	-	-	-	-	-	-	-	F	-	F	C	+	+	-	-	F	F	-	-	-	-	-	106524
9	36	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-	+	+	-	-	-	-	-	106518
10	15	C	-	-	-	-	-	-	S	-	-	S	S	-	S	-	-	-	-	-	-	-	-	106516
11	25-29	-	-	-	F	-	-	-	-	-	F	-	-	-	-	-	-	S	S	-	-	-	-	106517
12	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	F	-	-	-	-	-	106511
13A	44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	-	106510
B	52-56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	-	146511
14	97-100	-	S	-	-	-	-	S	-	-	-	-	-	-	-	-	C	C	-	-	-	-	-	146510
15	7	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	F	F	-	-	-	-	-	106502
16	20-25	-	-	-	-	-	-	-	S	-	C	-	-	-	-	-	F	F	-	-	-	-	-	106508
17	65-72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	-	106509
18A	6	-	-	-	-	S	S	-	C	-	C	-	S	S	-	-	F	F	-	-	-	-	-	106507
B	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	F	-	-	-	-	-	106506
19	44-46	-	-	-	-	-	-	-	-	-	-	-	-	-	S	-	F	F	-	-	-	-	-	134014
20A	7	S	-	-	-	S	-	-	C	-	C	-	-	S	-	-	F	F	-	-	-	-	-	106503
B	15	-	-	-	-	S	S	-	S	-	C	-	-	-	S	-	F	F	-	S	S	S	S	106504
C	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	F	S	-	-	-	-	106505
D	3-4	-	-	-	-	S	-	-	F	-	F	-	-	-	S	-	F	F	-	-	-	-	-	134015
21	21-22	-	-	-	-	S	-	-	-	-	-	-	-	-	S	-	F	F	-	-	-	-	-	134013
22	2-3	-	-	-	-	-	-	-	-	-	-	-	C	S	S	-	F	F	-	-	-	-	-	134012
23A	27	-	-	-	-	C	S	-	-	-	-	-	-	S	C	-	F	F	-	-	-	-	-	134010
B	42-46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	F	-	-	-	-	-	134011
24A	5-10	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	134002
B	25	-	-	C	-	-	-	-	-	-	-	-	-	-	F	-	C	-	-	-	-	-	-	134003
C	34	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	F	F	-	-	-	-	-	134004
25	10-16	-	-	-	-	C	-	-	-	-	-	-	S	S	C	-	S	F	-	-	-	-	-	134006
26	8-10	-	-	-	-	F	-	-	-	-	-	-	S	-	F	-	F	F	-	-	-	-	-	134007
27	10-20	-	-	-	-	F	-	-	-	-	-	-	-	-	-	-	F	F	-	-	-	-	-	134008

F frequent; C common; S scarce; + frequency not specified

**: Identified by K.S. Petersen

Whilst *Mya* is essentially an infauna species burrowing into soft sediments, *Hiatella* may be represented in both the infauna and epifauna, in the latter case attached to stones and algae. The faunal lists from Scoresby Sund (Thorson, 1944) show that both species occur in all types of shallow water communities down to depths of 50–100 m, but although *hiatella* may dominate the epifauna locally, both species are only minor components with recorded frequencies of less than 10 individuals per square metre. Further, in the faunal lists the two species are often represented only by juvenile animals.

As an explanation of this Ockelmann (1958) suggested that during their life time the animals migrate to greater depths in the sediments, and old individuals will often be beyond the reach of the bottom sampler. Burrowing depths up to 20 cm have been recorded for *Mya truncata* (Jensen & Spärck, 1934).

This observation seems to agree with the fact that the subfossil faunas are often dominated by large thick walled specimens of *Mya* and *Hiatella* – implying that the subfossil samples represent burrowing communities which may have been selectively preserved because of their protected habitat and robust shells. The implications of this assumption for C-14 dating have been mentioned above.

Astarte borealis and Astarte elliptica. These two species inhabit the top few centimetres of the bottom sediment, and are most frequent at depths of less than 20 m. At present both species are sparse or lacking in the interior fjord areas. Thorson (1933) suggested that their absence from these areas could be explained partly by sensitivity to fresh water shocks that may occur at shallow water in the early spring. Whatever the explanation the same distributional feature is recorded also by the subfossil faunas: while occurring abundantly in samples from the outer part of the area the two species have not been observed in raised deposits west of Danmark Ø at the mouth of Fønfjord.

Portlandia arctica. This species has been observed at only one locality, the southern part of Rypefjord, where it occurs abundantly in thick silt deposits (locality 24, fig. 3). It has earlier been observed in the interior of Gåsefjord in the southern part of the area by Hartz (in Jensen, 1905), and in Kjove Land by Sugden & John (1965).

Since in the past *Portlandia* often has been cited as an indicator of (high) arctic marine conditions (e.g. Laursen, 1950), its significance as a climatic indicator shall be commented upon briefly.

Thorson (1934) noted that in the East Greenland fjords *Portlandia* may dominate or indeed be the only bivalve present in areas with a large supply of fresh water and sediment, i.e. in front of rivers and glaciers. Jensen (1942) discussed the biology of the species, and showed that *Portlandia* is especially adapted to cope with the harsh conditions at these habitats. Jensen also showed that its distribution is typically (high) arctic, though this may not be in 'equilibrium' with the present climate in Greenland, since it may not have been able to settle in all suitable areas because of problems of dispersal.

In Rypefjord where *Portlandia arctica* occurred in profusion in the silt deposited by the receding Rypefjord Glacier, its occurrence can be dated from the emergence curve to the period 7300–7000 yr BP (fig. 5); which is contemporaneous with the immigration of thermophilous subarctic species in adjacent fjord areas (see below), and it seems reasonable to suggest that in this area *Portlandia arctica* is not an indicator of a specific climate, but of a specific type of environment.

Mytilus edulis and Pecten islandica. The present marine fauna in Scoresby Sund is distinctly arctic. However, it was noted already by Nathorst (1901) that the subarctic *Mytilus edulis* occurs in the raised marine deposits. *Mytilus* often occurs together with the other subarctic species *Pecten islandica,* the past and present distribution of the two species is seen from fig. 6. *Mytilus* is now extinct in the fjord zone and has its northern limit *c.* 500 km to the south, whereas *Pecten islandica* maintains a relic population in the fjords to the north of Scoresby Sund, with its nearest Greenland neighbours 1000 km to the south.

The subfossil occurrence of the two species and their climatic significance has been discussed in detail by Hjort & Funder (1974). *Mytilus* is now known from almost 40 localities in the fjord zone, and 17 C–14 dated faunas containing this

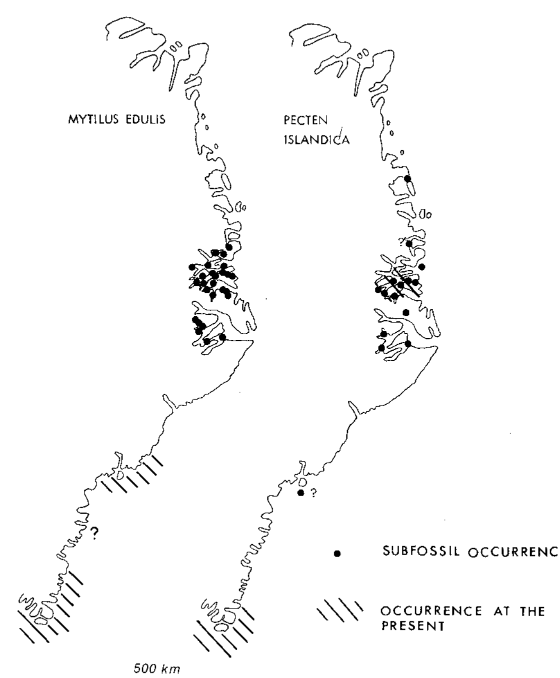


Fig. 6. Past and present distribution of *Mytilus edulis* and *Pecten islandica* in East Greenland. Including observations by Hartz (*in* Bay, 1895), Nathorst (1901), Jensen (1905, 1917), Noe-Nygaard (1932), Ockelmann (1958), Washburn & Stuiver (1962), Lasca (1969) and Street (1977). Modified from Hjort & Funder (1974).

species fall in the range 7700–5500 yr BP. Both species are dependant on long warm summers for the development of their larvae, and their presence in the area probably marks a period of warm climate, as suggested by Nathorst (1901) and Noe-Nygaard (1932). However, both in the past and at present the area must be considered to be marginal for them, and a slight shift in temperature could be decisive for their survival.

Recently Street (1977) obtained an age of 8430 yr BP for a shell fauna containing *Pecten islandica* from Schuchert Dal, thus extending the known duration of the period of subarctic faunal elements to last from 8400 to 5500 yr BP (Sample K–2387, table 1).

In West Greenland, with a climate and hydrography very different from that in East Greenland, *Mytilus edulis* and *Pecten islandica* seem to have been widespread already before 9000 yr BP (e.g. Kelly, 1973), and by 8500 yr BP *Mytilus* appeared in North Star Bugt near its present northern limit (Davies *et al.,* 1963). In West Greenland waters the 'marine optimum' is marked by the presence of the now extinct *Zirphaea crispata, Arctica islandica,* and *Anomia ephippium.*

Faunas containing *Zirphaea crispata* have been dated to 5040 and 4870 yr BP (Donner & Jungner, 1974), showing that at the time when *Mytilus* and *Pecten islandica* became extinct in East Greenland conditions were still favourable in central West Greenland. In the adjacent eastern Baffin Island *Mytilus* was more common than now in the period from 8200 to 2800 yr BP, and an 'optimum' was marked by the presence of *Pecten islandica* and *Macoma baltica* in the period 4000–3000 yr BP (Andrews, 1972).

Littorina sp. and Polydora sp. In a sample collected from a dredge haul from a depth of 15 m in Rypefjord off Rypenæs K.S. Petersen has identified a damaged shell of *Littorina* with traces of *Polydora* borings (plate 1, 11; K.S. Petersen, personal communication).

Only one species of *Littorina, Littorina saxatilis,* occurs in East Greenland with its northern limit at Angmagssalik, 600 km to the south of Scoresby Sund (Madsen, 1936; Thorson, 1944). However, according to K.S. Petersen the shell from Rypefjord cannot be referred to this species, but to types resembling *L. littorea.*

Also *Polydora* is represented in East Greenland by only one species, *Polydora coeca* with a boreal type of distribution, and known from only one locality, off Ella Ø in the fjords to the north of Scoresby Sund (Wesenberg-Lund, 1953).

Since no *Littorina* species of this type are known from Greenland, neither living nor subfossil, it seems likely that the shell came to Greenland by 'random contamination'. It was noted by K.S. Petersen that the borings appeared to have been made after the death of the snail, so the animal was probably dead on its arrival in Rypefjord.

Inevitably this starts speculation since transport to the area by European ships does not seem likely as less than ten ships probably have ever entered this fjord. A peculiar coincidence which should be mentioned here is that Potamogentonsø, a shallow lake at the side of Rypefjord and less than 1000 m from the dredging station, is the only known locality in Greenland for the two water plant species *Potamogeton praelongus* and *P. perfoliatus* (Lægård, 1960). Migratory geese which every summer come to the area by the thousands, via Iceland from winter quarters in Scotland, were held responsible for the latter occurrence by Halliday *et al.* (1974). Possibly the dead *Littorina* has been dropped in Rypefjord by a goose, although it does seem to be an immensely heavy and useless burden to bring.

GLACIATION HISTORY

Pleistocene glaciation

The histories of the fjord glaciers and major valley glaciers are recorded by their marginal deposits, and will be discussed below with special reference to their climatic significance.

The pre-Holocene chronology that has been established earlier by Funder & Hjort (1973) for the East Greenland fjord zone contains three stratigraphical units: (1) The Kap Mackenzie Stadial, during which all of the present land area was inundated by ice moving largely independent of the local topography. Thick deposits of glacial drift covering the high mountain plateaux of Jameson Land were referred to this period, as well as the dispersal of erratics of *Scolithos* quartzite over the whole of the fjord zone. A Saalian or Early Weichselian age was proposed for this event. (2) The Flakkerhuk Stadial, denoting a period when the Scoresby Sund basin was filled by a large outlet glacier extending to the outer coast. The dating of this episode and its correlation in other parts of the fjord zone are uncertain (e.g. Hjort, 1976). (3) The Jameson Land Interstadial, a period of widespread deglaciation in the coastal areas. A mid-Weichselian age was suggested for this event.

By Late Weichselian and Early Holocene times the margin of the Inland Ice lay in the western part of the region, its outlet glaciers occupying the inner fjord basin and forming the Milne Land Moraines.

The Milne Land Moraines

This term has been adopted to designate moraines of Younger Dryas and Preboreal age that occur at the mouths of fjords and major valleys on the western and northern perimeter of the Scoresby Sund – Hall Bredning Basin, and in Hurry Inlet near the outer coast (plate 11).

The morphostratigraphic significance of the moraines was first suggested by Funder (1970) from observations on eastern Milne Land (fig. 7), the moraines there were correlated with those observed earlier in Kjove Land by Sugden & John (1965).

The moraines often occur in swarms. In Kjove Land and Jameson Land there may be up to ten parallel ridges forming a belt of 5 km width (fig. 8), with individual ridges traceable for up to 5 km and rising up to 50 m above the surroundings (fig. 9). Besides lateral and frontal moraines this morphological zone is characterized also by a dense till cover, accumulations of glacifluvial sediments, and at Schuchert Dal and Hurry Inlet by marginal melt water channels incised into bedrock (fig. 10).

The general state of weathering in the area of the Milne Land Moraines appears to be one of uniform 'freshness', and it has not been possible to distinguish any

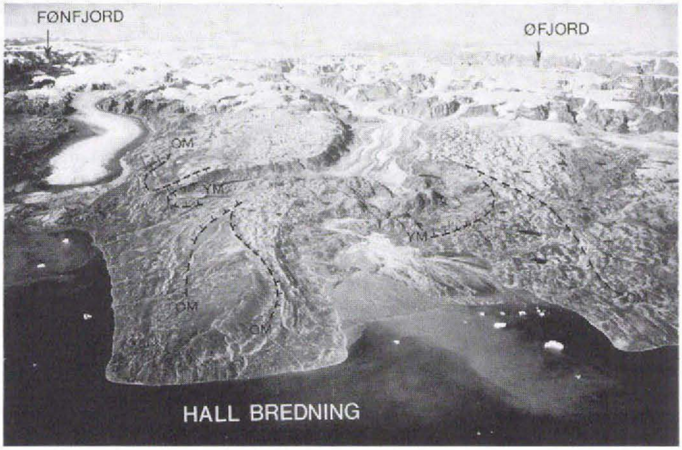


Fig. 7. Eastern Milne Land, looking west from Hall Bredning. *OM* and *YM:* old and young moraines of the Milne Land Moraines. In the background highland plateau covered by local ice caps and dissected by narrow fjords. Copyright Geodetic Institute.

Fig. 8. Kjove Land, looking east. In the foreground weathered and 'unglaciated' landforms at *c.* 500 m above sea level. *OM* and *YM* old and young moraines of the Milne Land Moraines, *A:* locality for shell sample K-1915 in front of outwash delta deposited by glacier in the valley Holger Danskes Briller, in the background Jameson Land. Copyright Geodetic Institute.

Fig. 9. Lateral moraine (Milne Land Moraines) in Kjove Land, looking east. Note for scale the person at the large erratic.

regional substages. The outer limit of the zone is defined as a boundary between 'fresh' till cover and weathered bedrock with scattered boulders and patches of till cover (fig. 8, 10). Frequently streams have been deflected at this boundary. The inner boundary marks a transition from areas of glacial accumulation to areas of predominantly glacial erosion, as seen especially in the steep narrow fjords.

From the course and gradient of the moraines it can be seen that the glaciers protruded into the outer fjord basins; in plate 11 the oldest and youngest moraines on each side of the fjords have been connected by hypothetical ice front lines. No ice marginal features have been identified on the fjord bottom, and the shapes of these lines are conjectural.

Although individual moraines probably signify glacier readvance it appears from plate 11 that the general picture is one of shrinkage and retreat, up to 30 km, from an early phase, where the fronts of neighbouring outlet glaciers were merged to form calving fronts in the fjords, to a younger phase with thin, separate and lobate fronts located at particular thresholds in the fjords. The period of formation of the Milne Land Moraines therefore seems to be one of 'oscillatory retreat'.

The moraines are dated relatively by their intersection with raised marine beaches. Unfortunately younger glacier activity has tended to destroy the early evidence, and the dating of the oldest phase is uncertain. In eastern Milne Land shorelines truncate some of the oldest moraines at 120 m above sea level (fig. 4, localities 26–29), and in southern Milne Land a boulder accumulation at the foot of an indistinct cliff formed in the till cover of the oldest phase, has been observed at 135 m (fig. 4, locality 31). By extrapolation from the emergence curve (fig. 5, no. 1) the age of these features would be 10 100 and 10 400 yr BP, providing a tentative dating of the initial retreat from the oldest moraines.

The end of the period of the Milne Land Moraines coincides in the areas to the west of Hall Bredning – Scoresby Sund with a sea level 90 m above the present, and frequently glaciomarine deltas in front of the younger moraines have been built up to this altitude, and erosion cliffs have been incised into the moraines. From the

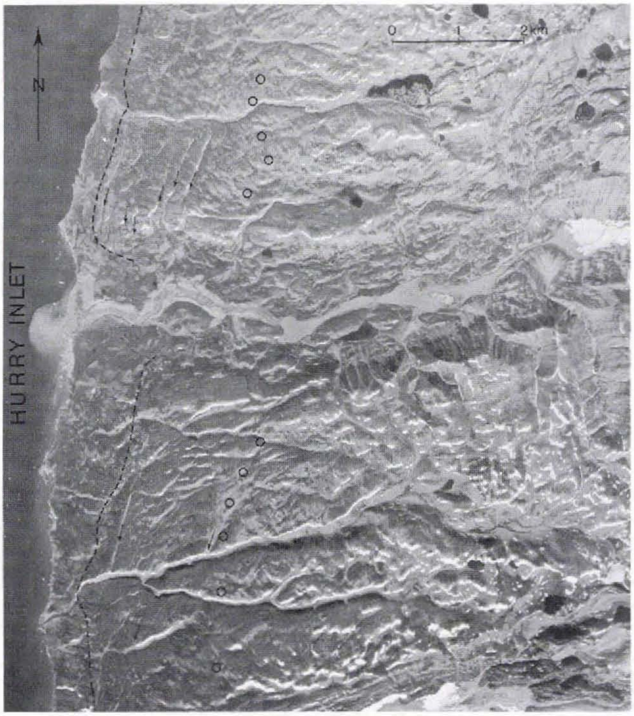


Fig. 10. The east side of Hurry Inlet. Line of open circles denote upper limit of 'fresh' till cover (c. 300 m above sea level). Broken line marks the upper limit of marine and marine-deltaic deposits. Arrows mark lateral drainage channels and kame terraces (The Milne Land Moraines). Copyright Geodetic Institute.

emergence curve (fig. 5, no. 1) the age of this event, i.e. the abandonment of the final frontal positions at the fjord mouths, is 9400 yr BP.

In Kjove Land a sample of shells was collected in silt overlain by glaciofluvial sand related to a readvance of a small glacier tongue through the valley of Holger Danskes Briller which represents a young phase in the period of the Milne Land Moraines. The age was 9750 yr BP which dates or is slightly older than this small readvance (fig. 8, sample K–1915, table 1).

In Hurry Inlet the 'boulder communities' and striations show that a local ice cap existed over Liverpool Land and northern Jameson Land with a main outlet through Hurry Inlet. The ice margin features in this area are mainly created by melt water, with kame terraces and drainage channels predominant, giving the impression of rapid retreat (fig. 10). Also the uniform altitudes of marine limits along the fjord, of 40–50 m, indicate rapid retreat (fig. 4). At the head of Hurry Inlet the age of 9800 yr BP for the onset of organic sedimentation in Morten Sø probably dates the deglaciation of the site, and of Hurry Inlet in general. It therefore appears that the outlet glacier in Hurry Inlet retreated rapidly prior to 9800 yr BP, in phase with the marginal variation of the Greenland ice sheet in the western part of the area.

The Milne Land Moraines therefore is a morphostratigraphic unit denoting a period of widespread moraine formation in areas around Hall Bredning and Scoresby Sund. Morphologically it is distinguished from older and younger glaciation phases also by a difference in general weathering. The moraines have been dated to the period from *c*. 10400 to 9400 yr BP, and they are interpreted to reflect oscillatory retreat in the major fjord and valley glaciers. The association of the area of the Milne Land Moraines to a zone of high marine limits has been discussed above (fig. 4). The climatic and regional significance of the moraines are discussed below.

Glacial retreat, the Rødefjord stages

After leaving their strongholds at Hall Bredning the fjord glaciers and major valley glaciers retreated and were followed by the marine invasion of the fjords and valley mouths. The ice margin deposits left from this period are mainly kame terraces and kame deltas, and their location appears to be determined to a large extent by the local topography, i.e. they are found at places where the topography changes from steep to gentle, where lowland areas occur adjacent to the fjords, and at the mouths of tributary valleys (fig. 11). In the interior of the fjords, where the isolated occurrence of sedimentary rocks of the Røde Ø Conglomerate gives rise to a gentle topography along Rødefjord and parts of Rypefjord and Harefjord, kame terraces occur as steps on the mountain sides up to 600 m. It has been convenient to group this evidence of glacier retreat under the term 'the Rødefjord stages' (Funder, 1971b).

The relation between topography and ice margin deposits seems to imply topographical control of the glacier margins in this period. This explains the lack of synchroneity in the glacier fluctuations as shown by the map of marine limits which here mark the time of deglaciation of the sites and give an indication of the process of deglaciation (fig. 4). For example, the course of the isoline for 40 m marine limits implies that while the fronts of the fjord glaciers in Harefjord and Rypefjord were close to their present positions, glaciers still lingered on in Rødefjord and the interior of Fønfjord.

Fig. 11. Mouth of Lerelv at Rødefjord. *A:* kame deltas deposited by a glacier in the fjord to the left, sloping up valley (Rødefjord stages). *B:* marine deltas sloping down valley.

From the emergence curve (fig. 5, no. 2) it can be deduced that the present state of deglaciation was achieved by *c.* 7000 yr BP in Rypefjord and Harefjord, and by *c.* 6700 yr BP in Rødefjord. For Schuchert Dal at Hall Bredning Street (1977) showed that this large valley was essentially free of ice as at present by *c.* 8500 yr BP.

The retreat of the fjord glaciers in the period from 9400 yr BP to 6700 yr BP appears to have been a smooth process, the rate of retreat of individual glaciers being to some extent determined by the local topography and there is no evidence for any regional readvance in this period.

The presence of marine deposits, up to 36 m above sea level, behind the front of the glacier at the head of Rypefjord shows that by 6800 yr BP this glacier had retreated behind its present front. This situation may also occur at other glaciers in the area (Funder, 1972b).

Glacial readvance

Apart from the qualitative evidence mentioned above there are few traces of Late Holocene, prehistoric glacier readvance in the area.

In Schuchert Dal J. P. Schafer obtained a date of 1490 ± 250 yr BP for turf incorporated in moraines in front of Roslin Gletscher, a glacier flowing down into the valley from the mountains of Stauning Alper (sample W–1378; Schafer in Levin *et al.,* 1965). The date appears to give a maximum age for an advance of this glacier. It should be noted that surging glaciers have been observed in Stauning Alper (Olesen & Reeh, 1969), and a complicated surging mechanism has been suggested by Rutishauser (1971) to operate at the neighbouring Bjørnbo Gletscher.

Moraines from historical times are a general feature in front of the present glaciers. No attempt has been made to date them. For historical moraines in West Greenland Weidick (1972b) has suggested ages from *c.* A. D. 1750–1800 to 1920.

Climatic implications

As noted above, the local topography may have exerted a major influence on the process of deglaciation in the area. It could be anticipated that the fjord mouths, where the Milne Land Moraines occur, and the heads of the fjords, where the present glacier fronts are situated, would offer the best topographical possibilities in the region for the establishment of a stable and long lasting equilibrium for the outlet glaciers (e.g. Mercer, 1961), and the deglaciation history therefore could be envisaged as the transition from one stable equilibrium to another. However, some climatic control is implied by the synchronism of glacier fluctuations in the area, the most decisive climatic event probably being recorded by the change from general stillstand or advance to general retreat by 10 100 – 10 400 yr BP, reflecting a climatic amelioration; this event seems to have been recorded by all glaciers in the area, and possibly in all parts of the East Greenland fjord zone (see below). The moraines formed during the subsequent retreat phase are interpreted to show minor climatic fluctuations in a period of general amelioration; at 9400 yr BP a persistent warm fluctuation finally upset the glacier equilibrium in this area, and rapid, topographically controlled retreat began in the steep, narrow fjords. The termination of the period of the Milne Land Moraines thus seems to have been determined by a combination of climatic and topographic factors, and probably is of less regional significance than the date for the beginning of the period.

Comparison with other areas

Through the work of C. Hjort, and based also on observations by Washburn (1965) and Lasca (1969), the Milne Land Moraines were extended to include also moraines in the fjords to the north of Scoresby Sund (Funder & Hjort, 1973). Recent work in the northernmost part of the fjord zone, 500 km to the north of Scoresby Sund, has indicated similar conditions, only there the termination of the period of the Milne Land Moraines is difficult to define and may not be synchronous with that proposed for the Scoresby Sund area (unpublished observations by C. Hjort and the author).

Along the western margin of the Inland Ice the Holocene deglaciation process may have been somewhat more complex; it was noted by Weidick (1972) that regional differences in the topography may have caused differences in the rates of deglaciation. In the large continental areas of central West Greenland the deglaciation may have been slow and interrupted by stillstand or small scale readvances. It is probably too early to make detailed comparisons between East and West Greenland; however, some general features should be mentioned: a change from general stillstand or advance to general retreat of the ice margin, as recorded by the abandonment of the earliest of the Milne Land Moraines in East Greenland, has been recorded in West Greenland only in the Holsteinsborg area where the Taserqat moraines have been tentatively dated to the Younger Dryas period (Ten Brink & Weidick, 1974). The Early Preboreal oscillations recorded in East Greenland have no equivalents in West Greenland, while the Fjord Stages reflecting widespread stillstand or readvance along the western margin of the Inland Ice in the period 8400–8100 yr BP (Weidick, 1968, 1972a) have no equivalents in East Greenland. The Fjord Stages, on the other hand, seem to correlate with the widespread Cockburn Moraines on Eastern Baffin Island in the Canadian arctic (Andrews & Ives, 1972; Andrews, 1975). In the latter area the Cockburn Moraines seem to mark a final readvance of the Laurentide ice sheet before large scale deglaciation started.

It should finally be mentioned that the deglaciation process outlined here for the Scoresby Sund area has similarities to that recorded in northern Norway where the fjord glaciers and ice sheet margin retreated – but with significant readvances – in the Preboreal (Andersen, 1968, 1975). Also the Billefjorden Advance inferred for northern Spitzbergen in the period from *c.* 11080 to *c.* 9800 yr BP (Boulton & Rhodes, 1974) seems reminiscent of the Milne Land Moraines. In both areas the recession seems to have proceeded smoothly in Boreal and Atlantic times.

POLLEN ANALYTICAL INVESTIGATIONS

Pollen analysis has been carried out on bottom sediments from five lakes in the region. The aim of the analysis was to establish a record of Holocene climatic and ecological change, both to serve as a tool in the stratigraphical work, and to provide knowledge of the dynamics and sensitivity of plant communities in a high arctic environment. The boring sites (plate 11) were selected to represent the two basic biogeographical zones in the area today: the interior fjord zone with its long warm summers and conditions close to low arctic (Bramgåssø and Potamogetonsø), and the area near the outer coast with a distinctly high arctic climate (Morten Sø, Hugin Sø, Munin Sø).

Field methods

At an early stage in the work it was noted that only lakes surrounded by gentle topography and rather dense vegetation could be expected to yield organic sediments suitable for pollen analysis. The lakes were all situated in lowland areas of glacigene or marine deposits, and their depths at the boring stations did not exceed 5 m.

Before boring each lake was sounded and reconnaissance borings made to ensure that the organic sediments were of a uniform thickness throughout the lake basin, and that no abrupt lateral changes occurred.

The sediment cores were acquired by means of a Dachnowsky type piston corer, constructed and kindly provided by M. Kelly. The corer utilizes PVC tubes with a diameter of 60 mm. The most convenient length of the cores was found to be 60 cm. The tubes were sealed immediately after recovery, and not opened till required for analysis or dating.

The piston corer is unable to work in minerogenic sediments, and to obtain some knowledge of these a Hiller type sampler was used.

The boring was carried out from a platform built on an inflated rubber boat. Between each boring the platform was moved 10 cm.

Lake sediments

The types of organic sediments found in the lakes appear from the sediment columns in the pollen diagrams; they comprise a mixture of gyttja substance, silt and sand in varying proportions.

Moss has been observed growing on the bottom of some lakes, particularly in the coastal area. In these lakes moss remains also make up a part of the sediments in the cores. In Hugin Sø and Morten Sø moss occurs characteristically in a thin layer at the lower transition from minerogenic to organic sediments, and appears again in the upper part of the profiles. Both the subfossil and the modern moss has been determined to the species *Drepanocladus exannulatus* by G. Halliday

Table 4. C-14 dates on lake sediments from the Scoresby Sund area

GGU No.	Lab. No.	LOCALITY	DEPTH IN SEDIMENT, cm	AGE, yr BP	$\delta^{13}C$ o/oo PDB	No. OF CORES USED FOR DATING
146505 A	K-1916	Morten Sø	377-380	9,630 ± 120	-20.0	5
B	K-2689	-	341-351	8,060 ± 120	-20.4	1
C	K-2688	-	266-275	5,720 ± 100	-20.4	1
D	K-2775	-	223-235	4,780 ± 90	-14.8	1
E	K-2776	-	184-197	4,060 ± 85	-16.9	1
F	K-2785	-	98-108	2,780 ± 65	-18.7	1
G	K-2777	-	0- 13	1,330 ± 75	-17.7	1
106522	K-1741	Hugin Sø, A	155-160	8,580 ± 140		H
146513 A	K-2034	Hugin Sø, B	172-175	10,050 ± 150	-21.5	6
B	K-2035	-	164-167	8,010 ± 120		5
C	K-2036	-	103-106	4,900 ± 100		5
D	K-2037	-	70- 73	3,840 ± 100		5
106515	K-1740	Munin Sø	53- 58	2,290 ± 140		H
134018 A	K-1743	Bramgåssø	187-195	6,780 ± 140	-17.7	3
B	K-2512	-	159-170	4,610 ± 90	-20.0	1
C	K-2637	-	39- 47	1,050 ± 50	-19.3	1
D	K-2773	-	138-152	4,220 ± 85	-19.0	1
E	K-2774	-	80- 97	2,470 ± 55	-16.3	1
134016 A	K-1742	Potamogetonsø	140-143	6,200 ± 140	-26.7	3
B	K-2769	-	108-118	4,390 ± 90	-24.9	1
C	K-2770	-	66- 86	2,480 ± 60	-21.3	1
D	K-2771	-	21- 36	1,890 ± 70	-21.9	1
E	K-2772	-	7- 16	1,360 ± 70	-25.1	1

H: Sample obtained with a Hiller sampler

Loss on ignition and ^{13}C content of sediments

Loss on ignition has been determined by combustion at 600–700°C of samples of dried sediments throughout the pollen profiles, and the values obtained appear in the pollen diagrams (plates 6–10).

The loss on ignition gives a measure of the content of organic matter although decomposing $CaCO_3$ and ferrosulphides and water adsorbed to clay minerals may contribute significantly to the loss (Andersen, 1961). No free $CaCO_3$ has been observed in any of the lake sediments, and the very low values, less than five per cent, obtained in the minerogenic part of sequences indicate that in this area the loss on ignition gives a fair estimate of the content of organic matter. The loss on ignition varies from 10–60 per cent in Morten Sø to 2–30 per cent in Potamogetonsø.

The organic matter in the sediments can be accounted for by two sources: primary production in the lake with carbon being obtained from the lake water, and production in the surrounding land areas with carbon assimilated from the atmosphere and washed into the lake as organic detritus. The ^{13}C content gives an indication of the relative importance of these two components, the first being characterized by high concentrations of ^{13}C, generally

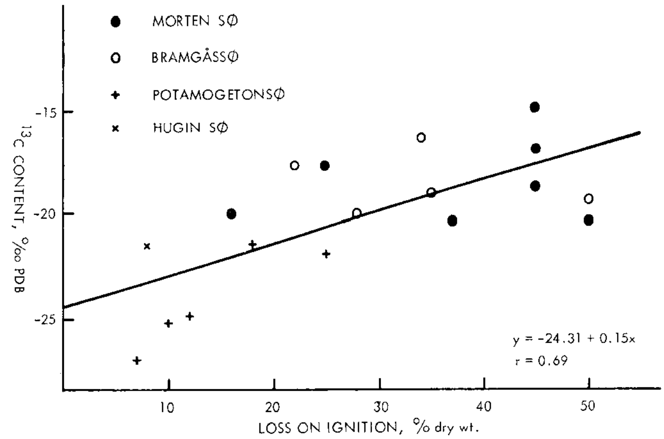


Fig. 12. Regression line for observations on loss on ignition and ^{13}C content of lake sediments. The correlation coefficient is highly significant ($1\% > P > 0.1\%$).

−8 to −20 per mille PDB, the second by lower concentrations, generally −25 per mille or less (Olsson & Osadebe, 1974; see also discussion of C-14 dating of marine molluscs above).

The ^{13}C content of the dated samples of lake sediments appear from table 4; from fig. 12 it appears that there is a significant correlation between ^{13}C content and loss of ignition, low values for ^{13}C followed by low values for loss on ignition. The implication seems to be 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 a smaller supply of minerogenic material the organic production in the lake is responsible for a higher proportion of the sedimentation. These considerations are relevant for the evaluation of the C-14 dates obtained, and give reasons to suspect that secondary pollen should occur especially in periods with minerogenic sedimentation.

C-14 dates of lake sediments and rates of sedimentation

C-14 dates of lake sediments

The gyttja ages (table 4) date incidents in the pollen diagrams. The dated sediments are poor in organic matter and large amounts of material were required for each age determination. Therefore either the dated sediment interval must be long, up to 25 cm, or the dated sample must be pieced together from several parallel cores. The latter method has been used where changes in the sediment allow a precise correlation from core to core, as is normally the case at the lower transition from minerogenic to organic sediments. The number of sediment cores used for each date is listed in table 4, and where only one core has been used this is the same as the one used for pollen analysis.

As discussed above the ^{13}C concentration in the samples may give a clue to the origin of the sediments, and from these measurements it seems likely that the lowermost part of the organic sequences in the lakes are composed to a great extent of organic detritus washed into the lake basins from the surroundings. This interpretation indicates that no 'hard water effect' should be expected. This type of error may seriously affect C-14 dates from the early phases of lake sedimentation (Blau *et al.*, 1953). Since most sites have been covered by ice or inundated by the sea immediately before the start of lake sedimentation, it seems unlikely

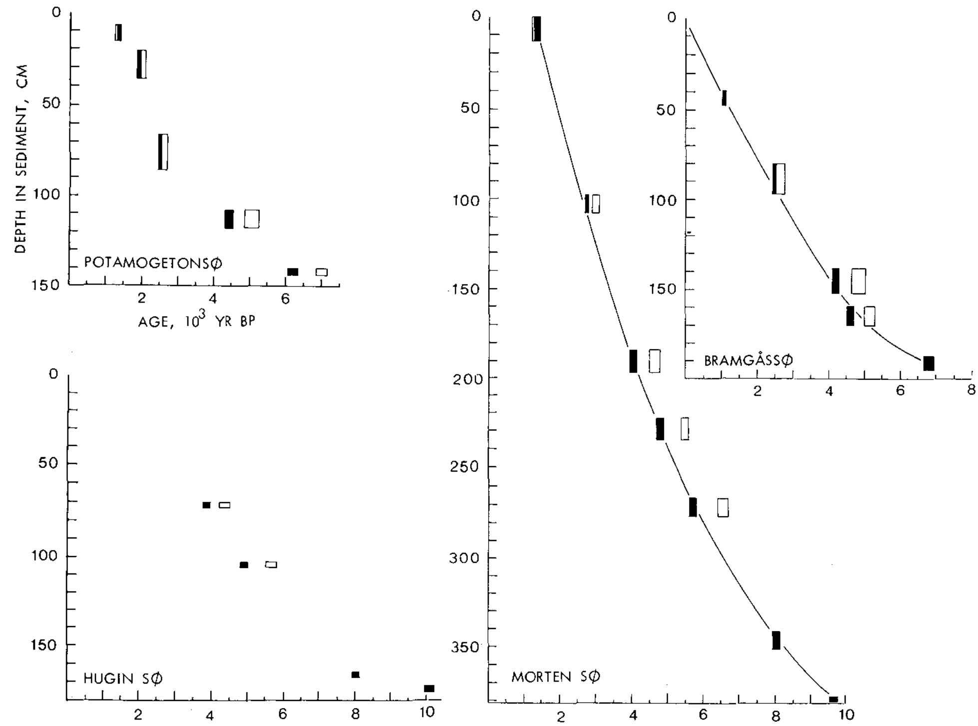


Fig. 13. Age/depth relation of lake sediments. Horizontal length of rectangles represents ± 1 standard deviation on C-14 counts, the height marks the dated core interval. Open boxes denote dates corrected according to tree ring chronology after Damon *et al.* (1972).

that old organic matter should have been available in the areas to affect the dates. On the other hand, there is a possibility that the samples from the upper minerogenic part of the profiles have been contaminated by old organic detritus washed out from the surroundings. This could explain the anomalously high ages obtained for the top sediments in Morten Sø and Potamogetonsø (fig. 13), although also the difficulty in sampling the liquid upper sediments may have a part in this deviation.

It should finally be mentioned that no correction of the dates relative to tree-ring chronology has been applied, since a large part of the dates are beyond the present range of this correction (Damon *et al.,* 1972). However, in fig. 13 the corrected ages have been included for comparison.

Sedimentation rates

The age/depth relations of the sediments are shown in fig. 13. The general pattern of sedimentation seems to be the same in all the lakes: after a slow start constant rates prevail. Only in Potamogetonsø do the dates suggest irregularities in the sedimentation process, with the possibility of abrupt changes. As noted above, Potamogetonsø is characterized by its highly minerogenic sediments, and the irregularities may be caused by local variations in the supply of silt and sand.

The fastest rate of sedimentation appears in Morten Sø with an average of *c.* 0.4 mm per year and range between 0.2 and 0.7 mm per year. The slowest sedimentation took place in Hugin Sø with an average of *c.* 0.2 mm per year and range between 0.04 and 0.3 mm per year. In general the values agree with those observed in other arctic lakes (Fredskild, 1973; Hyvärinen, 1976; Hyvärinen & Ritchie, 1975).

For Morten Sø and Bramgåssø where smooth sedimentation rates seem to be well established, curves have been drawn to provide a basis of the calculation of pollen deposition rates, and for the comparison of the pollen records from the two lakes.

Pollen preparation and calculation procedures

Preparation procedure

The following treatment was used in the preparation of the samples for pollen analyses: boil in 10 % KOH for 10 minutes, decant sand, boil in HF for 30 minutes and washing in warm 10 % HC1 for 15 minutes, acetolyse in boiling water for 1 minute, mount in silicone oil.

In the samples where the absolute pollen frequency was determined by the 'Stockmarr method' (see below) *Lycopodium* tablets were added before preparation and the samples were evacuated in order to facilitate the settling of the air filled spores during centrifuging. After the KOH treatment these samples were treated with HC1 to remove the calcium carbonate matrix of the tablets.

Relative pollen frequencies

Relative pollen frequencies were calculated from a sum comprising the pollen and spores of all land plants in the area. Excluded from the sum were pollen from plants not growing in East Greenland (*Pinus, Picea, Quercus, Fagus, Alnus, Corylus, Tilia, Artemisia*), and pollen from water plants (*Hippuris, Potamogeton*). It was attempted in all samples to reach a sum exceeding 500 grains, but in some samples this was not possible.

Absolute pollen frequencies

Absolute pollen frequencies have been determined in two different ways: in the diagram counted first, from Hugin Sø, the method described by Jørgensen (1967) was used, weighing samples, aliquots and analysed slides on a balance reading to 1/100 000 g. In the diagrams from Morten Sø, Bramgåssø and Potamogetonsø the method described by Stockmarr (1972) was used, in which tablets with a known quantity of *Lycopodium clavatum* spores were added to the samples.

In order to investigate the relation between the two methods they were both used for a number of samples, and it appeared that the estimates of pollen frequency arrived at by the 'Jørgensen method' were consistently lower than those obtained by the 'Stockmarr method'. In 22 samples from Bramgåssø the average difference was 31 per cent with a variation from 11 to 54 per cent. In 11 samples from Morten Sø the average difference was 33 per cent, varying from 26 to 43 per cent. And in 5 samples from the lowermost part of the profile in Hugin Sø the average difference amounted to 84 per cent with a range from 77 to 92 per cent. If the *Lycopodium* tablets were added after acetolysis there was little or no difference, showing that the difference is due to a loss pollen during preparation.

In an attempt to increase the efficiency of recovery of pollen from the samples – sparse as it is – decanting was omitted, centrifuging times increased to four minutes (at 3500 rpm), the number of centrifugings in each procedure reduced from 15 to 11 by omitting extra washing, and the liquid removed with a pippette after centrifuging; however, these remedies did not affect the loss to any significant extent.

A similar loss of pollen during sample preparation has been observed by Peck (1974), who recorded a loss of 11 to 86 per cent, and suggested that it could in part be related to sediment types. It is here postulated that the loss affects the fossil pollen and the added spores alike, and that therefore the 'Stockmarr method' gives the most reliable estimate of absolute pollen frequency.

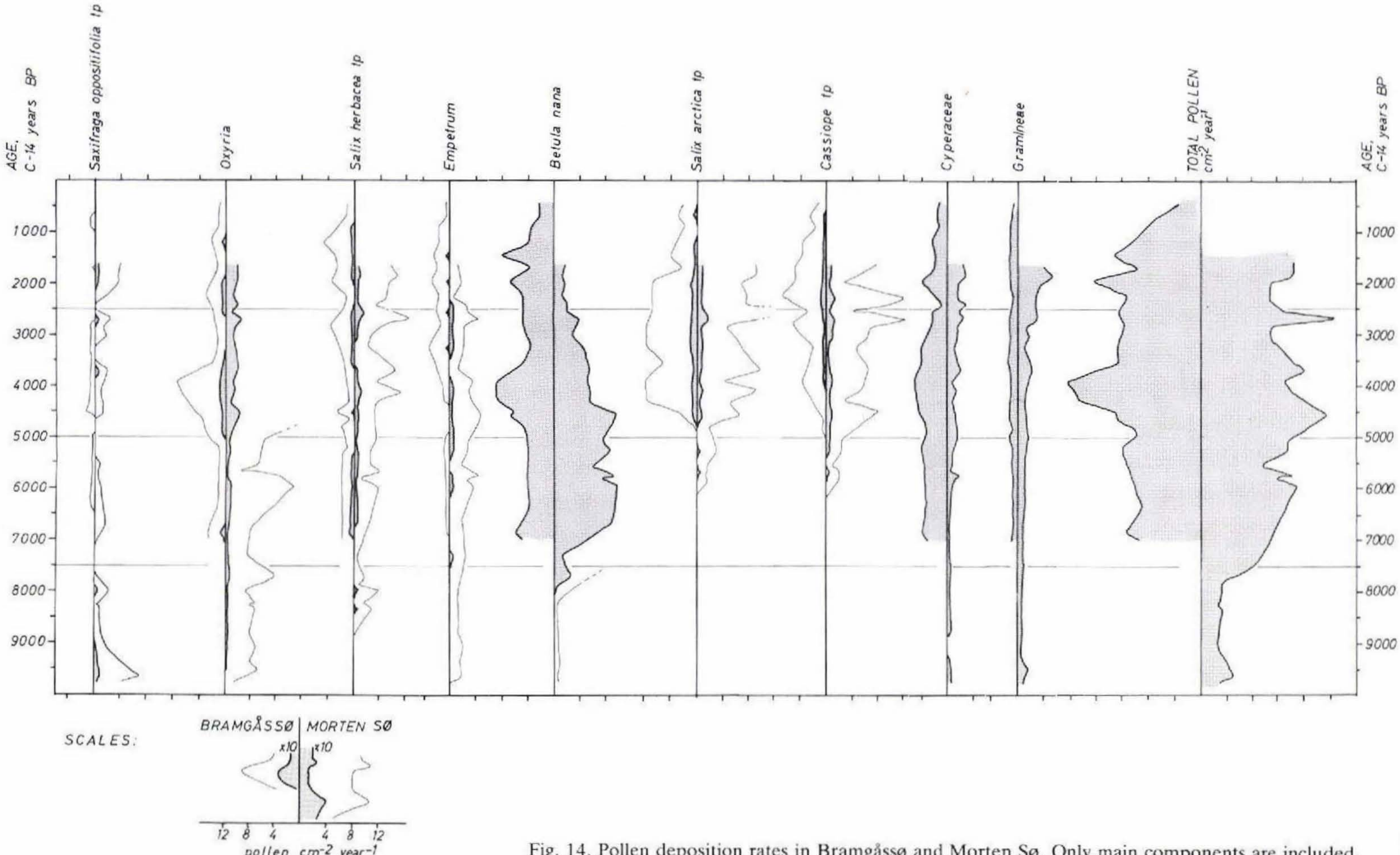


Fig. 14. Pollen deposition rates in Bramgåssø and Morten Sø. Only main components are included.

In the pollen diagrams the absolute frequencies are expressed as pollen concentration values, i.e. pollen grains per gram dry sediment. This parameter is well defined but is controlled both by the pollen production of the area and by the rate of sedimentation, in the lake, and therefore cannot be interpreted directly in terms of vegetational change. Pollen deposition rates, i.e. pollen grains per square centimetre per year (Davis, 1965), describe only the pollen productivity of the area, but are dependant on a precise knowledge of sedimentation rates which in the period prior to 6500 yr BP can only be calculated with uncertainty owing to the present lack of knowledge of possible corrections of C-14 dates in this period (Damon *et al.,* 1972). For the period around 6000 yr BP where the difference between corrected and uncorrected values attains a maximum the use of corrected values would here increase the pollen deposition rates by 10–20 per cent.

Accepting this uncertainty, pollen deposition rates have been calculated for Morten Sø and Bramgåssø (fig. 14) where the sedimentation rates seem best established. The sedimentation rates used in the calculations have been derived from the curves in fig. 13, which also have been used to 'date' individual samples to provide a comparable time scale for the two lakes. (The lowermost three samples in the diagram from Bramgåssø have been left out in this calculation since they come from the minerogenic sediment below the organic sequence, and a sharp change in sedimentation rate is likely.

The volumetric data necessary for the calculations have been procured by measuring volumes of fresh sediment in a cylinder glass, or by taking samples from the cores with a sampler of known volume.

The standard deviation on the values for pollen deposition rates is ± 5–7 per cent, which includes the standard deviation on the count of *Lycopodium* spores, the count of fossil pollen, and on the content of spores in the tablets, as supplied by Stockmarr with the tablets.

The rates of pollen deposition in the two lakes are similar, varying from a minimun of 15–20 grains per square centimetre per year in the early phases to a maximum of *c.* 200 in the period around 5000 yr BP.

From low arctic lakes in south-west Greenland Fredskild (1973) obtained maximum values generally of 500–3000 with a maximum of 60 000 at one site, while in northernmost Greenland a sedimentation rate of 2.5 pollen grains per square centimetre per year was measured in a pollen trap (Fredskild, 1969).

Pollen identification

The criteria used for pollen and spore identification generally conform with those outlined by Fægri & Iversen (1975) and for Greenland by Fredskild (1967, 1973). Because of their potential importance as indicator species some groups have been given special attention here, i.e. the ericaceous dwarf shrubs and the *Salix* species; these and a few other types will be dealt with here.

The botanical nomenclature follows 'The Flora of Greenland' (Böcher *et al.,* 1966), the pollen terminology is that of Fægri & Iversen (1975).

Salix species

At present three species of *Salix* occur in the area *Salix glauca, S. arctica,* and *S. herbacea.* The three species have a very different distribution and ecology, and after counting the diagrams from Hugin Sø and Munin Sø, it was decided that it was essential that the *Salix* pollen should be determined to species if possible.

The problem is complicated by the difficulty of distinguishing living plants of *Salix arctica* and *S. glauca.* Although the former is typically a small prostrate shrub and the latter a scrub form many transitions occur in the Scoresby Sund area, which is the only part of East Greenland where the two species occur together in their pure forms. Different authorities have held very different opinions on the occurrence of the two species, and their possible hybridization, or hybridization with species that are not known from Greenland, has been a matter of controversy (Floderus, 1923; Seidenfaden & Sørensen, 1937; Böcher, 1938). Recently, however, the herbarium specimens at the Botanical Museum in Copenhagen have been revised by Skvortsov (1971) and his concept has been followed here. The distribution of *Salix glauca, Salix arctica* and their putative hybrids, according to Skvortsov's determinations is shown in fig. 20. A large part of the type material used here for comparison of the pollen types comes from these herbarium specimens which have kindly been made available by the Museum (see list below).

It should be noted that a fourth species of *Salix, S. arctophila,* had been reported earlier from the Mesters Vig area by Raup (1965); however, according to Skvortsov (1971) Raup's specimens could be referred to *Salix arctica.* It has been attempted to distinguish the pollen from the three species by size measurements and pollen morphology. The scanning electron microscope has been used to find differences which could then be identified in the light microscope.

Size measurements. The results of measuring modern *Salix* pollen are given in table 5, and the size frequency distribution of the fossil pollen appears from plate 5.

The measurements were made with a Leitz Ortholux microscope, using an immersion objective of 90 × magnification and 0.88 μm micrometer units. The modern pollen has been prepared the same way as the fossil. Both length and width of the grains were measured, but the width appeared to vary greatly with the state of preservation, and has not been considered here. Unfortunately the anthers of the herbarium specimens were almost emptied of their pollen, and it was difficult to reach an adequate sum.

It appears from table 5 that it should be possible to distinguish *Salix herbacea* from *Salix arctica/glauca* by the size frequency distribution of the pollen.

Pollen morphology. Based on a study under the light microscope of the type material listed below three types of *Salix* pollen have been distinguished in the pollen diagrams from Morten Sø, Bramgåssø and Potamogetonsø (plates 6, 9, 10). Each grain has been studied with a 90 × immersion objective, and the criteria for distinction are listed below and shown in scanning electron microscope photographs (poates 2, 3, 4). It should be noted that the criteria are based on acetolysed silicone mounted material and collumellae cannot be seen; in stained glycerine mounted material collumellae can be seen, but such features as vallae undulations are difficult to observe.

Salix arctica tp: Exine thin (<1 μm). Reticulum with even surface (uniform intensity of colour if focused on top of vallae). Few ruptures of vallae (less than ten in each intercolpium). Verrucae often appear as 'islands' in the luminae of the reticulum. Heterobrochate (luminae < 5 μm in diameter). Grains often oval. In all collections of *S. arctica* at least 85 per cent of the pollen were of this type. *Salix glauca* tp: Exine ≥ 1 μm. Reticulum with undulating surface (uneven colour intensity if focused on top of vallae). No or few ruptures of vallae. Vallae high, verrucae usually not seen. Homobrochate, luminae 2–4 μm in diameter. Grains spherical or oval. In all collections of *S. glauca* at least 60 per cent of the pollen were of this type. *Salix herbacea* tp: Exine > 1 μm. Reticulum with strongly undulating surface (appears broken if focused on top of vallae). Many ruptures of vallae. Vallae

Table 5. Size measurements of modern Salix pollen

	Coll. No	n	*Salix*, µm	*Corylus*, µm
Salix arctica	2	100	23.6 ± 2.7	26.9 ± 2.0
	6	31	21.7 ± 1.6	23.6 ± 1.2
	10	80	21.6 ± 2.7	23.5 ± 1.7
	1	104	21.5 ± 1.4	25.9 ± 1.6
	5	32	21.2 ± 1.6	23.6 ± 1.2
	Total	347	$\bar{x}$ 22.1 ± 2.2	$\bar{x}$ 25.2 ± 1.7
Salix glauca	21	104	23.7 ± 1.6	26.6 ± 1.0
	14	46	22.2 ± 1.3	23.3 ± 1.3
	15	100	21.7 ± 1.4	26.7 ± 1.2
	16	33	21.4 ± 1.5	23.1 ± 1.4
	17	21	19.7 ± 1.6	24.3 ± 2.0
	Total	304	$\bar{x}$ 22.3 ± 1.5	$\bar{x}$ 25.6 ± 1.3
Salix herbacea	27	35	19.5 ± 2.1	23.1 ± 1.7
	30	104	17.9 ± 1.1	25.6 ± 1.6
	29	56	17.6 ± 1.0	25.7 ± 1.2
	28	25	16.9 ± 1.5	25.0 ± 2.4
	Total	220	$\bar{x}$ 18.0 ± 1.3	$\bar{x}$ 25.2 ± 1.5
Salix arctophila	31	64	20.7 ± 3.0	24.2 ± 2.5
Salix uva-ursi	32	61	18.2 ± 2.0	24.7 ± 2.5

high, usually no verrucae seen. Heterobrochate, luminae < 4 µm in diameter. Grains often spherical. In all collections of *S. herbacea* at least 90 per cent of the pollen were of this type.

It appears that both *Salix arctica* and *S. herbacea* have well defined pollen types whereas the pollen of *S. glauca* is variable and may approach both of the former types in its morphology. Therefore, combining size measurements with pollen morphology two groups can be distinguished with a high degree of certainty, i.e. *Salix herbacea* and *S. glauca/arctica.* The distinction between the latter two species is problematic, but the morphology will at least tell which of the two species dominate the populations.

Finally, in order to investigate the effects of hybridization on the pollen some of the putative hybrids between *Salix arctica* and *S. glauca* listed by Skvortsov have been examined. Some of these had the high vallae which do not occur in *S. arctica,* i.e. coll. 23 and 26 (plate 4, 2–4), and would fall within the range of *S. glauca,* while one specimen (coll. 24, plate 4, 1) seems to be of *S. arctica* type. A very high proportion of deformed pollen was noted in some of these specimens, thus in a putative hybrid from Liverpool Land more than 15 per cent of the pollen had four colpi fused to two rings (coll. 26, plate 2, 1). In a specimen determined by Skvortsov to *S. glauca* more than 10 per cent of the pollen had the reticulum ruptured into a frustillate sculpture (coll. 12, plate 3, 6). One specimen which had originally been determined by Raup to *Salix arctophila,* re-determined by Skvortsov to *S. arctica,* showed this frustillate sculpture in more than 35 per cent of the grains (coll. 10). In all other specimens, and in the subfossil pollen, these deformities comprise less than one per cent.

Type material of East Greenland *Salix* species

Salix arctica. (1) Inglefield Fjord, North Greenland. Leg. G. Olesen, 1917. Det. A. Skvortsov, 1969. (Determined by B. Floderus to *S. arctica* × *chloroclades* × *glauca*). MBH. (2) Heilprin Land, 82°10'N, 31°00'W, North Greenland. Leg. & det. K. Holmen, 1949 (No. 642a); A. Skvortsov, 1969. MBH. (3) Hold with Hope, 74°N, East Greenland. Leg. & det. N. Hartz, 1891 (no. 91) (*S. groenlandica*); A. Skvortsov, 1969. MBH. (4) Mesters Vig air field, 72°14'N, 25°15'W, East Greenland. Leg. & det. S. Funder, 1971. (5) Sefströms Gletscher, 72°02'N, 25°15'W, East Greenland. Leg. & det. F. H. Schwarzenbach, 1954. ULH. (6) Ryders Elv, 70°52'N, 22°25'W, Scoresby Sund area. Leg. J. Taggart, 1963. Det. G. Halliday. ULH. (7) Lollandselv, 70°58'N, 24°12'W, Scoresby Sund area. Leg. P. Moore. Det. A. Skvortsov, 1969. MBH. (8) Kalkdalen, 70°50'N, 22°23'W, Scoresby Sund area. Leg. & det. S. Funder, 1970. (9) Kap Dalton, 69°25'N, East Greenland. Leg. & det. T. W. Böcher, 1932 (*S. arctica*×*glauca*); A. Skvortsov, 1969. MBH. (10) Mesters Vig air field, 72°14'N, 23°55'W, East Greenland. Leg. & det. H. Raup (*S. arctophila*); A. Skvortsov, 1969. MBH.

Salix glauca. (11) Hvalrosbugt, Scoresby Sund area. Leg. A. Rosenkrantz; det. A. Skvortsov, 1969. MBH. (12) Danmark Ø, Scoresby Sund area. Leg. & det. N. Hartz, 1892 (*S. glauca* var. *subarctica*); A. Skvortsov, 1969. MBH. (13) Fjord north of Kap Ravn, 68°31'N, East Greenland. Leg. & det. T. W. Böcher, 1932 (*S. arctica* × *chloroclades* × *glauca*); A. Skvortsov, 1969. MBH. (14) Nunatak at Paris Gletscher, 66°47'N, 36°43'W, Leg. R. G. Swainson, 1967. Det. G. Halliday. ULH. (15) at 'Nigertussoq', [now Nigertuluk] 66°21'N, 35°03'W, East Greenland. Leg. & det. J. E. Elsley, 1967. ULH. (16) Torssukátak, 65°53'N, 36°57'W, East Greenland. Leg. & det. J. E. Elsley, 1967. ULH. (17) Kulusuk, 65°34'N, 37°10'W, East Greenland. Leg. G. Stocken, 1966. Det. G. Halliday. ULH. (18) 'Ikerasausak' [now Ikâsaulaq], 65°56' N, East Greenland. Det. T. W. Böcher, 1932 (no. 613) (*S. arctophila* × *glauca* × *arctica*); A. Skvortsov, 1969. MBH. (19) Østdal, 63°06'N, East Greenland. Leg. R. Bøgvad. Det. A. Skvortsov, 1969. MBH. (20) Dyrnæs, 60°11'N, 46°03'W, south Greenland. Leg. & det. S. Funder, 1967 (ssp. *callicarpaea*). (21) Dyrnæs, 60°11'N, 40°03'W, south Greenland. Leg. & det. S. Funder, 1967 (spp. *callicarpaea*). (22) Claushavn, 69°05'N, 50°03'W, West Greenland. Leg. & det. M. Kelly, 1963.

Salix arctica × *glauca?* (23) Kangerdlugssuaq, 68°56'N, 31°44'W, East Greenland. Leg. & det. T. W. Böcher, 1932 (*S. arctica* × *chloroclades* × *glauca*); A. Skvortsov, 1969. MBH.

Salix arctica (× *glauca?*). (24) Danmark Ø, 70°27'N, 26°12'W, Scoresby Sund area. Leg. & det. N. Hartz, 1892 (*S. brownii*); A. Skvortsov, 1969. MBH. (25) Kap Dalton, 69°25'N, East Greenland. Leg. & det. T. W. Böcher, 1932 (no. 709) (*S. arctica* × *glauca*); A. Skvortsov, 1969. MBH.

Salix glauca (× *arctica?*). (26) Kalkdal, 70°50'N, 22°20'W, Scoresby Sund area. Leg. & det. Th. Sørensen, 1933 (no. 656) (*Salix* sp.); A. Skvortsov, 1969. MBH.

Salix herbacea. (27) Sefströms Gletscher, 72°02'N, 25°15'W, East Greenland. Leg. & det. F. H. Schwarzenbach, 1954. ULH. (28) Angmagssalik, 65°50'N, 37°07'W, East Greenland. Leg. & det. J. Elsley, 1967. ULH. (29) Dyrnæs, 60°11'N, 46°03'W, south Greenland. Leg. & det. S. Funder, 1967. (30) Langjökull, Iceland. Leg. & det. S. Funder, 1973.

Salix arctophila. (31) Dyrnæs, 60°11'N, 46°11'N, 46°03'W, south Greenland. Leg. & det. S. Funder, 1967.

MBH: herbarium specimen at the Botanical Museum in Copenhagen.
ULH: herbarium specimen at the University of Lancaster.

Oxyria

The problem of distinguishing pollen of *Oxyria* from that of *Rumex* in poorly preserved material has been discussed by Fredskild (1967). In the material from East Greenland the well preserved grains were all of *Oxyria* type.

Oxyria digyna occurs abundantly in all parts of the area, while *Rumex* is represented only by *R. acetosella* which occurs sparsely in the interior fjord zone.

'Ericales' (Ericaceae, Vacciniaceae, Empetraceae, Pyrolaceae)

Based on a study of type material from Greenland the following types of 'Ericales' pollen tetrads have been distinguished, scanning electron microscope photographs of some characteristic types are shown in plate 5.

Empetrum nigrum, tetrad large (≥ 30 μm). Surface unevenly scabrate. Costae heavy. 2c/D ≥ 0.5 μm. Tetrad often globular.

Vaccinium uliginosum, tetrad 25–35 μm. Surface evenly scabrate. Costae distinct, tapering. Colpus long (2c/D ≥ 0.5). Well preserved tetrads often globular or lobate.

Phyllodoce coerulea, tetrad large (≥ 30 μm). Verrucate. Verrucae fuse to margo. Costae indistinct. Colpus long (2c/D ≥ 0.5).

Loiseleuria procumbens, tetrad 20–30 μm. Surface indistinctly scabrate. Costae heavy. Colpus short (2c/D ≤ 0.3). Tetrad often lobate.

Cassiope tp, tetrad small (20–28 μm). Surface faintly scabrate. Costae heavy. Colpus long (2c/D ≥ 0.5). Tetrad often triangular. This type includes *Cassiope tetragona* and *Harrimanella hypnoides.*

Rhododendron lapponicum, tetrad very large (≥ 40 μm). Surface scabrate. Costae heavy, tapering. Colpus short (2c/D ≤ 0.3). Tetrad often lobate.

Arctostaphylos alpina, tetrad large (≥ 30 μm). Surface indistinctly scabrate. Costae indistinct. Colpus short (2c/D ≤ 0.3). Tetrad globular or crumpled.

2c: total length of two adjoining colpi. D: diameter of tetrad.

Description of sites and pollen diagrams

The location of the five lakes which have been sampled is shown in plate 11, the pollen diagrams from the lakes appear in plates 6–10.

Regional pollen zones. The same broad outline of vegetation development has been recognized in all the lakes and a simple system of regional 'interval zones' has been established (Mangerud *et al.,* 1974). The zonation is based on the following criteria:

Zone 1: begins with the first pollen record and ends with the rise of the *Betula* curve. Locally it may be divided into two subzones:
subzone 1a: from the first pollen record to the decline in *Oxyria.*
subzone 1b: to the rise of *Betula* curve.

Zone 2: from the rise of *Betula* to rise of *Salix* (*arctica*).

Zone 3: from rise of *Salix* (*arctica*) to top of profiles. The zone may locally be divided into two subzones:
subzone 3a: to rise of *Oxyria.*
subzone 3b: to top of profile.

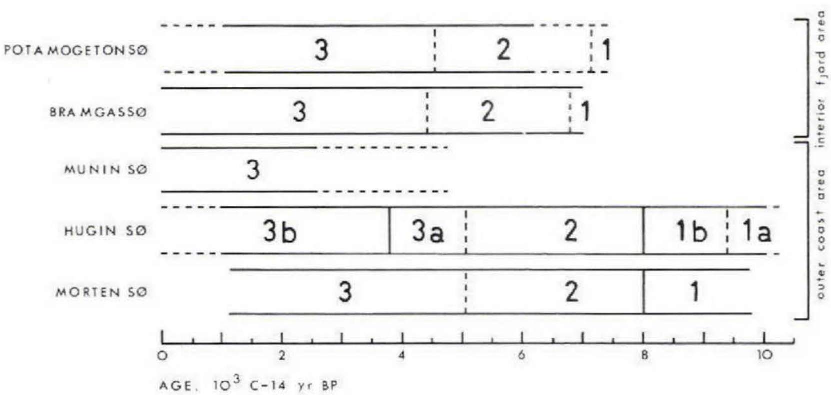


Fig. 15. Dating of pollen interval zones in the Scoresby Sund area.

The zones are not synchronous and their dating at individual sites appear from fig. 15. The zone boundaries in Morten Sø and Bramgåssø have been dated from the curves in fig. 13, in Hugin Sø and Potamogetonsø either 'directly' or by interpolation between the available C–14 dates. In Potamogetonsø the beginning of sedimentation is dated from the emergence curve from the area (fig. 5, no. 2). The dating of the beginning of sedimentation in Munin Sø is highly speculative, based on extrapolation from one date.

Morten Sø (fig. 16, plate 6)

The lake measures *c.*200 × 200 m, and lake water level is at 48 m above sea level. Depths were recorded down to 8 m, but over the greater part of the lake and at the boring station, the bottom is flat at a depth of 3.5 m. The lake has no major inlets or outlets, but is fed throughout the summer by melt water seeping away from snow patches. The terrain is characterized by rounded gneiss knolls rising 50–100 m above the lake, between the knolls and in areas around the lake there is a cover of till. The vegetation is dominated by open *Dryas* heath with some *Salix arctica* and *Vaccinium uliginosum*. On south facing slopes there is a dense cover of dwarf bush heath with *Cassiope tetragona, Empetrum nigrum* and *Betula nana*. In shallow water along the lake shore there is scattered vegetation of *Hippuris vulgaris, Potamogeton filiformis* and *Ranunculus hyperboreus*.

Fig. 16. Morten Sø, looking south over Hurry Inlet. Note tents for scale.

The lower 3 cm of organic sediments with a 1–2 cm thick layer of *Drepanocladus exannulatus* remains have been dated to 9630 yr BP. By extrapolation (fig. 13) this gives an age of *c.* 9800 yr BP for the onset of organic sedimentation in the lake. The lake is very close to the marine limit in the area, and the relation between this date and a shell date from a lower altitude at the locality (sample K–1919, fig. 5) shows that it is a likely estimate for the deglaciation of the site, and formation of the marine limit.

Zone 1: Gramineae dominate, with high frequencies also for Cyperaceae and Polypodiaceae. Among the minor constituents *Empetrum, Potentilla, Ranunculus, Saxifraga oppositifolia* tp, *Oxyria, Silene acaulis* and other Caryophyllaceae attain their maximum relative frequencies in this zone, also *Dryas* is frequent. However, the pollen depositional rates are low (fig. 14), and although the species dominated the vegetation their flowering intensity was not significantly higher than in later zones.

The low but consistent values for *Betula* are interpreted as far distance transport; also the exotic pollen reach a maximum in this zone.

The zone shows a development from an early phase with maximum frequencies for *Saxifraga oppositifolia* tp and *Potentilla* to a later phase with maximum frequencies for *Oxyria.* This feature is not known from other diagrams in the area and is believed to reflect a local succession.

At *c.* 8400 yr BP in the late part of the zone *Salix herbacea,* as determined both by pollen morphology and size (plate 5), attains maximum frequencies. A similar peak of *Salix herbacea* may possibly be identified also at other sites.

Above the basal moss layer the sediment is a silty gyttja with an increasing content of organic matter upwards, the loss on ignition is 20–40 per cent.

By interpolation the zone lasts from 9800 to 7900 yr BP.

Zone 2: *Betula* dominates whilst the relative frequencies for Gramineae, Cyperaceae, Polypodiaceae and the herbs from zone 1 decline. Among the minor constituents *Thalictrum alpinum* attains its maximum frequency in the upper part of the zone, this herb also occurred throughout zone 1.

At *c.* 5700 yr BP *Salix arctica* makes its first appearance in the area, as seen from the morphology of the *Salix* pollen and its size (plate 6). At the same time *Cassiope* tp pollen starts to appear with constant but low frequencies, it occurred sporadically in the upper part of zone 1 and the lower part of zone 2.

In the sediments the zone corresponds with the occurrence of laminated silt gyttja, with a loss on ignition of 50–60 per cent. The pollen depositional rates are high (fig. 14), and it is evident that the change from zone 1 to zone 2 involves invasion of new land rather than competition between species.

By interpolation the zone is dated to the period *c.* 7900–5100 yr BP.

Zone 3: *Betula* declines steadily from the beginning to the end of the zone. *Salix,* notably *S. arctica,* increases. *Cassiope* tp attains maximum frequencies, and *Oxyria* returns to the high frequencies it has in zone 1. Also *Dryas* which apparently suffered a setback in zone 2 returns.

Besides *Salix arctica* also *S. herbacea* increases. *Salix glauca* tp pollen occurs throughout the zone, but with so low values that they could represent 'overlap' from the other species.

The sediment changes from silt gyttja with 50 per cent loss on ignition in the lower part to highly minerogenic gyttja with 20 per cent loss on ignition in the upper part. At *c.* 2800 yr BP a marked change in sedimentation coincides with a rise of Gramineae and Cyperaceae, further decline in *Betula.*

By interpolation the zone is dated to the period 5100–1100 yr BP.

Hugin Sø (fig. 17, plate 7)

The lake measures *c.* 300 × 300 m, and the lake water level is at 55 m above sea level. The bottom is flat at a depth of 2.5–2.75 m. A small stream leaves the lake. The surrounding terrain is flat, composed of marine silt and fluvial sand. The vegetation is extremely monotonous, consisting of open *Salix – Cassiope tetragona* heath. The lake is surrounded by a fringe of moist meadow with *Eriophoron scheuzeri* and *Carex* spp. The lake bottom is covered by *Drepanocladus exannulatus* and in shallow water

Fig. 17. Hugin Sø, looking north over Jameson Land. The monotonous grey vegetation is *Salix arctica–Cassiope tetragona* heath.

along the shores there are scattered individuals of *Equisetum variegatum, Eriophoron scheuzeri, Koenigia islandica, Ranunculus hyperborea* and *Cardamine pratensis*.

The organic sediments have a thickness of 150–175 cm with a basal 1–2 cm thick layer of *Drepanocladus exannulatus,* resting on 50 cm of dark, laminated silt with scattered moss remains, which overlies grey, sandy silt penetrated to 250 cm below the lake bottom.

The lake has been sampled twice: in 1969 it was sampled with a Hiller borer (boring A), and a C–14 date of 8580 yr BP was obtained for the lower contact of the organic sediments. In order to obtain more material for dating the lake was sampled again in 1971, this time with the piston corer (boring B). The new boring station was *c*. 50 m to the south of boring A, but the organic sediments were 15 cm thicker, and contrary to the first boring the organic sediments terminated with a moss layer, such as has often been observed to initiate organic sedimentation in the lakes in the fjord zone. The pollen analysis showed the presence of a new subzone, and the onset of organic sedimentation in this boring was dated to 10 040 yr BP.

In order to correlate the two borings 30 samples were analysed from boring B with a sum of 100, and C-14 dates were obtained for characteristic intervals. These dates have been transferred to the pollen diagram from boring A where they are represented by open boxes (Plate 7). In addition 12 samples at close intervals have been counted in the lower part of boring B, and have been inserted in the pollen diagram.

As noted earlier the altitude of the Holocene marine limit in the area is not known. A sample of shells from the marine deposits surrounding the lake gave an age of 21 000–24 000 yr BP (sample I–5419, table 1), and it is uncertain whether the lake basin has been inundated by the sea since then. In order to investigate the origin of the minerogenic sediments below the organic sequence reconnaissance diatom analysis was carried out by N. Foged. Unfortunately the sediment is extremely poor in diatoms. However, all valves and fragments found belonged to freshwater species, only at 192 cm depth in the sediment a fragment of a marine species was identified (N. Foged, personal communication). Although admittedly sparse the evidence would seem to suggest that the lake existed before the onset of organic sedimentation, and that the change to organic sedimentation reflects a change in vegetation cover and climate, analogous to the sedimentation shift known from many north European lake basins at the transition from Younger Dryas to Preboreal times.

Zone 1: Over all domination of Gramineae which comprise 50–90 per cent of the pollen. *Oxyria,* Polypodiaceae and *Lycopodium* occur frequently, and among the minor constituents also Caryophyllaceae and *Salix*.

No attempt has been made to differentiate the *Salix* pollen in this diagram, but by analog with the results from Morten Sø, Bramgåssø, and Potamogetonsø it is assumed that the early Salix pollen represents *Salix herbacea.*

The low frequencies are again interpreted as far distance transport, also the exotic pollen has a maximum in this zone.

The pollen concentration values are low, probably indicating open vegetation with low pollen production. Above the basal layer of moss remains the sediments are gyttja with a high minerogenic content, with a loss on ignition of 5–10 per cent.

The zone lasts from *c.* 10 000 yr BP to *c.* 8 000 yr BP, and is divided into two subzones:

Subzone la: – maximum of *Oxyria.* Among the minor constituents *Empetrum* should be noted.

Subzone 1b: – maximum of Graminaeae. High values for *Salix* (*herbacea?*). *Oxyria* declines.

Zone 2: Rapid rise and dominance of *Betula. Thalictrum alpinum* which at other sites occurs only as a minor constituent here attains very high values, up to 20 per cent of the pollen. The rise and fall of *Thalictrum* coincides, although possibly with a slight delay, with that of *Betula.* Also the frequencies of Cyperaceae show the same development, unfortunately they cannot be determined to species. Contrary to conditions at Morten Sø *Cassiope* tp occurs frequently throughout this zone. Near the top of the zone, at *c.* 5500 yr BP, the *Salix* curve begins to rise; by analogy with other diagrams the rise is here interpreted to show the immigration of *Salix arctica* into the area. Pollen concentration values in this zone are high, indicating dense vegetation cover. The sediment is silt gyttja with *c.* 40 per cent loss on ignition. The zone lasts from *c.* 8 000 yr BP to *c.* 5 000 yr BP.

Zone 3: *Salix,* probably mainly *Salix arctica,* increases and attains dominance of the pollen with values up to 50 per cent. Also *Oxyria* increases.

At the beginning of the zone *Drepanocladus exannulatus* returns to the lake bottom where it has been growing ever since. In the upper part there is a change to minerogenic sedimentation, with a loss on ignition of 10 per cent, coinciding with a change in vegetation in the area.

Subzone 3a: High frequencies for *Salix* (*arctica?*) indicates that it was an important component of the vegetation.

Subzone 3b: A sudden rise of *Oxyria* occurs, and a decline of *Betula,* which probably disappeared from the area where it is absent today. This change is dated to 3800 yr BP; a renewed increase of *Oxyria* and a shift to minerogenic sedimentation takes place at 2900 yr BP, by extrapolation.

Munin Sø (plate 8)

The lake measures *c.* 250×250 m, with a lake water level at 26 m above sea level. The bottom is flat at 1.9 m depth. A small stream enters and leaves the lake. The surrounding terrain is flat, composed of fluvial sand and marine silt. The vegetation is richer than at Hugin Sø, and besides *Salix arctica – Cassiope tetragona* heath patches of *Betula nana* heath occur at sheltered sites. The organic sediments have a thickness of only 55 cm and rest on sand and silt with a content of gyttja, penetrated to 105 cm. The lower 5 cm of the organic sediments have been dated to 2290 yr BP which dates a change in sedimentation probably caused by a change in the local supply of minerogenic material. Only relative pollen frequencies have been worked out in this diagram, and only zone 3 is present.

Zone 3: Characterized here as in Hugin Sø by very high frequencies for *Salix,* up to 65 per cent of the total pollen, but with low values for *Oxyria.* Somewhat before 2300 yr BP there is a sudden decline of *Betula* and *Hippuris.*

Fig. 18. Bramgåssø, looking west over Rødefjord.

Bramgåssø (fig. 18, plate 9)

The lake measures c. 400×200 m, with a lake water level at 200 m above sea level. The bottom is flat at 2.1–2.5 m, and the depth at the boring station 2.5 m. The lake is surrounded by low knolls of gneiss rising up to 100 m above the lake. Between the knolls there are lateral moraines of the Rødefjord stages and till cover. No streams enter or leave the lake, but it is surrounded by meadows with *Eriophoron scheuzeri* and *E. triste* and *Carex* spp. On dry ground the vegetation is dense dwarf bush heath dominated by *Vaccinium uliginosum* but with much *Cassiope tetragona* and *Betula nana*. No submerse vegetation was observed in the lake.

The organic sediments have a thickness of 180 cm and rest on sandy silt penetrated to a depth of 207 cm. The lower 8 cm of the organic sediments were dated to 6780 yr BP, by extrapolation this gives an age of 7000 yr for the onset of organic sedimentation in the lake (fig. 13). This would be 100–200 years older than deglaciation at sea level and formation of the local marine limit which is at c. 35 m (fig. 4).

Zone 1: Gramineae predominate and Cyperaceae and *Salix herbacea* occur with high frequencies (see also plate 5). *Betula* rises rapidly. Among the minor constituents should be noted the high frequencies for *Ranunculus, Saxifraga oppositifolia* tp, *Saxifraga nivalis* tp, *Oxyria, Silene acaulis* and other Caryophyllaceae.

The sediments are silt and silt gyttja. From the curve in fig. 13 the zone can be dated to the period 7000–6800 yr BP.

Zone 2: *Betula* dominates while the herbs that were frequent in zone 1 decline. *Salix arctica* tp pollen occurs with small frequencies. *Oxyria* which suffered a setback in the early part of the zone returns with higher frequencies near the top.

The sediments are silt gyttja with 10 to 30 per cent loss on ignition, increasing towards the top.

The curve in fig. 13 dates the zone to the period 6800–4400 yr BP.

Zone 3: Increase of *Salix arctica*, which apparently gained a firm foothold in the area by the beginning of the zone, and a slight decline of *Betula*. Also *Cassiope* tp occurs with high frequencies. *Empetrum, Vaccinium, Phyllodoce* and *Loiseleuria* tp have higher frequencies than in the other diagrams. *Salix glauca* tp pollen occurs with small frequencies. Pollen concentration values and pollen deposition rates (fig. 14) are high in the early part of the zone, but decline near the top, indicating a decrease in the pollen productivity of the area.

Fig. 19. Potamogetonsø, looking north over Rypefjord and Eielson Gletscher. The dark vegetation around the lake is dense dwarf shrub heath.

The sediment is silt gyttja with a transition to minerogenic sediment near the top, the loss on ignition in the lower part is 30–50 per cent.

Potamogetonsø (fig. 19, plate 10).

The lake is triangular with 300 m long sides, and a lake water level at 58 m above sea level. The bottom slopes from 1.5 m depth in the north to 3.5 m in the south, with the boring station at 2.9 m depth. A stream enters and leaves the lake. Rounded gneiss knolls rising up to 100 m above the lake characterize the surrounding area with till, glacifluvial sand and littoral gravel forming a dense cover in the hollows. The vegetation is *Betula nana* heath, and to the south large meadows with *Eriophorum* and *Salix arctica*. At depths below 2 m the lake bottom is covered by a dense growth of *Potamogeton perfoliatus* and *P. praelongus*. These two species are not known from any other locality in Greenland (Lægård, 1960; Røen, 1962). At shallow water near the shore there are scattered plants of *Hippuris vulgaris, Potamogeton filiformis,* and *Ranunculus confervoides.*

The organic sediments attain a thickness of 170 cm and overlie 45 cm of laminated silt and sand, followed by 55 cm of layered grey silt with partly dissolved shells of *Portlandia arctica,* and at least 40 cm of reddish laminated silt. The minerogenic sequence is interpreted as showing a development from glacimarine/lacustrine to marine sedimentation which lasted until the lake was isolated from the fjord at *c.* 7400 yr BP (fig. 5). The lower contact of the organic sediments were dated to 6200 yr BP marking a change in the supply of sand and silt. The large supply of this material throughout the lake's history probably accounts for the uneven sedimentation rates appearing from the C-14 datings (fig. 13).

Zone 1: Dominance of Gramineae and high frequencies for *Salix herbacea* (see also plate 6). *Ranunculus, Saxifraga oppositifolia* tp, Polypodiaceae and *Lycopodium* attain their maximum frequencies in this zone.

The sediment is sand with a content of gyttja, loss on ignition less than five per cent.

Zone 2: *Betula* predominates, while the herbs from the preceding zone decline. The sediments are silt gyttja with up to 20 per cent loss on ignition. By interpolation between the dates the end of the zone can be dated to *c.* 4400 yr BP.

Zone 3: *Betula* dominates, but declines near the top. *Salix arctica* tp pollen appears for the first time at *c.* 4500 yr BP together with *Cassiope* tp pollen tetrads. *Empetrum, Vaccinium,* and *Phyllodoce* retain their frequencies from zone 2. *Salix glauca* tp pollen occurs, as in the other lakes, with values that are so low that it is doubtful whether it represents the species or 'overlap' from the other *Salix* species.

Pollen concentration values are high, but variable; at the top of the zone they drop to low values, the decline, at *c.* 1500 yr BP coincides with a change to minerogenic sedimentation, and whether it is due to increased sedimentation rate, decreased pollen productivity, or both is uncertain.

The sediments are silt gyttja with 30 per cent loss on ignition in the lower part, 5–10 per cent in the upper part.

NOTES ON THE PRESENT VEGETATION

Comprehensive work on the flora of the Scoresby Sund area was carried out during the early expeditions to the area (Hartz, 1895a, b; Kruuse, 1905). Since then a large amount of botanical knowledge has accumulated from adjacent areas to the south and north (Böcher, 1933b; Sørensen, 1933; Gelting, 1934; Seidenfaden & Sørensen, 1937; Halliday *et al.*, 1974), and from northernmost Greenland (Holmen, 1957; Fredskild, 1966). The results from this works with special reference to the East Greenland fjord zone have been summarized by Raup (1965, 1971) during his detailed work at Mesters Vig.

The type of vegetation which areally dominates the Scoresby Sund region is that of 'fell field', i.e. scattered plants growing in raw mineral soil. A higher productivity may be attained at sites with stable soil and an adequate supply of water, where meadow vegetation, herb fields and dwarf shrub heaths may form a dense cover.

The highest plant productivity is probably attained in the dwarf shrub heath. For the present purpose two main types can be distinguished: a 'poor' type consisting of scattered individuals of *Salix arctica* and *Cassiope tetragona* with some *Vaccinium uliginosum;* and a 'rich' type containing a variety of species: *Betula nana, Empetrum nigrum, Phyllodoce coerulea, Arctostaphylos alpina, Rhododendron lapponicum,* and also the three species from the aforementioned type. The poor type of dwarf shrub heath covers vast areas in southern Jameson Land and in the coastal area, while the rich type of heath forms a dense vegetation cover especially in the interior part of the fjords, but also at sheltered sites in the coastal area. The distribution of the two types of dwarf shrub heath stresses the fact that besides the general climatic gradient which is related to latitude, there is also a climatic gradient at right angles to the coastline.

In a plant geographical sense the area belongs to the high arctic but lies close to the boundary to the low arctic (Böcher, 1938, p. 301). The boundary situation is here illustrated by the distribution in the area of two *Salix* species (fig. 20). *Salix arctica* is a high arctic species occurring in the north of Greenland with a southern limit just south of Scoresby Sund, while *Salix glauca* is a low arctic species which is widespread in south Greenland and has its northern limit in the Scoresby Sund area. *Salix glauca* normally occurs in the area as a prostrate shrub, but it has been observed by Hartz (1895a) to form copses in the south-eastern corner of the area at the head of Fønfjord; these are probably the northernmost representatives of copse type vegetation in East Greenland.

For the present purpose the flora of Scoresby Sund may be divided into three groups according to the species' distribution in Greenland: (a) high arctic species

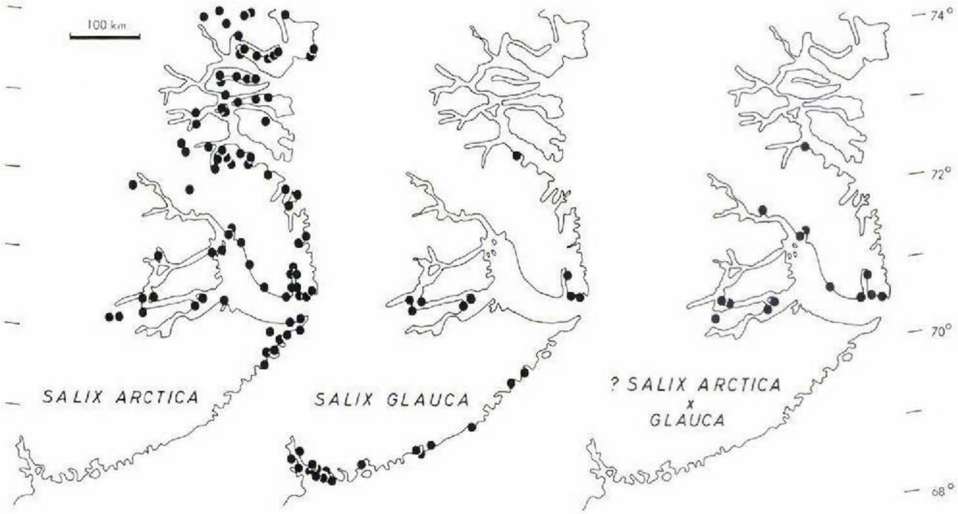


Fig. 20. Distribution of *Salix arctica, Salix glauca* and their putative hybrids in central East Greenland, according to herbarium specimens at the Botanical Museum in Copenhagen determined by A. Skvortsov.

which occur in the north of Greenland but not in the south, (b) low arctic and subarctic species which occur in the south but not in the north, and (c) ubiquitous species occurring in all parts. The species of interest in the interpretation of the pollen diagrams have been listed according to their type of distribution in table 6, for groups a and b respectively the southernmost and northernmost known occurrence of the species in East Greenland is added. This classification gives some indication of the temperature requirements of the species, also the general ecology of the plants may be related to their type of distribution; thus in this area the high arctic and ubiquitous species often show very wide ecological amplitudes and occur in a wide range of habitats, whereas the low arctic species have considerably narrower tolerances.

DISCUSSION AND RECONSTRUCTION OF VEGETATION TYPES

Zone 1. This zone, the pre-*Betula* phase, is clearly metachronous in the region (fig. 15). In the coastal area (Morten Sø and Hugin Sø) it covers the period from 10 000 to 8000 yr BP, while in the interior fjords (Bramgåssø and Potamogetonsø) it follows immediately on the deglaciation of the sites at 7500–7000 yr BP with a duration of only a few centuries.

Grasses and herbs dominate the pollen spectra, but the low pollen concentration

Table 6. Distribution in Greenland of some East Greenland plant species

(a)	High arctic	south limit	Reference
	Cassiope tetragona	65°05'	(Fredskild, personal communication)
	Salix arctica	69°38'	(Halliday *et al.*, 1974)
(b)	Low arctic and subarctic	north limit	
	Betula nana	76°46'	(Eastwood, 1948)
	Botrychium lunaria	72°32'	(Sørensen, 1933)
	Diphasium alpinum	70°27'	(Hartz, 1895b)
	Empetrum nigrum ssp. *hermaphroditum*	76°46'	(Gelting, 1934)
	Lycopodium dubium	72°42'	(Sørensen, 1933)
	Phyllodoce coerulea	72°10'	(Sørensen, 1933)
	Salix glauca	c. 72°00'	(Skvortsov, 1971)
	Salix herbacea	76°46'	(Seidenfaden & Sørensen, 1937)
	Thalictrum alpinum	74°06'	(Fredskild, personal communication)
(c)	Ubiquitous		
	Chamaenerion latifolium		
	Cystopteris fragilis		
	Dryas octopetala/integrifolia		
	Hippuris vulgaris		
	Oxyria digyna		
	Polygonum viviparum		
	Saxifraga oppositifolia		
	Saxifraga nivalis		
	Silene acaulis		
	Vaccinium uliginosum ssp. *microphyllum*		

values and pollen deposition rates (fig. 14) suggest sparse vegetation cover; also the high mineral content in the sediments indicate that plenty of open ground was available for erosion around the lakes.

Among the herbs ubiquitous species dominate (table 6), i.e. *Oxyria, Silene acaulis, Polygonum viviparus* and *Saxifraga oppositifolia* tp (including also *S. aizoides* and *S. nathorstii* in the area). These species have in common very wide ecological amplitudes and in some communities with a very low plant productivity they may dominate, notably on newly exposed soil and on heavily cryoturbated surfaces. In the pollen diagrams they mark the first phase in the colonization succession, and have no climatic significance. This is seen also from their metachronous appearance in the area as noted above.

There is also a group of low arctic and subarctic species which are present from the very beginning of the pollen record: *Empetrum, Salix herbacea, Thalictrum alpinum, Botrychium, Lycopodium dubium, Diphasium alpinum.* In the reconstruction of former climates the latter three are especially interesting. *Botrychium* is represented in the area only by *B. lunaria,* and all three species are rare, their northern limits lying in Scoresby Sund or a short distance to the north (table 6). Their occurrence in the area is generally restricted to south exposed slopes where they are found in herb fields or dwarf shrub heath. As pointed out by Böcher (1938) this type of occurrence suggests that temperatures are critical, and their presence at 10 000 yr BP indicates that summer temperatures must have been similar to those at the present. From Godthåbsfjord in West Greenland Iversen (1953) noted that the three species were among the earliest immigrants and pointed out that their dispersal mechanism, by 'air currents' made them well adapted to settle in new areas.

With these thermophilous species present it is difficult to understand why more than a millenium apparently had to pass before dense plant cover was established in areas arround the lakes in the coastal area. The explanation could lie in the formidable obstacles facing the potential immigrants, but it could also be instability of the climate which especially affected the migration rates of the less mobile species.

In the interior fjord area, at a later time, the transition from raw soil to dense vegetation cover seems to have taken place within a few centuries.

Finally, the rather high frequencies for *Empetrum* and *Vaccinium* in this zone in the diagrams from Morten Sø and Hugin Sø indicate that dwarf shrub heath existed in the coastal area already at this early stage.

Zone 2. Also this zone, the *Betula* phase, is slightly metachronous when the coastal area (Morten Sø and Hugin Sø) is compared to the interior fjord area (Bramgåssø and Potamogetonsø) (fig. 15). It is characterized by the rapid expansion and dominance of *Betula nana* in the pollen spectra.

In the coastal area (Morten Sø and Hugin Sø) *Betula* rises abruptly from low to very high frequencies at *c.* 8000 yr BP. The rise is interpreted to show the immigration of *Betula* into an area where suitable habitats occurred abundantly (see discussion below). *Betula nana,* though generally widespread, is a continental species in Greenland, being more abundant in the interior fjords than in coastal areas (e.g. Böcher, 1954). Though its present northern limit in East Greenland is 500–700 km to the north (table 6) the coastal parts of the Scoresby Sund area are critical; in large areas of southern Jameson Land it is missing or restricted to sheltered sites. In spite of an intensive search not a single individual could be found in the areas around Hugin Sø. In all parts of the area *Betula nana* has a preference for moist stable soil, and generally occurs as a component of a dense type of dwarf shrub heath with *Empetrum, Vaccinium* and *Phyllodoce coerulea.* Unfortunately these ericaceous dwarf shrubs are much underrepresented in the pollen diagrams, and since *Betula* is not known to form pure heath anywhere in East Greenland it is likely that the high frequencies signify the prevalence of this 'rich' type of dwarf shrub heath, probably the most productive plant community in the area.

Thalictrum alpinum is a tiny wind pollinated herb with a subarctic and somewhat oceanic type of distribution (table 6; Böcher, 1938). It usually occurs only as a minor constituent in the pollen diagrams, but in Hugin Sø it rises to become extremely frequent in the later part of zone 2; the same feature, though less pronounced, can be seen also in Morten Sø, but is not found in the diagrams from the interior.

Thalictrum today occurs sporadically in the area and is most frequent in moist sedge meadows and herb fields. In Hugin Sø the high frequencies coincide with an abundance of Cyperaceae and although the latter cannot be determined to species it seems probable that they mark the presence of dense meadow vegetation around the lake with *Thalictrum* indicating a mild and somewhat humid type of climate. The combined high frequencies of the continental *Betula nana* and the slightly oceanic *Thalictrum* seems to point to a general northwards displacement of plant geographical borders, and a climate warmer than the present. It should be noted here that Seidenfaden & Sørensen (1937), from its type of distribution, listed *Thalictrum* among a group of plants which "... seems to have had a much wider distribution at a time when the climate was warmer ..." (p. 191), this judgement seems to be fully confirmed by the pollen analysis.

In the interior fjord area (Bramgåssø and Potamogetonsø) the ericaceous components have higher frequencies in the diagrams, thus the thermophilous *Phyllodoce coerulea* occurs rather frequently throughout zones 2 and 3. This feature is in harmony with the present distribution of the species in the region, and together with the scarcity of *Thalictrum alpinum* pollen in these diagrams indicates that the climatic difference between the coastal area and that of the interior fjords existed also at this time.

Zone 3. This zone is characterized in all diagrams by the decline of *Betula* and rise of *Salix,* notably *Salix arctica.* However, the development in the coastal area is rather different from that in the interior fjords.

In the coastal area (Morten Sø, Hugin Sø and Munin Sø) the decline in *Betula,* though gradual, brings the species down to near extinction. At Morten Sø the decline is to some extent compensated by a rise of *Salix arctica* which seems to have appeared for the first time in the area at *c.* 5700 yr BP, in the later part of zone 2. In Hugin Sø a similar rise in *Salix* pollen can be dated by extrapolation to 5500 yr BP.

Salix arctica is a pronouncedly high arctic species with its southern limit in East Greenland just south of Scoresby Sund (fig. 20). The species is noted for its wide ecological amplitude, thus Raup (1965) noted from the Mesters Vig area that "A list of the kinds of sites in which it was found becomes merely a list of nearly all the kinds that were examined" (p. 50). In southern Jameson Land it is dominant in the 'poor' *Salix arctica – Cassiope tetragona* heath which covers vast areas; in active polygon fields it was often the only species observed, its particular endurance of cryoturbation and root damage was noted by Raup (1971).

Also the other main component in this type of heath, *Cassiope tetragona,* seems to increase in this zone. Some problems regarding this species will be discussed below.

In Hugin Sø there is a sudden rise of *Oxyria* at 3800 yr BP coinciding with a final drop in *Betula* (subzone 3b). Somewhat later, at *c.* 2800 yr BP, there is a renewed rise of *Oxyria* this time coinciding with a change to minerogenic sedimentation. A similar, though gradual, development is seen also in Morten Sø where a change to minerogenic sedimentation takes place at *c.*2800 yr BP. In Munin Sø a similar event is recorded.

This development seems to reflect a step by step climatic decline during which the vegetation cover was broken up and *Salix arctica – Cassiope tetragona* heath expanded onto the open cryoturbated surfaces. Also, the ubiquitous herb species from zone 1 return to high frequencies.

In the interior fjord areas (Bramgåssø and Potamogetonsø) the development is similar, but much less dramatic. The decline of *Betula* is not very conspicuous, and apparently *Salix arctica* did not get a firm foothold in the area until *c.* 4500 yr BP. However, also here the immigration of *Salix arctica* is followed by a rise of *Cassiope, Oxyria* and Gramineae, indicating climatic deterioration.

PLANT IMMIGRATION AND CLIMATIC CHANGE

In areas as isolated as Greenland the understanding of the immigration histories of the plants is an important aspect of the vegetation history as demonstrated repeatedly by pollen analysis in West Greenland (Iversen, 1953; Fredskild, 1973; Kelly & Funder, 1974). Some notes will be given here on the immigration of *Betula nana, Salix arctica, Cassiope tetragona, Salix glauca,* and *Loiseleuria procumbens.*

At 8000 yr BP the frequencies for *Betula* change abruptly from very low to very high in the diagrams from Morten Sø and Hugin Sø. The abrupt rise has been interpreted to show that the species arrived in an area where conditions had been suitable for some time, the low values preceding the rise being due to far distance transported pollen. The high relative values for other exotic pollen types (*Pinus, Picea*) give some support to this assumption. The argument for maintaining that the other low arctic and subarctic components of the early pollen spectra grew in the vicinity of the lakes, rests on the absence of an 'arrival peak' in the frequencies of these species. The implication of this interpretation is that the sudden rise of *Betula* holds no climatic significance.

Betula nana was widespread in northern Europe by the end of the Weichselian, and Greenland was probably colonized from that area. Its passage over the North Atlantic is imperfectly known although Jóhansen (1975) dated its arrival on the

Shetland Islands to some time after 10 400 yr BP, and on the Faeroe Islands to 9300 yr BP. In West Greenland the species occurs at present in the area from 74° to 64° N., and is lacking in the southern parts (Böcher, 1954). In Disko Bugt it was present before 7900 yr BP (Kelly & Funder, 1974), while in Godthåbsfjord to the south it probably did not arrive till *c.* 6400 yr BP (Fredskild, personal communication).

Perhaps the most striking aspect of the pollen diagrams from Scoresby Sund is the apparent absence of *Salix arctica* and *Cassiope tetragona* in the early period – the two species which more than any characterize the vegetation in the area today. *Salix arctica* was not present in the vegetation around the lakes until it arrived at Morten Sø at *c.* 5700 yr BP, in the warm interior it was sparse or absent until 4500 yr BP. The expansion apparently was slow and, contrary to that of *Betula nana,* probably in 'equilibrium' with the changing environment which began to deteriorate at this time.

At Klaresø in northernmost Greenland Fredskild (1969, 1973) noted that *Salix arctica* was absent in the earliest phase and arrived at *c.* 4800 yr BP. However, whether its arrival was due to climatic change or records a stage in a local succession was uncertain.

The record for *Cassiope tetragona* in the area is more ambiguous since its pollen is difficult to distinguish from that of *Harrimanella hypnoides. Harrimanella* is a tiny dwarf shrub with a low arctic type of distribution which occurs sporadically in snow patch communities and herb fields near the lakes. The possibility that *Harrimanella* was more abundant in the early periods, and contributed significantly to the pollen cannot be excluded. However, in most diagrams the frequencies for *Cassiope* tp pollen correlates with those for *Salix arctica,* the other main component in the 'poor' type of dwarf shrub heath, and since *Cassiope* tp pollen is very sparse in zone 1, it can be concluded that if present the species was rare in the areas around the lakes.

Both *Cassiope tetragona* and *Salix arctica* have their main distribution in arctic North America, and probably came to the East Greenland fjord zone via North Greenland, and their apparent absence in zone 1 could possibly be due to problems of dispersal.

Salix glauca tp pollen is sparse in the diagrams, apparently suggesting that the species never became important in the vegetation. However, the record is ambiguous because of the problems both in determining the pollen and the plants. Hartz (1895b) and Lægård (1960) held it to be common in the interior parts of the area, but the herbarium material has not given any evidence of this; most of the few specimens from this area were determined by Skvortsov to *S. arctica.* The size measurements of the pollen shows that at least the species was not present in the area before the arrival of *Salix arctica* (plate 5), probably it should be considered a recent immigrant to the area.

In pollen diagrams from West Greenland it has generally been assumed that most of the *Salix* pollen came from *Salix glauca,* and its arrival at a number of sites was dated to the period from 8900 to 7200 yr BP (Fredskild, 1973; Kelly & Funder, 1974). At Angmagssalik, 600 km to the south of Scoresby Sund, Bick (in press) assumes it to be present before 6000 yr BP.

Loiseleuria procumbens is a prostrate dwarf shrub with a low arctic type of distribution in Greenland. It was not known from the Scoresby Sund area until found by the author on a locality on southern Milne Land. *Loiseleuria* pollen occurs with low frequencies in the two diagrams from the interior area (Bramgåssø and Potamogetonsø); although the pollen tetrads may be confused with those of *Vaccinium* when not well preserved, the constant values indicate that the species once was more widespread in the area.

SUMMARY OF THE VEGETATION HISTORY

The main features in the pollen diagrams which have been discussed above are presented in fig. 21. Morten Sø and Bramgåssø have been chosen to show the typical development in the coastal area and that of the interior fjords respectively. In the diagrams the species have been grouped into the plant communities in which they have their optimal frequency.

In all parts of the area the vegetation history seems to fall in three phases: (a) an early colonizing phase where grasses, sedges and pioneering species (*Oxyria, Saxifraga oppositifolia* tp, *Silene acaulis*) dominate suggesting an open type of vegetation similar to the present fell field vegetation, (b) a phase with dense and 'rich' dwarf shrub heath growing around the lakes, characterized by high frequencies of *Betula* pollen, and (c) a decline phase during which the 'rich' heath disappeared or was reduced, giving place to 'poor' *Salix arctica – Cassiope* heath with abundant pioneer species, which now returned.

Having observed this broad similarity it should be noted that dissimilarities exist between the development in the coastal area and that in the interior fjords with regard to the timing and development of the phases, thus in the coastal area the record starts at *c.* 10 000 yr BP while in the interior, owing to later deglaciation, it does not start till 7500–7000 yr BP. Also, in the interior the decline phase is much less pronounced, the 'rich' type of heath persisting till the present day.

The presence of such thermophilous species as *Botrychium, Lycopodium dubium* and *Diphasium alpinum* in the coastal area at *c.* 10 000 yr BP indicate that

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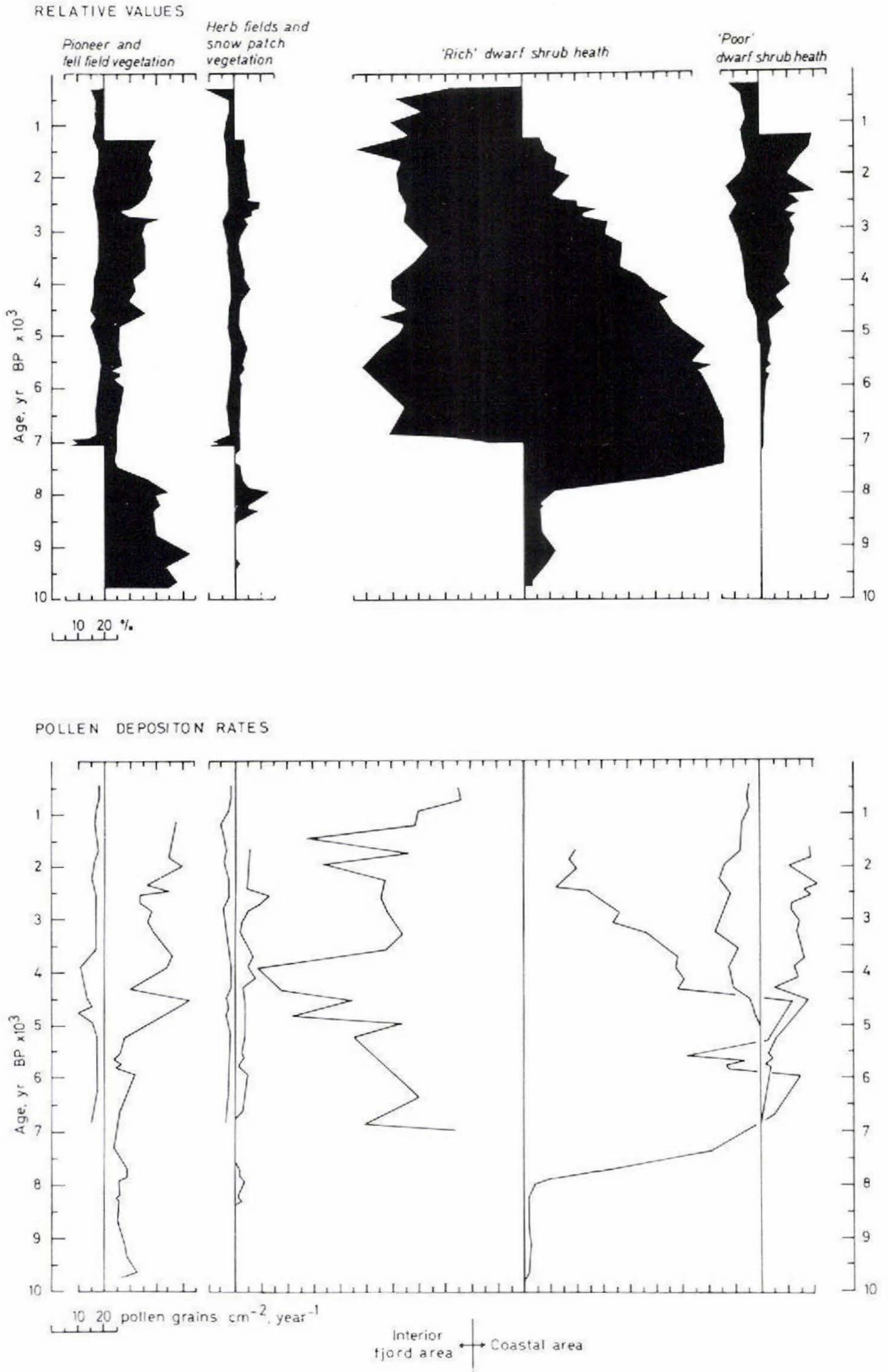
Fig. 21. Compilation pollen diagrams from interior fjord area (Bramgåssø) and coastal area (Morten Sø). The plant communities shown in the diagrams are represented by the following species and pollen types. 'Pioneer and fell field vegetation': *Chamaenerion* tp, *Cystopteris fragilis, Dryas, Oxyria, Polygonum viviparum, Saxifraga oppositifilia* tp, *Saxifraga nivalis* tp, *Silene acaulis.* 'Herb fields and snow patch vegetation': *Botrychium, Salix herbacea* tp, *Thalictrum alpinum.* 'Rich dwarf shrub heath': *Betula, Diphasium alpinum, Empetrum nigrum, Lycopodium dubium, Phyllodoce coerulea.* 'Poor dwarf shrub heath': *Cassiope* tp, *Huperzia selago, Salix arctica* tp, *Vaccinium uliginosum.*



RELATIVE VALUES
Pioneer and fell field vegetation
Herb fields and snow patch vegetation
'Rich' dwarf shrub heath
'Poor' dwarf shrub heath
Age, yr BP x10^3
1 2 3 4 5 6 7 8 9 10
10 20 %
POLLEN DEPOSITON RATES
10 20 pollen grains cm^{-2}, year^{-1}
Interior fjord area
Coastal area

summer temperatures were similar to the present already at this early stage, and it should also be noted that the high arctic *Salix arctica,* now a dominant plant in all parts of the area, apparently was absent. At 8000 yr BP *Betula nana* immigrated into the area and expanded rapidly, the very high frequencies attained by this species in the period from 8000 to 5000 yr BP indicate a climate warmer than the present, though with a distinction between an oceanic coastal area and a continental interior as shown by the abundance of *Thalictrum alpinum* in the coastal area. At *c.* 5700 yr BP *Salix arctica* apparently made its first appearance in the coastal area, and later expanded together with the other high arctic component *Cassiope tetragona;* that this expansion reflects climatic deterioration is seen from the simultaneous rise of the pioneer species. At *c.* 2800 yr BP a change to minerogenic sedimentation in lakes in the coastal area show that open ground was now again available for erosion around the lakes.

The interpretation has been based mainly on the relative frequencies. However, fig. 21 also shows the pollen deposition rates for the plant communities. A comparison between the diagrams shows a general agreement, the most conspicuous differences lie in the curves for pioneer and fell field vegetation. The high relative values obtained for this group in the period 10 000–8000 yr BP do not show up in the rates of pollen deposition, i.e. the species dominated in a scattered vegetation with a low pollen production. Rather the opposite seems to be the case in the upper part of the curves from *c.* 5000yr BP; here the increase in pollen production of this group is larger than the increase in relative frequencies, the reason must be that other species also showed a similar increase in this period, notably those of the 'poor' type of dwarf shrub heath.

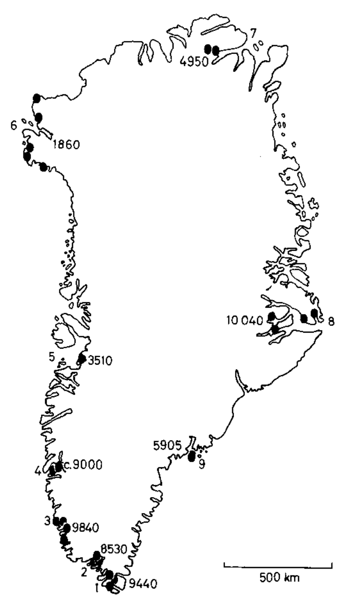
The same features, though less pronounced, appear in the curves for herb field and snow patch species. Here an early peak at *c.* 8400 yr BP is rather inconspicuous in its pollen production, while a second peak at *c.* 2500 yr BP is more pronounced in its absolute frequencies.

Thus the vegetation history for the Scoresby Sund area outlined here seems to reflect an oscillation of plant geographical borders in East Greenland; in the period from at least 8000 to 5000 yr BP these were displaced, probably some hundred kilometres, to the north of their present position. The vegetation in the coastal area reacted strongly to this oscillation, while that in the interior area appeared more stable, in agreement with the oblique trend of these diffuse border lines.

COMPARISON WITH OTHER AREAS

The location of available pollen diagrams in Greenland is shown in fig. 22. The low arctic and subarctic areas of West Greenland have the best documented record (Iversen, 1953; Fredskild, 1973; Kelly & Funder, 1974). In basic outline the development of these sites resembles that in Scoresby Sund; especially the early

Fig. 22. Location of published pollen diagrams from Greenland with the oldest age obtained in each area (C-14 yr BP). The areas are: 1, Kap Farvel (Fredskild, 1973). 2, Julianehåb (Fredskild, 1973). 3, Frederikshåb (Kelly & Funder, 1974). 4, Godthåbsfjord (Iversen, 1934, 1953; Fredskild, 1973). 5, Disko Bugt (Fredskild, 1967). 6, Thule and Inglefield Land (Malaurie *et al.*, 1972). 7, Peary Land (Fredskild, 1969, 1973). 8, Scoresby Sund (this work). 9, Angmagssalik (Bick, in press).



colonization phase with its abundance of ubiquitous species is similar. In West Greenland *Botrychium, Lycopodium dubium, Diphasium alpinum,* and *Angelica archangelica* are among the earliest immigrants, suggesting a low arctic climate by the opening of the pollen record 9000–10 000 years ago.

However, as observed by Kelly & Funder (1974) there are several problems in the correlation of the pollen diagrams. Thus the timing of the 'climatic optimum', i.e. the period in which maximum plant production was achieved at each site, varies with 1000 to 2000 years and at all sites is distinctly later than in Scoresby Sund (fig. 23). As noted by Kelly & Funder (1974) the differences may to some extent be explained by the lag in dispersal of indicator species. Some of these apparently arrived very late in West Greenland, and from the available evidence their subsequent expansion in the area was peculiarly slow and random. The different dates obtained for the termination of the 'optimum' were explained by Kelly & Funder (1974) by different critical thresholds being reached at different times. However, not all the evidence is related to biological phenomena; in northernmost Greenland Fredskild (1969) was able to show that the large Independence Fjord, now permanently frozen, was open in the period from 5000 to 2100 yr BP when driftwood was deposited along its shores.

Obviously it is too early to fit the development of the vegetation of Greenland into a consistent climatic model. As discussed by Kelly & Funder (1974) the pollen analytical evidence from other parts of the arctic seems to be as conflicting with regard to climatic development as that from Greenland. Evidence comparable to that presented here from East Greenland has been published by Ritchie & Hare

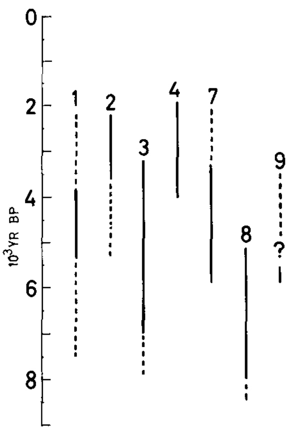


Fig. 23. Dating of the 'climatic optimum' from pollen analytical evidence in different parts of Greenland. Numbers refer to the locality numbers in fig. 22 which also states individual authors.

(1971) who reported an oscillation of the tree line in north-western Canada to the north of its present position in the period 8500-5000 yr BP. For the tree line in northern Fennoscandia Hyvärinen (1976) arrived at similar results, only here the period did not begin till 8000 yr BP, owing to the lag in dispersal of *Pinus*.

GENERAL NOTES ON THE CLIMATIC DEVELOPMENT

The main features of the deglaciation history and of the development of the marine faunas and terrestrial vegetation in the area are outlined in fig. 24, and from the data a curve of fluctuations in the relative summer temperatures has been derived. The evidence for climatic change will be briefly summarized:

At 10 400–10 100 yr BP, dated by extrapolation, the major fjord and valley glaciers started to retreat from the outermost moraines in the area of the Milne Land Moraines, reflecting a decisive climatic amelioration. The same climatic event may possibly be recorded by the transition to organic sedimentation in Hugin Sø, dated to 10 040 yr BP.

Up until 9400 yr BP the major fjord glaciers showed an oscillatory retreat, indicating fluctuations of climate during a period of general climatic amelioration. The pollen record gives no evidence of fluctuations, but the presence in the area of the thermophilous *Botrychium, Lycopodium dubium* and *Diphasium alpinum* indicates that summer temperatures were similar to the present.

At 8400 yr BP the first of the subarctic marine faunal elements (*Pecten islandica*) make an appearance in the fjords (Street, 1977), indicating that summer temperatures were possibly warmer than the present. By then the outer coastal area was probably as deglaciated as at present.

At 8000 yr BP *Betula nana* immigrated and expanded rapidly, probably expressing the widespread development of a 'rich' and dense type of dwarf shrub heath

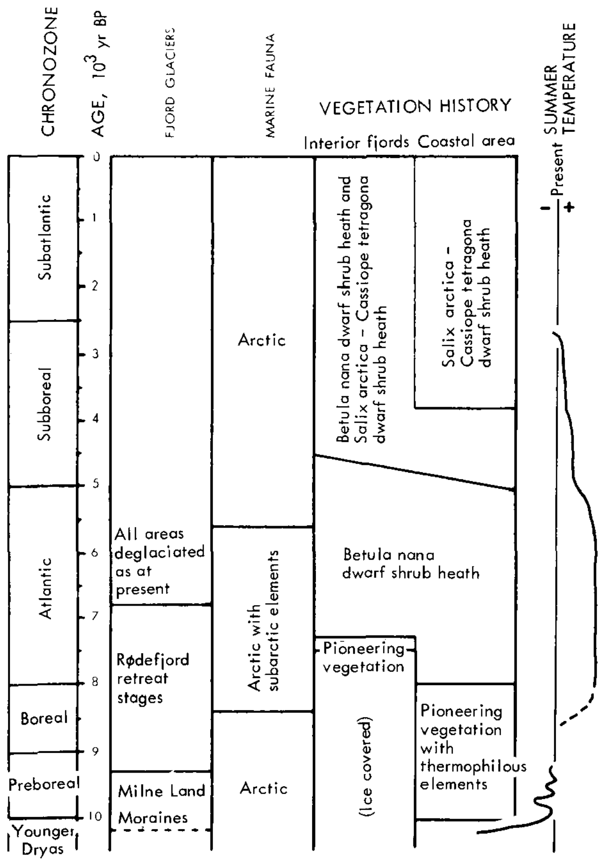


Fig. 24. Correlation of different types of stratigraphical evidence from the Scoresby Sund area, and derived relative summer temperatures.

which at present is restricted to the interior fjords and to favourable sites in the coastal area. The summers were warmer than the present.

At 7700 yr BP the subarctic *Mytilus edulis* occurred in the fjords to the north of Scoresby Sund, and at least by 6900 yr BP it was also present in the latter area (Hjort & Funder, 1974).

At 6700 yr BP the present state of deglaciation had been achieved in all parts of the area, and some fjord glaciers had retreated behind their present fronts.

Soon after 5600 yr BP (the youngest dated find of *Mytilus edulis*) this species became extinct in the fjord zone (Hjort & Funder, 1974), and in Scoresby Sund probably also *Pecten islandica* disappeared at this time. At the same time the high arctic *Salix arctica* appeared for the first time in the vegetation around the lakes, showing that the culmination in summer temperatures had been passed, and a decline was underway. At present *Salix arctica* is a dominant species in all parts of the area.

At 5100 yr BP *Betula nana* suffered its first setback in the coastal area, when 'poor' dwarf shrub heath represented by *Salix arctica* and *Cassiope tetragona* expanded together with plants characteristic of open ground.

At 4500 yr BP the deterioration was felt also by the vegetation in the continental areas of the interior fjords.

At 3800 yr BP, and especially at 2900–2800 yr BP the 'rich' *Betula nana* heath suffered severe reductions and nearly disappeared in the coastal area, where the present type of vegetation, dominated by 'poor' dwarf shrub heath was established. The return of 'pioneer' plants as well as the recurrence of minerogenic sedimentation in most lakes show that open ground was again available, probably as a result of cryoturbation in the soil.

Comparing these results with those obtained from adjacent areas there seems to be similarities especially with the development in north-western Europe. It has been noted above that the Early Holocene deglaciation in Scoresby Sund seems to be in phase with that recorded for the north-western margin of the Scandinavian ice sheet (Andersen, 1968, 1975), and also the general outline of vegetation history in Scoresby Sund may compare to that obtained for areas in northernmost Fennoscandia (Hyvärinen, 1975, 1976). Ruddiman & McIntyre (1973) dated the postglacial retreat of Polar water in the North Atlantic and found that after a possible readvance at 10 200 yr BP there was a period of very rapid retreat from 8500 to 6500 yr BP – the commencement of this coinciding with the period of maximum summer temperatures in Scoresby Sund. After 6000 yr BP no retreat seems to have occurred. This evidence obviously has a bearing on the conditions in Scoresby Sund, since the Polar water is supplied mainly by the East Greenland Polar Current running along the outer coast and having a major influence on the climate.

Considering these broad similarities it is surprising that the correlation with sites in West Greenland, as discussed above for the deglaciation history and the vegetation history, is not very good. The available evidence might be interpreted to show that after the initial amelioration the postglacial warming up was slower in West Greenland.

If real, the differences could be explained by the proximity of the Laurentide ice sheet which persisted in North America till 8000–7500 yr BP (Bryson *et al.,* 1969). As implied earlier by Andrews & Ives (1972) and Miller (1973) there is evidence to suggest that an anticyclone over the persisting Laurentide ice sheet inhibited the penetration of warm moist air into the Davis Strait before 8500 yr BP. Lamb (1971) has analysed this situation, and noted that the 'anomalous' distribution of ice sheets, i.e. the presence of a large ice sheet over North America while only an insignificant amount of ice was left in Scandinavia, could have resulted in the development of strong geothermal winds on the outskirts of the Laurentide anticyclone, which would bring abundant warm air into the Greenland and Norwegian Seas and to northern Europe, and ". . . explain the rapid opening of Iceland and east Greenland to plants and birds . . ." (p. 160).

From the evidence presented here it is suggested that the Holocene stratigraphy in Scoresby Sund is related to the disappearance of the Scandinavian ice sheet; while that in West Greenland possibly may have been influenced by the proximity of the Laurentide ice sheet.

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Plates

Plate 1

Mollusc shells from Scoresby Sund

Fig. 1. *Propeamussium groenlandicum* (Sowerby). (MGUH 14096, GGU 146510). Length of shell 6 mm.
Fig. 2. *Yoldia* cf. *hyperborea* Torell. (MGUH 14097, GGU 146510. Length of shell 7 mm.
Fig. 3. *Macoma loveni* (Steenstrup). (MGUH 14098, GGU 146514). Length of shell 9 mm.
Fig. 4. *Macoma calcaria* (Chemnitz). (MGUH 14099, GGU 134010). Length of shell 30 mm.
Fig. 5. *Astarte crenata* (Gray). (MGUH 14100, GGU 106524). Length of shell 36 mm.
Fig. 6. *Astarte montagui* (Dillwyn). (MGUH 14101, GGU 146502). Length of shell 19 mm.
Fig. 7. *Astarte elliptica* (Brown). (MGUH 14102, GGU 146515). Length of shell 20 mm.
Fig. 8. *Arca glacialis* Gray. (MGUH 14103, GGU 106517). Length of shell 18 mm.
Fig. 9. *Pecten islandica* O. F. Müller. (MGUH 14104, GGU 134010). Length of shell fragment 36 mm.
Fig. 10. *Natica* sp. (MGUH 14105, GGU 146502). Height of shell fragment 10 mm.
Fig. 11. *Littorina* sp. with *Polydora* borings (MGUH 14106, GGU 134005). Height of shell fragment 13 mm.


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Plate 2

Scanning electron microscope photographs of East Greenland Salix pollen

Fig. 1. *Salix arctica* Pall. Coll. No. 3, Hold with Hope. × 3500.
Fig. 2. *Salix arctica* Coll. No. 3, Hold with Hope. × 3500.
Fig. 3. *Salix arctica* Coll. No 8, Hurry Inlet. × 2100.
Fig. 4. *Salix arctica* Coll. No 8, Hurry Inlet. × 2100.
Fig. 5. *Salix arctica* Coll. No 6, Hurry Inlet. × 1900.
Fig. 6. *Salix arctica* Coll. No 9, Kap Dalton. × 2600.
Fig. 7. *Salix glauca* L. Coll. Coll. No 13, Kap Ravn. × 2500.
Fig. 8. *Salix glauca* Coll. No 13, Kap Ravn. × 2500.
Fig. 9. *Salix glauca* Coll. No 15, 'Nigertussoq' [*now* Nigertuluk]. × 2700.
Fig. 10. *Salix glauca* Coll. No 11, Hvalrosbugt. × 2300.
Fig. 11. *Salix glauca* Coll. No 11, Hvalrosbugt. × 2800.
Fig. 12. *Salix herbacea* L. Coll. 28, Angmagssalik. × 2700.
Fig. 13. *Salix herbacea* Coll. 28, Angmagssalik. × 3300.

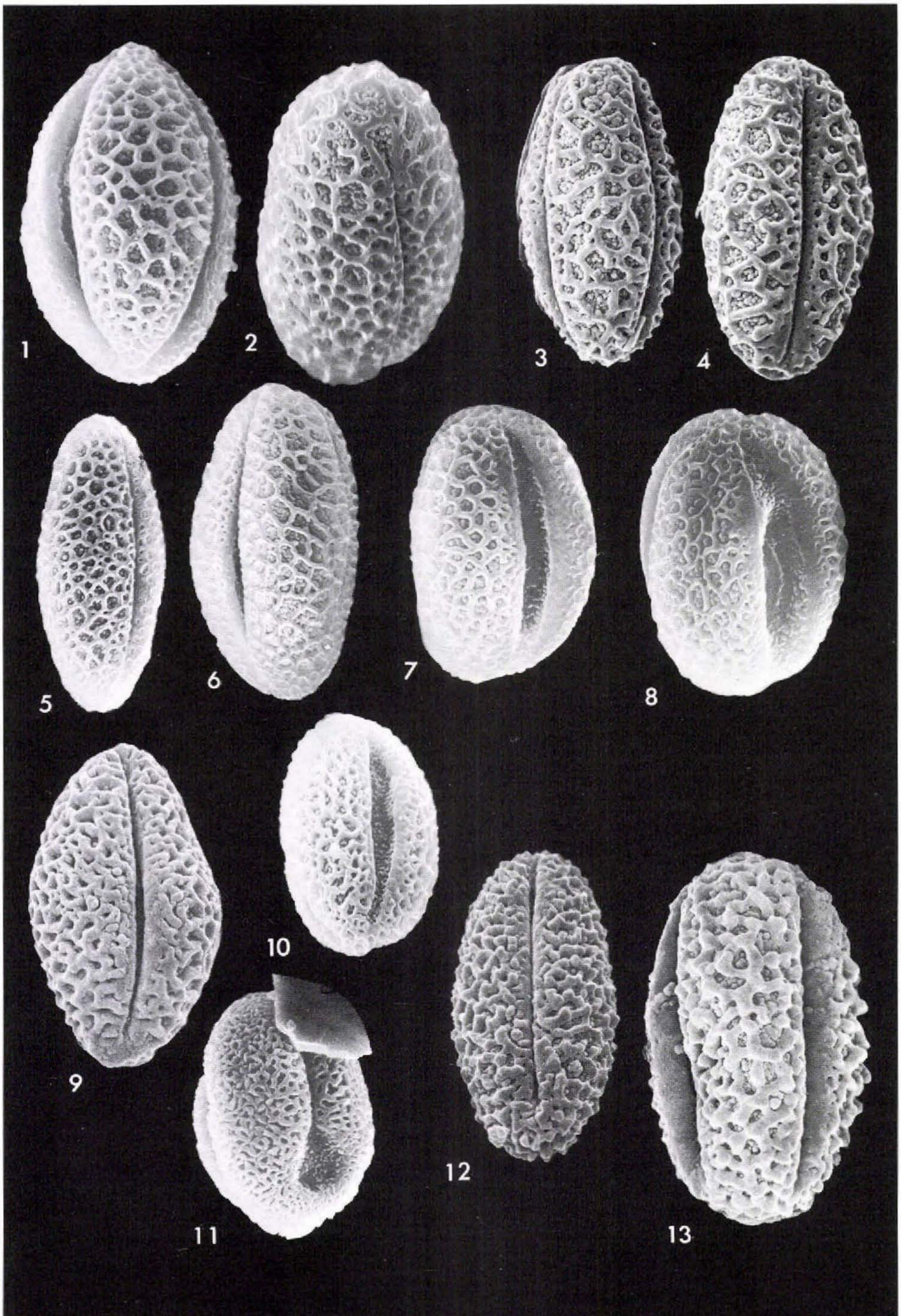

Plate 3

Scanning electron microscope photographs of East Greenland Salix pollen

Fig. 1. *Salix herbacea* L. polar area. Coll. No 28, Angmagssalik. × 4000.
Fig. 2. *Salix glauca* L. coll. polar area. Coll. No 15, 'Nigertussoq' [*now* Nigertuluk]. × 4000.
Fig. 3. *Salix arctica.* Pall. detail of sculpture. Coll. No 8, Hurry Inlet. × 6600.
Fig. 4. *Salix glauca* L. coll. detail of sculpture. Coll. No 15, 'Nigertussoq' [*now* Nigertuluk]. × 6600.
Fig. 5. *Sàlix herbacea* L. detail of sculpture. Coll. No 28, Angmagssalik. × 6700.
Fig. 6. *Salix glauca* L. coll. detail of deformed sculpture. Coll. No 12, Danmark Ø. × 6700.

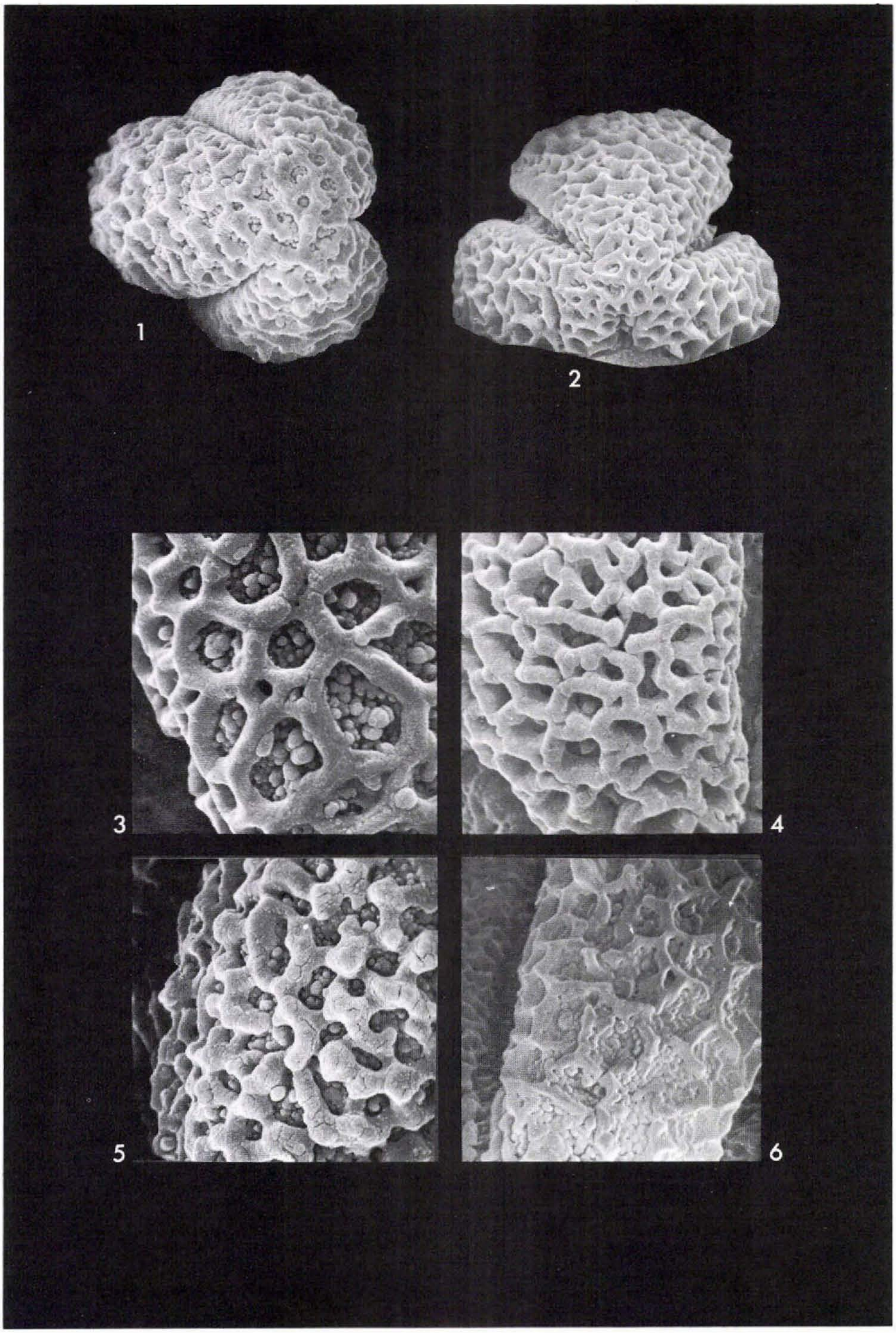
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Plate 4

Scanning electron microscope photographs of East Greenland Salix and 'Ericales' pollen

Fig. 1. *Salix arctica* (× *glauca?*). Coll. no 24, Danmark Ø. × 3500.
Fig. 2. *Salix glauca* (× *arctica?*). Coll. No 26, Hurry Inlet. × 3500.
Fig. 3. *Salix glauca* (× *arctica?*). Coll. No 26, Hurry Inlet. × 3400.
Fig. 4. *Salix arctica* × *glauca?*. Coll. No 23, Kangerdlugssuaq. × 2600.
Fig. 5. *Empetrum nigrum* L. ssp. *hermaphroditum* (Hagerup) Böcher. Kap Hope, Scoresby Sund. × 1700.
Fig. 6. Same specimen and tetrad, detail of polar area. × 3300.
Fig. 7. Same specimen. × 1700.
Fig. 8. *Phyllodoce coerulea* (L.) Bab. Bjørneøer, Scoresby Sund. × 2200.
Fig. 9. Same specimen as 8. × 1700.
Fig. 10. *Cassiope tetragona* (L.) D. Don. Hurry Inlet, Scoresby Sund. × 2500.
Fig. 11. Same specimen as 10. × 2400.

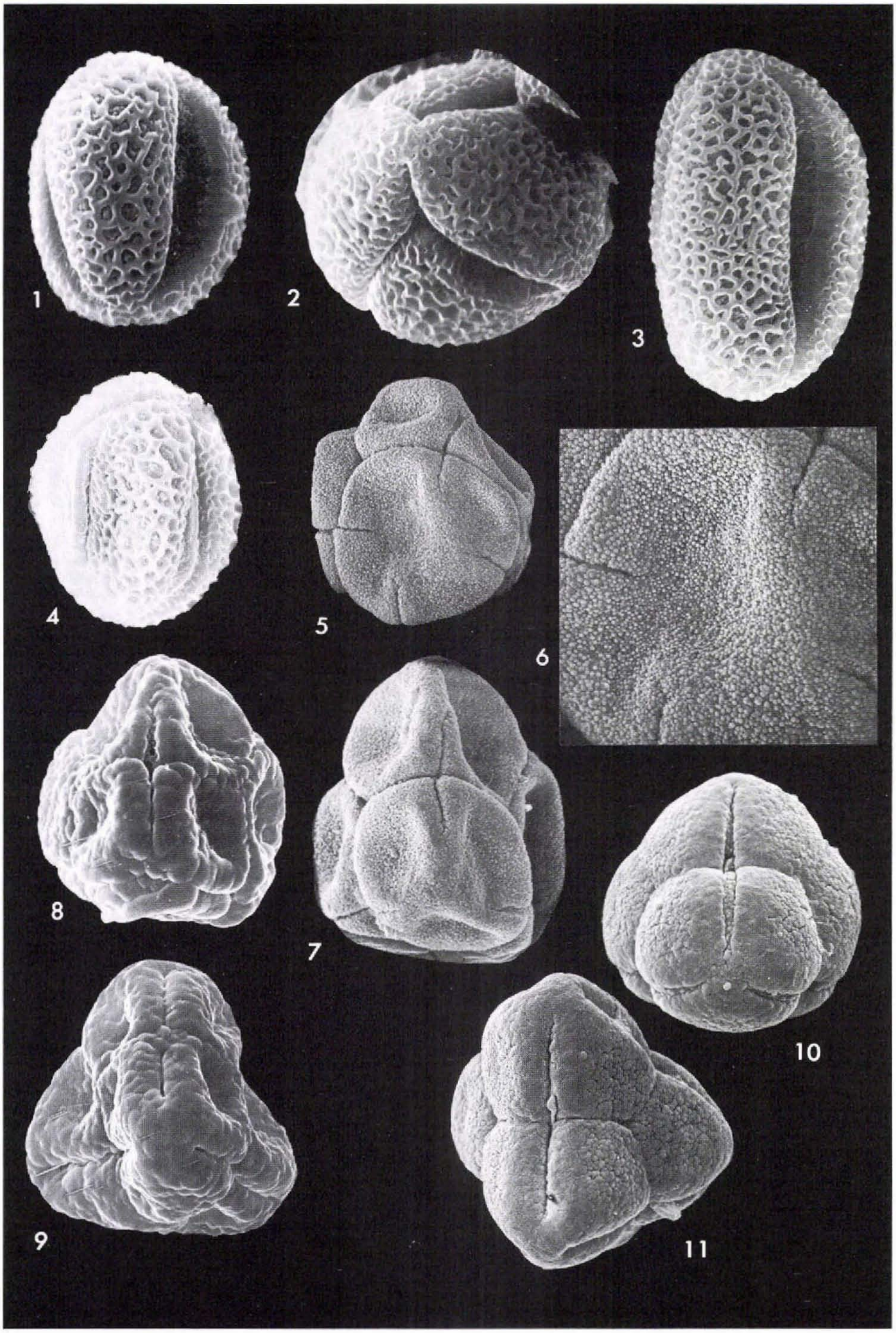
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Plate 5. *Size frequency distribution of fossil Salix pollen*

Plate 6. *Pollen diagram from Morten Sø*

Plate 7. *Pollen diagram from Hugin Sø*

Plate 8. *Pollen diagram from Munin Sø*

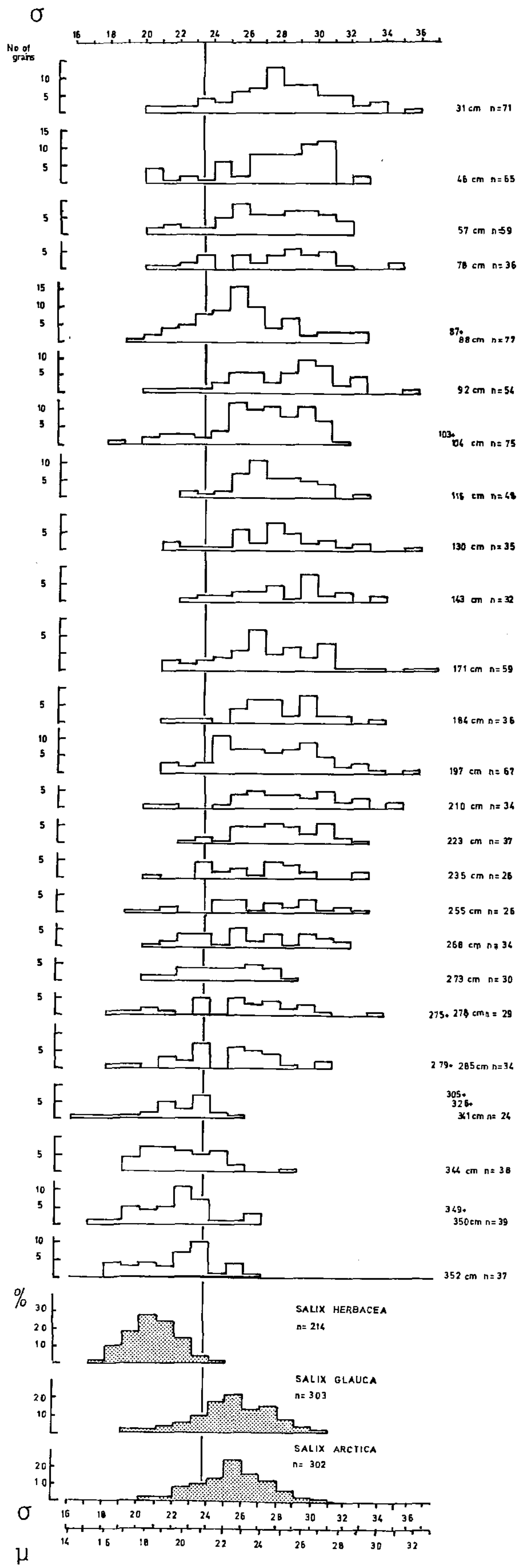
Plate 9. *Pollen diagram from Bramgåssø*

Plate 10. *Pollen diagram from Potamogetonsø*

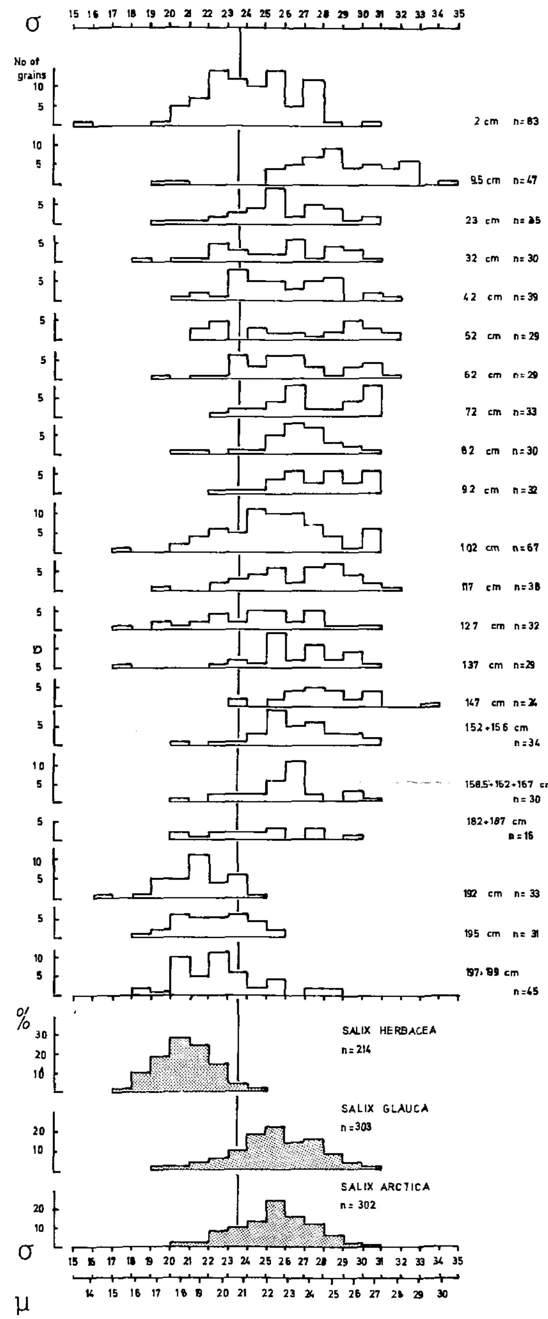
Plate 11. *Ice margin features in the Scoresby Sund area*

SIZE FREQUENCY DISTRIBUTION OF SALIX POLLEN

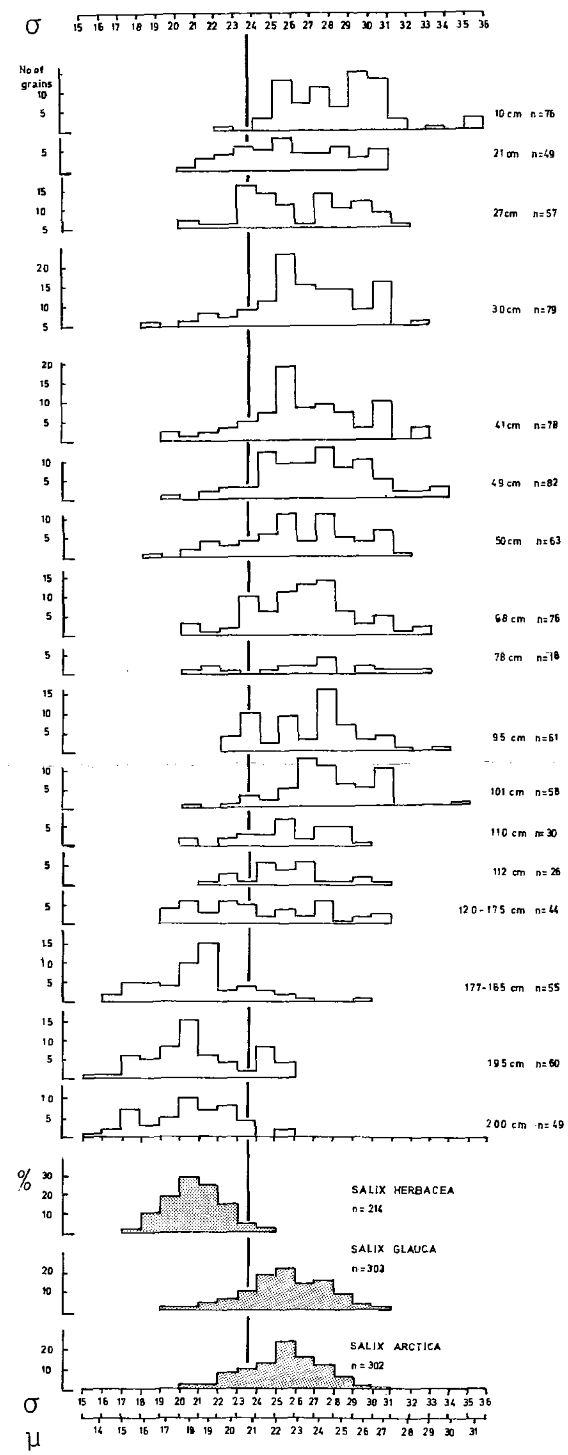
MORTEN SØ



BRAMGÅSSØ



POTAMOGETONSØ

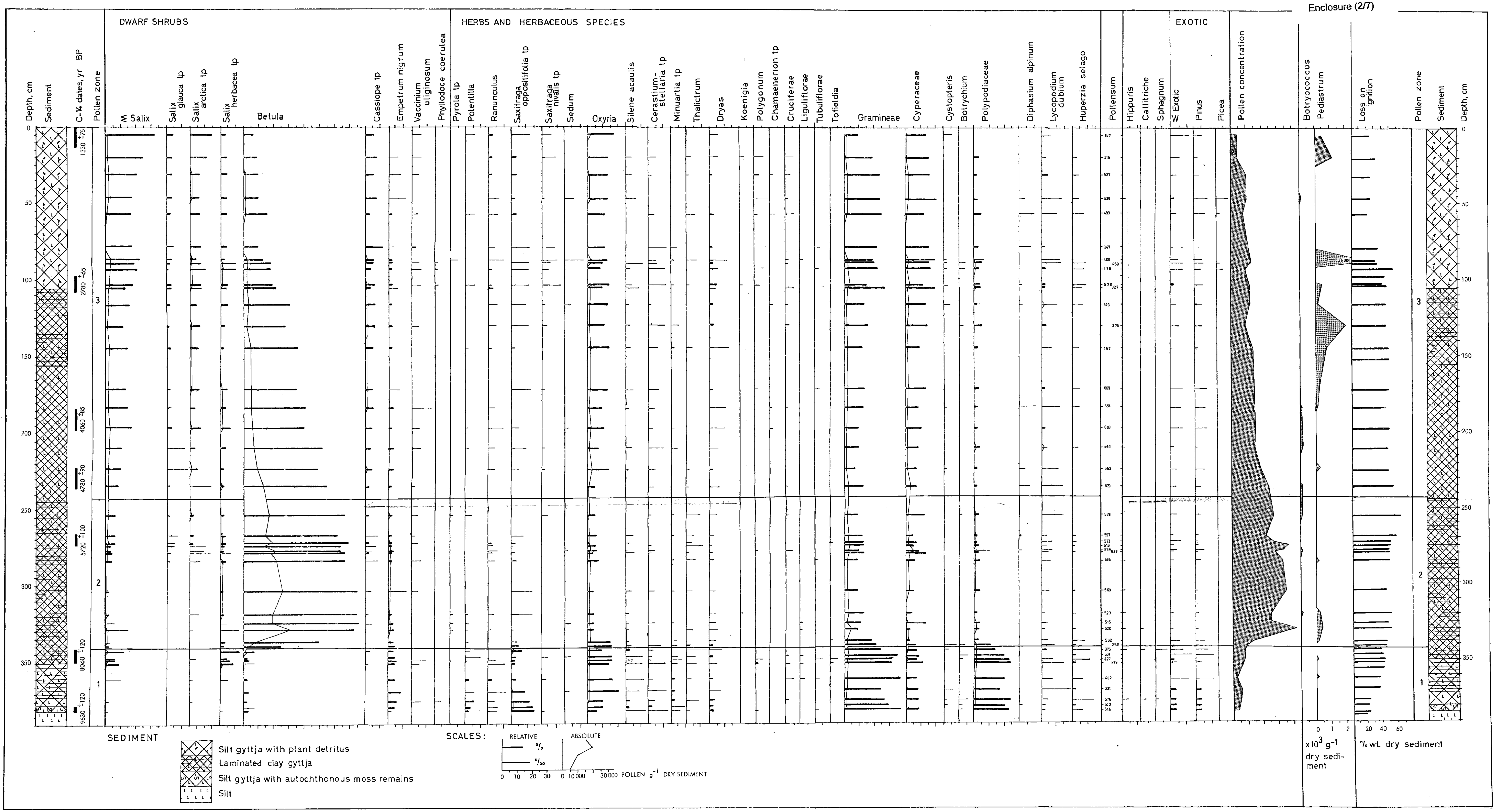


MORTEN SØ, Klitdal

70° 52' N 22°27' W East Greenland

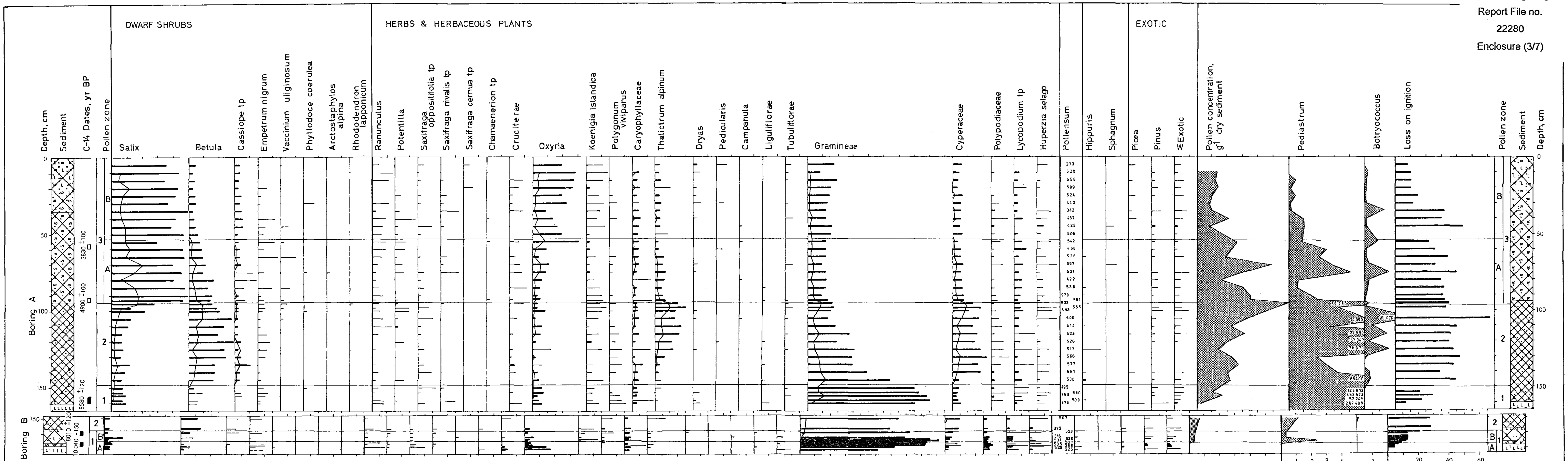
GEUS
Report File no.
22280
Enclosure (2/7)

GGU 146505



HUGIN SØ, Heden, Jameson Land
70° 46' N 24° 07' W East Greenland

GGU 106522 & 146513



SEDIMENT

- Silt with autochthonous moss remains and gyttja substance
- Gyttja with silt and moss
- Gyttja with silt
- Silt

SCALES

Grønlands geol. Unders. 129

GEUS

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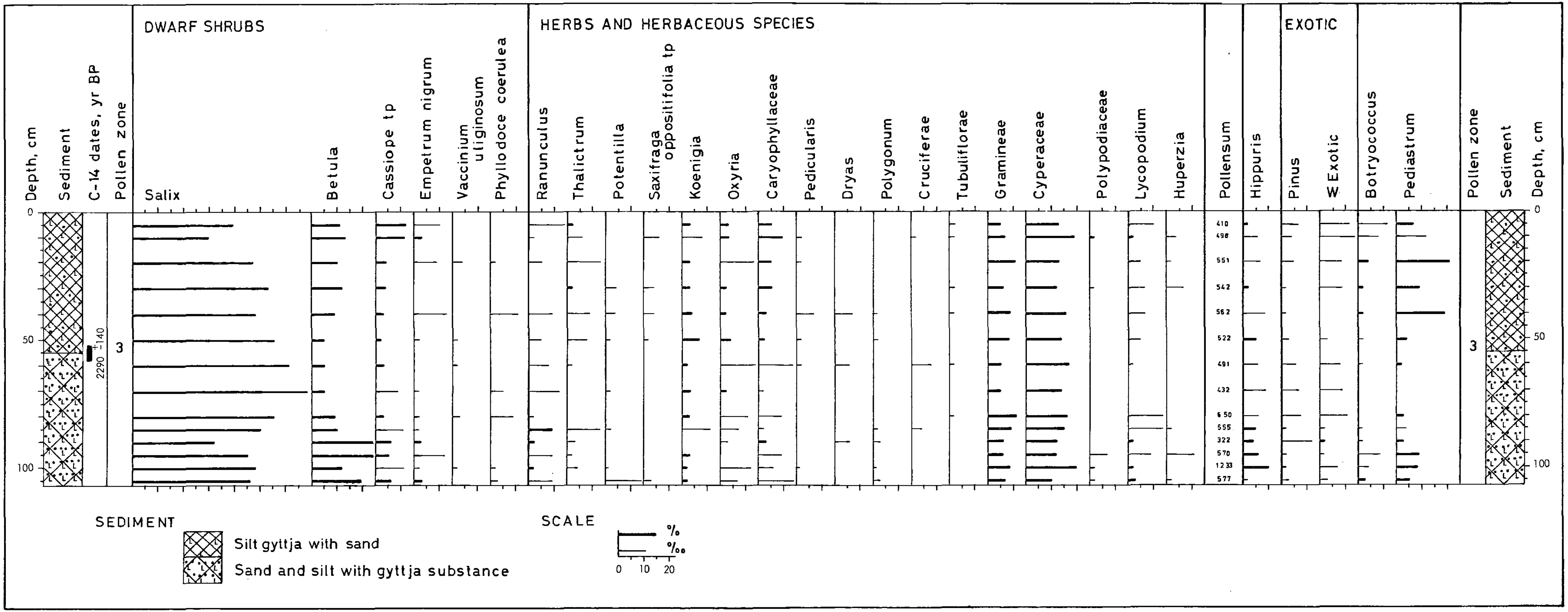
Enclosure (4/7)

Plate 8

MUNIN SØ, Jameson Land

71° 08' N 24°22' W East Greenland

GGU 106515



Grønlands geol. Unders. 129

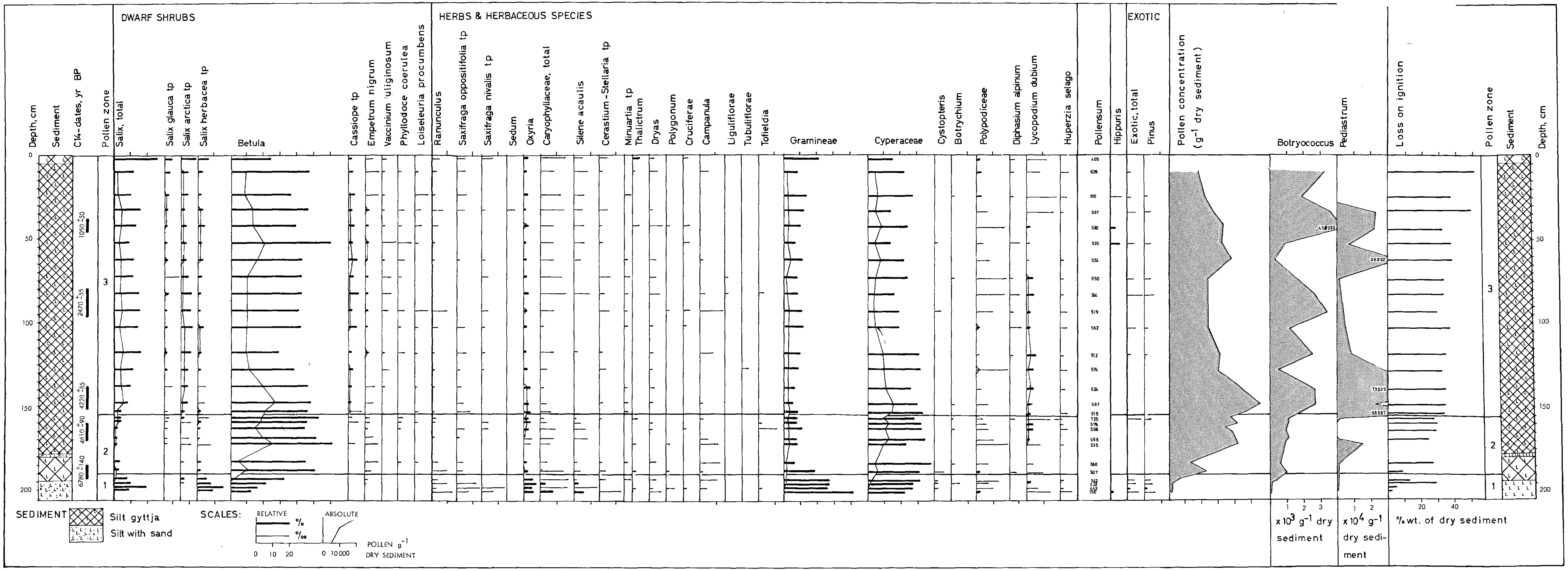
GEUS Report File no. 22280 Enclosure (5/7)

Plate 9

BRAMGÅSSØ, Milne Land

70° 31′ N 28° 02′ W East Greenland

GGU 134018



Grønlands geol. Unders. 129

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Plate 10

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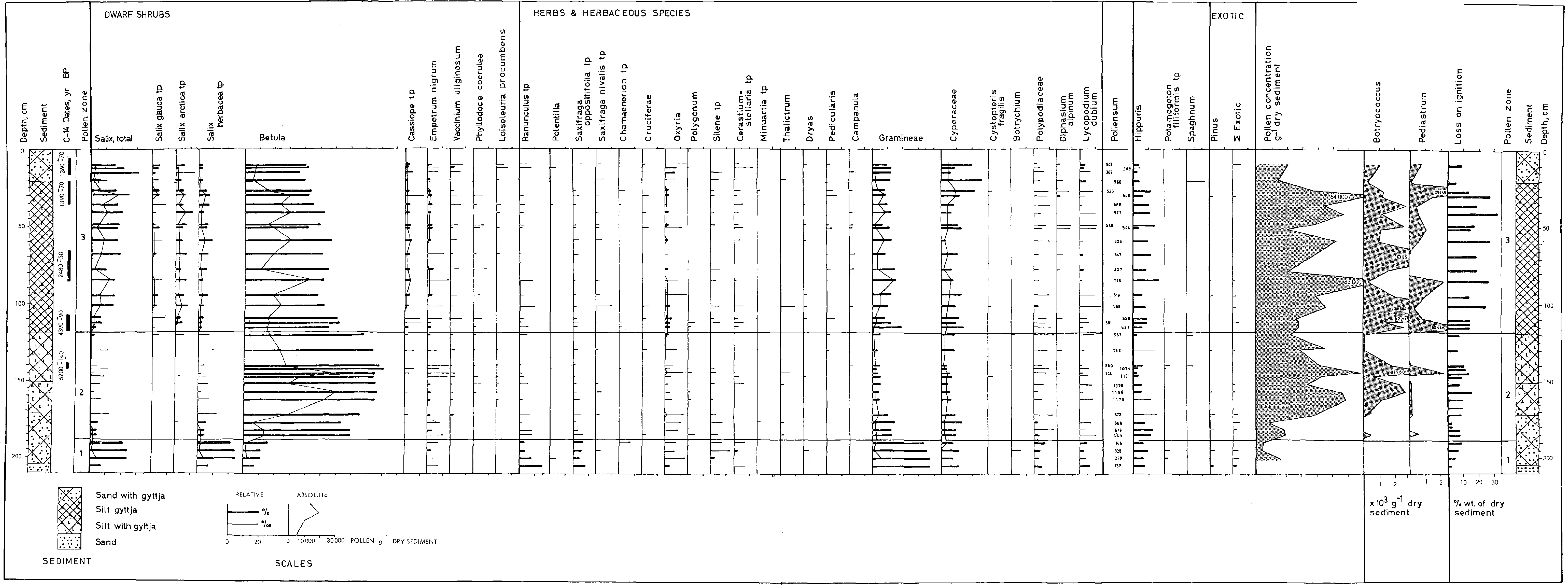
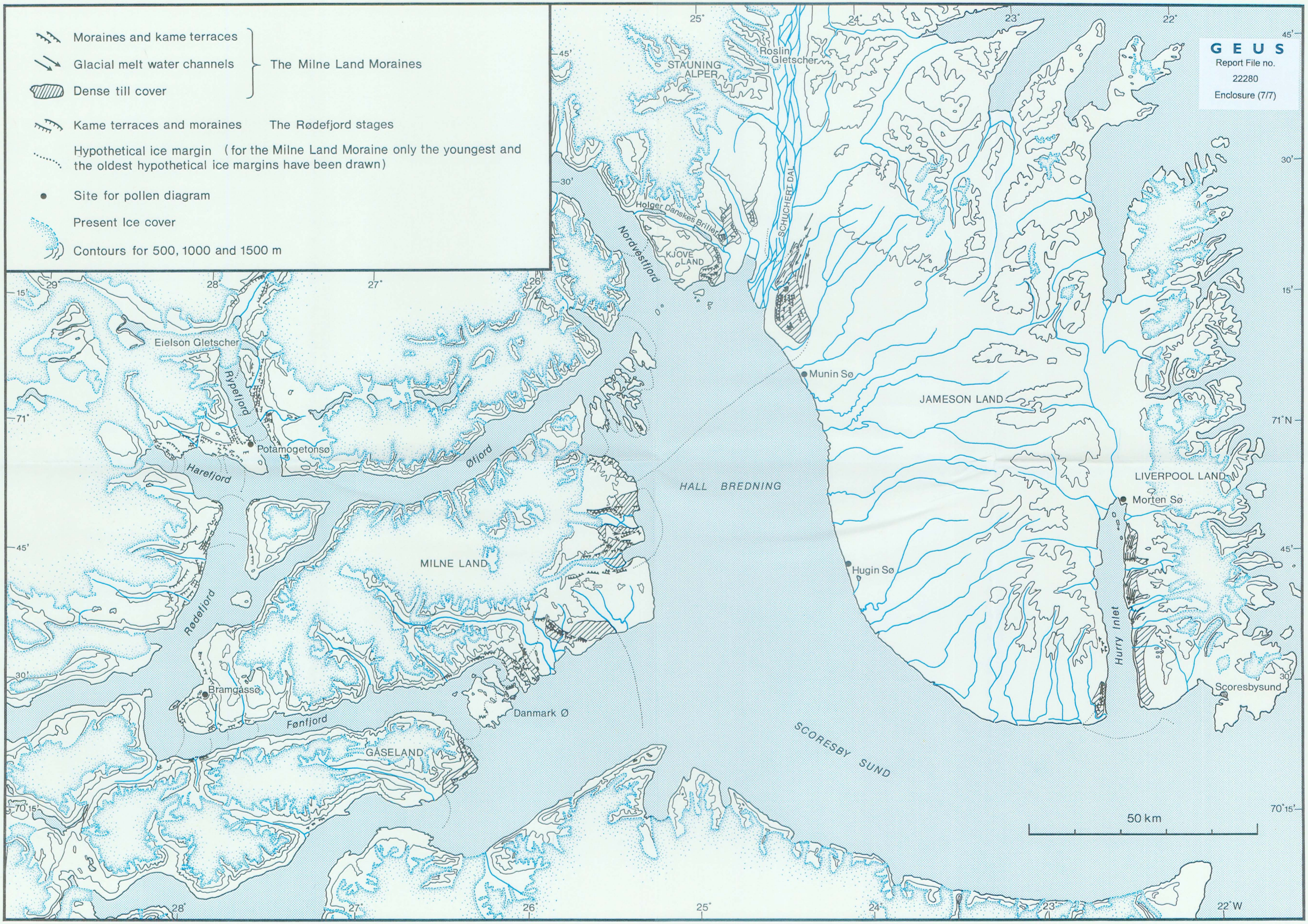
POTAMOGETONSØ, Rypefjord

70° 57' N 27°44' W East Greenland




Moraines and kame terraces
Glacial melt water channels
Dense till cover
The Milne Land Moraines
Kame terraces and moraines
The Rødefjord stages
Hypothetical ice margin (for the Milne Land Moraine only the youngest and the oldest hypothetical ice margins have been drawn)
Site for pollen diagram
Present Ice cover
Contours for 500, 1000 and 1500 m
STAUNING ALPER
Roslin Gletscher
Holger Danskes Briller
KJOVE LAND
Nordvestfjord
SCHUCHERT DAL
Munin Sø
JAMESON LAND
LIVERPOOL LAND
Morten Sø
Hugin Sø
Hurry Inlet
Scoresbysund
Eielson Gletscher
Rypefjord
Potamogetonsø
Harefjord
Øfjord
HALL BREDNING
MILNE LAND
Rødefjord
Bramgåssø
Fønfjord
Danmark Ø
GÅSELAND
SCORESBY SUND
50 km
71°N
70°15'
22°W