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The Kap København Formation: stratigraphy and palaeobotany of a Plio-Pleistocene sequence in Peary Land, North Greenland

Ole Bennike

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The Kap København Formation in eastern Peary Land, latitude 82°30′N, comprises essentially two facies: silt and sand. The former was deposited in sublittoral environments below wave base, and contains *in situ* marine faunas, while the latter was deposited in the littoral zone: in the backshore, foreshore and shoreface. Part of this facies was deposited near river mouths, and contains allochthonous remains of freshwater and terrestrial organisms. Virtually all major groups of plants and animals are represented in the formation. This paper deals mainly with remains of vascular plants.

Seeds, fruits and leaves of *c.* 60 taxa show that the area was vegetated by forest-tundra growing in a humid subarctic climate. Boreal upland plants include *Larix groenlandii* sp. nov., an extinct species which was the dominant tree, *Picea mariana*, *Thuja occidentalis*, *Betula alba*, *Taxus*, *Alnus*, *Myrica arctogale* sp. nov., *Cornus* spp. and *Viburnum*. Tundra plants include *Dryas octopetala*, *Oxyria digyna*, *Betula nana*, *Salix reticulata* and *Vaccinium uliginosum* ssp. *microphyllum*. A number of wet land habitats existed in the area; they supported e.g. *Aracites globosa* comb. nov. The largest tree trunk measures 18 cm in diameter, and growth rings are extremely narrow and variable. The pollen flora, which is dominated by *Betula*, comprise only a minor part of arboreal pollen, indicating that trees were of minor importance in the regional vegetation. Many of the species represented in the assemblage are of modern circumpolar range, but the flora shows a marked affinity to the modern North American flora.

Biostratigraphical correlations of mammals, foraminifers, molluscs and ostracodes, supplemented by palaeomagnetic work, show that the sequence is 2 to 2.5 Ma (million years) in age (Plio-Pleistocene). The vascular plant flora resembles Neogene floras from the Arctic Ocean borderland, notably that from the Beaufort Formation on Meighen Island in northernmost Canada.

The flora and vegetation point to a much warmer climate at the Plio-Pleistocene boundary than today. By extrapolation of the climatic interpretations it is suggested that the Inland Ice of Greenland did not exist at this time, and that the Arctic Ocean was not covered by perennial sea ice.

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Eastern Peary Land was not explored by Europeans until the arrival in 1907 of the "Danmark-Ekspeditionen til Grønlands Nordøstkyst 1906–08", during which "Kap Kjöbenhavn" was named (I. P. Koch 1916, fig. 43). In 1921 Lauge Koch travelled around Peary Land (L. Koch 1926, 1928) and made astronomical observations from a hill in the area. He erected a small cairn on this hill, which incidentally is composed of the Kap København Formation.

Later the area was briefly visited by Troelsen (1952) and Davies (1963). They followed Koch (1928) in regarding the elongated hills of the area as former moraines marking the maximum extent of the Inland Ice. Two photographs from the Kap København area were published by Davies (1963, fig. 4 and 1972, fig. 11). Both are close to localities 120 and 122 of this work.

In 1979, during mapping for the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse, GGU), S. Funder discovered the Kap København sequence (Funder & Hjort 1980; Fig. 1). At first the sequence was assigned a Late Quaternary interglacial age, but analyses of benthonic foraminifers indicated a Late Pliocene and Early Pleistocene age (Funder et al. 1985b).

Two samples containing organic detritus from this expedition were analysed by Fredskild & Røen (1982) and Mogensen (1984). These samples contained several southern extralimital taxa.

Fig. 1. Map of Greenland showing the location of Kap København in eastern Peary Land, North Greenland. 1: Independence Fjord, 2: Station Nord.

The sequence was briefly revisited in 1980 by C. Marcussen and the author as members of the GGU expedition to North Greenland. Samples were collected for palaeomagnetic studies (Marcussen 1981), and the type section of the formation was examined.

In the summer of 1983 most of the area covered by the formation was investigated by four geologists and two biologists and subsequently the Kap København Formation was formally named (Funder et al. 1984). Some other preliminary results from this expedition visit are published in Funder et al. (1985b), Bennike (1985), Feyling-Hanssen (1986, 1987), K. S. Petersen (1986).

In 1986 the entomologist Jens Böcher and the author supplemented the earlier work (Bennike 1987a). By now virtually the whole area covered by the formation (*c.* 300 km^2) has been surveyed.

Various aspects of the Kap København Formation have been dealt with in popular accounts (Bennike 1987b, 1988, Funder 1984a, 1984b, Funder et al. 1985a, 1988).

Prior to the 1950's the pre-Holocene Late Cainozoic history of Greenland was almost completely unknown. The first "infinite" radiocarbon dates on shells were from the Thule area (Suess 1954), and subsequently pre-Holocene deposits were found to be widespread in Greenland (reviewed by Funder 1989). In 1978 a Plio-Pleistocene sequence, later named the Lodin Elv Formation was discovered in East Greenland (Feyling-Hanssen et al. 1983).

On the other hand, the youngest Tertiary deposit known from Greenland is of Miocene age (Hassan 1953), and this occurrence, the Kap Brewster Formation, provides no evidence on the terrrestrial flora and vegetation. The Kap København Formation discussed here throws light on both the marine, terrrestrial and limnic environments at the Plio-Pleistocene boundary and therefore fills a marked gap in the geological record of Greenland.

Some Late Cainozoic deposits from Canada and Alaska may correlate with the Kap København Formation, but it must be stressed that Alaska and northwest Canada are situated between 60° and 70°N, much further south than Kap København at 82°30'N. Different environments are to be expected at these localities in the past, just as today.

This work deals in detail with the stratigraphical, sedimentological and palaeobotanical aspects of the Kap København Formation.

The pioneering works on Quaternary terrestrial and limnic palaeobiology were based on macrofossils (Mannion 1986), but with the introduction of pollen analysis in the early twentieth century studies involving macrofossils have been somewhat neglected. In recent years, it is becoming clear that all types of plant remains should be studied.

This study concentrates on seeds, fruits, cones, leaves, twigs and wood, with only minor attention paid to pollen and spores. Such macrofossils are valuable because they can generally be identified to lower taxonomic levels than microfossils, often to species level. Also, insect-pollinated, autogamous and vegetatively reproducing plant species are not especially poorly represented as they are in pollen spectra.

Most studies of macroscopic plant remains within the Quaternary have been on peat and lake deposits (H. H. Birks 1980), where in the remains are of very local origin, and upland plants are sparsely represented (e.g. Greatex 1983). In the Kap København Formation, however, which was deposited in near-shore coastal marine environments, upland plants are well represented, although aquatic and semi-aquatic plants are undoubtedly overrepresented. Despite this bias, the fossils discussed in this paper provide critical palaeoenvironmental information for a time when Greenland was much different from at present.

Geological and environmental setting

Bedrock geology and topography

To the west of Kap København extensive areas are covered by the Peary Land Group, which is dominated by siltstone and sandstone turbidites of Silurian age (Hurst & Surlyk 1982). This unit is overlain with angular unconformity by the Wandel Sea Basin sequence, which in eastern Peary Land northwest of Kap København comprises a variety of Late Palaeozoic and Mesozoic strata. Many different rock types are present, including sandstone, conglomerate, limestone, chert and shale (Håkansson 1979). The base of the Kap København Formation is nowhere exposed, but the formation is assumed to rest on the rocks of the Wandel Sea Basin sequence.

Opposite Independence Fjord (Fig. 1) is a large area of Proterozoic plateau basalts, the Zig-Zag Dal Basalt Formation (Jepsen et al. 1980). This formation overlies the Independence Fjord Group which consists of sandstones containing numerous igneous intrusive rocks (Jepsen & Kalsbeek 1979).

The area around Kap København and Mudderbugten (Fig. 2) forms part of the coastal plain which extends along the east and north coast of Peary Land. It has a width of 20–30 km and consists of hilly areas and plains. Some of the hills in the Kap København area are elongate and represent thrust floes of the Kap København Formation (Funder & Hjort 1980). The highest hill reaches a height of *c.* 230 m. To the west of Kap København the landscape rises gently, but remains of low relief.

Numerous brooks and brooklets which originate in local snow drifts run through the Kap København area. The only large stream is Ladegårdsåen which begins in Kim Fjelde, an area of low mountains to the northwest of Kap København. Lakes and ponds are rare in most of the area.

Present vegetation, flora and climate

The vegetation is high arctic (Holmen 1957). It exhibits a zonal development from the coast inland. Along the coast of northeastern Peary Land is a narrow fringe of land where the soil is wet throughout the summer, but the vegetation is extremely depauperate, being dominated by algae, lichens and mosses. Some 20 species of herbs form a very low cover, the most common are *Saxifraga oppositifolia* L. and *Papaver radicatum* Rottb. coll. Woody plants are entirely absent.

Inland from this zone *Salix arctica* Pall. and *Dryas* make their appearance, along with a number of herbs. Wet soil with an organic crust of algae and lichens is no longer continuous.

In a sheltered area protected from coastal fog and wind between Kim Fjelde and Ladegårdsåen small patches of *Cassiope tetragona* (L.) D. Don heaths and sedge meadows of *Carex stans* Drej. and *Eriophorum scheuzeri* Hoppe are frequent. This area also has the most diverse flora which includes *c.* 60 species of vascular plants. The soil in this area is gravelly with a mosaic of dry and wet sites.

Small patches of closed vegetation occur in connection with manured soil, which occurs around lemming nests, around old, decayed musk-ox carcasses and around bird stones. In areas with sandy soil vegetation is almost lacking. Permanent snow-fields are rather rare in the lowland areas, but more common in Kim Fjelde, where small glaciers also occur. The only water plants are *Ranunculus hyperboreus* Rottb. and the semi-aquatic grass *Pleuropogon sabinei* R. Br.

Based on the vegetation, the climate of the coastal fringe corresponds to that of the weather station at Station Nord, about 100 km to the southwest. Here the mean temperature for the warmest month is *c.* 3°C, and the mean temperature for the coldest month is *c.* −31°C. The mean annual precipitation is around 250 mm. Coastal fog is frequently encountered during the summer, and the cold summer climate of the coastal area is hostile to vegetation. The presence of small dwarf shrub heaths in the sheltered area mentioned above indicate a mean temperature for the warmest month of 3.5–4°C (Edlund 1983).

At Kap København (82°30′N) the period with midnight sun is 4.7 months long, and the period without sun 4.5 months, taking refraction into account (Rasmussen 1954). The long period of midnight sun compensates for the long and cold winter.

Age estimate

The age estimate of the Kap København Formation is based primarily on biostratigraphy using mammals, foraminifers, molluscs and ostacodes, and secondarily on magnetostratigraphy.

Notes on the Plio-Pleistocene

Because the present disagreement on the age of the Plio-Pleistocene boundary has given rise to confusion about the dating of the Kap København Formation, this controversy will be briefly reviewed.

Estimates of the Plio-Pleistocene age have varied from *c.* 0.6 Ma (million years) to more than 4 Ma (Haq et al. 1977). At the 18th International Geological Congress in London 1948 it was recommended to place the boundary at the base of the Calabrian Stage in Italy (King & Oakley 1949). This stage is characterised by the appearance of so-called northern immigrants.

The age of the Plio-Pleistocene boundary thus defined was first determined to *c.* 1.8 Ma, but it has been redetermined by palaeomagnetic stratigraphy (Tauxe et al. 1983) and by biostratigraphical correlation with deep sea cores (Backman et al. 1983) to *c.* 1.6 Ma. However, much debate is still going on about the proper and exact place of the boundary and its age (e.g. Jenkins 1987). In northwest Europe the Plio-Pleistocene boundary is often placed around 2.5 Ma (e.g. Zagwijn & Doppert 1978, Mangerud 1986, Watts 1988). This suggestion is followed here.

Mammals

The mammalian remains were kindly identified by C. A. Repenning, and were discussed by Repenning et al. (1987). The remains include a tooth of a large species of the extinct rabbit *Hypolagus* and an upper jaw fragment referable to the extant hare *Lepus*, besides some indeterminable bone fragments. All remains come from sample GCI 56692, locality 119, unit B3.

Hypolagus became extinct in Europe about 0.8 Ma ago, but the youngest record in North America, which is from Kansas, is 2.0 Ma old (Repenning 1984). On the other hand, the oldest record of *Lepus* in North America is from the 2.0 Ma old fauna from Kansas which also contains *Hypolagus*. The first record of the genus is in the Krestovka section in Siberia where *Lepus* appears about 2.3 Ma ago (Sher et al. 1979, Repenning et al. 1987).

Thus, the simultaneous occurrence of these lagomorphs in the Kap København Formation points to an age of 2.0 to 2.3 Ma for the upper part of the formation.

Foraminifers

The foraminifers are being studied by Feyling-Hanssen, who has published some preliminary results (Funder et al. 1985, Feyling-Hanssen 1986, 1987).

Member A (see later) usually contains fairly poor foraminiferal faunas, while unit B2 usually contains richer and taxonomically more diverse faunas. The faunas of the formation are divided into three assemblage zones.

The lower zone which conforms with member A is termed the *Nonion erucopsis* zone. Besides *Nonion erucopsis* Todd may be mentioned *Cibicides grossa* Ten Dam & Reinhold, an extinct species whose last appearance is fairly well dated in the North Sea Basin to about 2.5 Ma (King 1983). The assemblages of this zone also show great similarity to Late Pliocene assemblages in borings from the central North Sea (Feyling-Hanssen 1987).

The middle zone, conforming with the upper part of unit B1 and unit B2 of locality 50 and localities in the surrounding area northwards to localities 130 and 75 (in part), is named the *Elphidiella rolfii* zone. It is dominated by *Nonion niveum* Lafrenz, but characterised by *E. rolfii* Gudina & Palovova. Also present are rare specimens of *Elphidiella hannai* (Cushman & Grant), a species which originated in the Pacific and immigrated to the North Atlantic in the Pliocene, perhaps after the opening of the Bering Strait. In the North Sea Basin it is found in Pliocene and Early Pleistocene deposits, and it typifies littoral and inner sublittoral sediments of the Early Pleistocene (West et al. 1980).

The upper zone which conforms with unit B2 of locality 72, 124, 128–129 and part of unit B2 of locality 75 is named the *Elphidium excavatum* zone. *E. excavatum* Terquem is a common foraminiferal species within the Quaternary. The assemblages of this zone are diverse, including e.g. *Nonion niveum*, *N. orbiculare* (Brady), *Elphidiella hannai* and *E. rolfii*. Feyling-Hanssen (1987) correlates this zone with Early Pleistocene foraminiferal faunas from the North Sea and elsewhere.

Thus the formaniferal assemblages are interpreted as indicating an age of ≥ 2.5 Ma for member A, and a somewhat younger age for member B.

Molluscs

The molluscs are being studied by S. Funder, K. S. Petersen and L. Símonarson. Some results have been published by Funder & Hjort (1980), Funder et al. (1984, 1985b, 1987) and Bennike (1987, 1989).

Of particular importance to the age question is the occurrence of species which originated in the Pacific Ocean and immigrated to the Arctic and Atlantic Oceans with the first opening of the Bering Strait around 3 Ma ago, as dated in the Tjörnes sequence of northern Iceland (Albertsson 1978, Gladenkov 1979). Among these species may be mentioned *Musculus nigra* (Gray) which is present in member A, and from member B *Serripes groenlandicus* (Brugière), *Cardium ciliatum* Fabricius, *Macoma calcarea* (Chemnitz) and *Trichotropis bicarinata* (Sowerby) (Durham & MacNeil 1967). These molluscs provide an appoximate maximum age for the Kap København Formation.

The first appearance datums of a number of the species present is also of interest. The oldest record of *Portlandia arctica* (Gray) is from the Tjörnes sequence, where it appears in the Hörgi Formation dated to 1.25–2.1 Ma (Eiríksson 1981). In the Bering Strait region it appears much later (Hopkins 1967). *Cyrtodaria kurriana* Dunker first appears in Alaska in Beringian Beds (Hopkins 1967), presently dated to 3.0–2.7 Ma (Repenning & Brouwers in press). Along the north coast of Siberia it first appears in the Early Pleistocene (Nesis 1965). *Astarte borealis* (Schumacher) has its oldest records in the Bering Strait region about 2.7–2.5 Ma ago in Anvillian beds (Hopkins et al. 1974, Repenning & Brouwers in press). In the East Anglian sequence it first appeared about 2 Ma ago (Long & Cambridge 1988). *Macoma balthica* (Linné) first occurs about 1.6 Ma ago in the North Sea area (Norton & Spaink 1973, Gibbard & Zalasiewicz 1988), and in Alaska probably about 2.4 Ma ago (Repenning et al. 1987).

It is also worthy of note that no extinct mollusc spe-

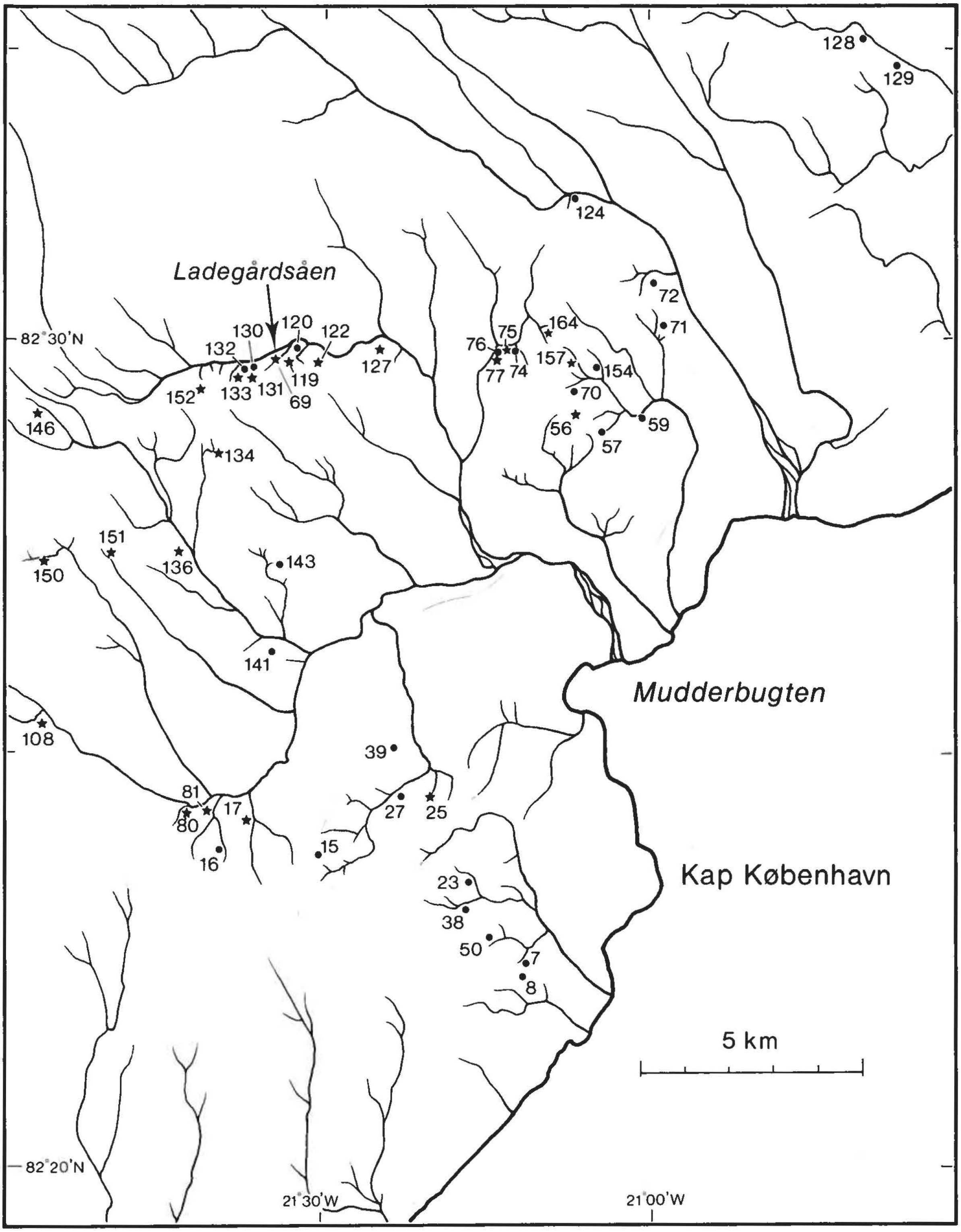


Fig. 2. The Kap København area, showing field localities, localities with *in situ* driftwood in unit B3 (marked by an asterisk) and place names mentioned in this paper. Locality numbers according to Funder (1983) and Bennike (1986). Map based on orthophotos.

cies have so far been identified from the Kap København Formation. Early Pliocene faunas from the North Atlantic and North Pacific include 25–30 % extinct forms according to Gladenkov (1979).

In conclusion, both member A and B contain mollusc species of Pacific origin and thus postdate the first opening of the Bering Strait at about 3 Ma ago. The occurrence of several other species points to an age of probably no more than 2–2.5 Ma.

Ostracodes

Marine ostracodes from the Kap København Formation are being studied by E. M. Brouwers and N. O. Jørgensen. The evidence from this group seems to support the other biostratigraphical evidence (E. M. Brouwers, pers. comm.).

Palaeomagnetism

Due to difficulties of sampling the most fine-grained and hard sediments only parts of the Kap København Formation have been investigated. These parts were deposited during a period of reversed polarity of the geomagnetic field, and a combined age estimate in the older part of the Matuyama chron, between 1.89 Ma (pre-Olduvai) and 2.48 Ma (post-Gauss) was suggested by Abrahamsen & Marcussen (1986).

It is concluded that the Kap København Formation was probably deposited between 2 and 2.5 Ma ago, at the Plio-Pleistocene transition. It is difficult to evaluate the precision of this dating, but it rests to a great degree on the accuracy of datings of sections in other parts of the northern hemisphere, and on long distance correlations using events that are more or less time transgressive. Many species undoubtedly migrated southwards with the general Late Cainozoic climatic cooling, and thus appeared at an earlier date at Kap København than further south.

List of localities

Below follows a list of important localities, with some brief comments. The numbers are not continuous as field numbers are retained. The numbering follows Funder (1983, No. 7–108) and Bennike (1986, No. 119–164). The position of the localities is shown on Fig. 2.

7 – 20 m high sections along brook in member A, overlain by unit B1 towards the southwest. The boundary is at about 50 m a.s.l. (above sea level). Member A in this area consists of fine-grained, laminated mud, but also contains a lens of diamict sediment.

15 – 20 m high section at the northern edge of a low-lying plateau, 160 m a.s.l. Organic sand from this locality yielded extremely well preserved leaves of dwarf shrubs. Tentatively referred to unit B1.

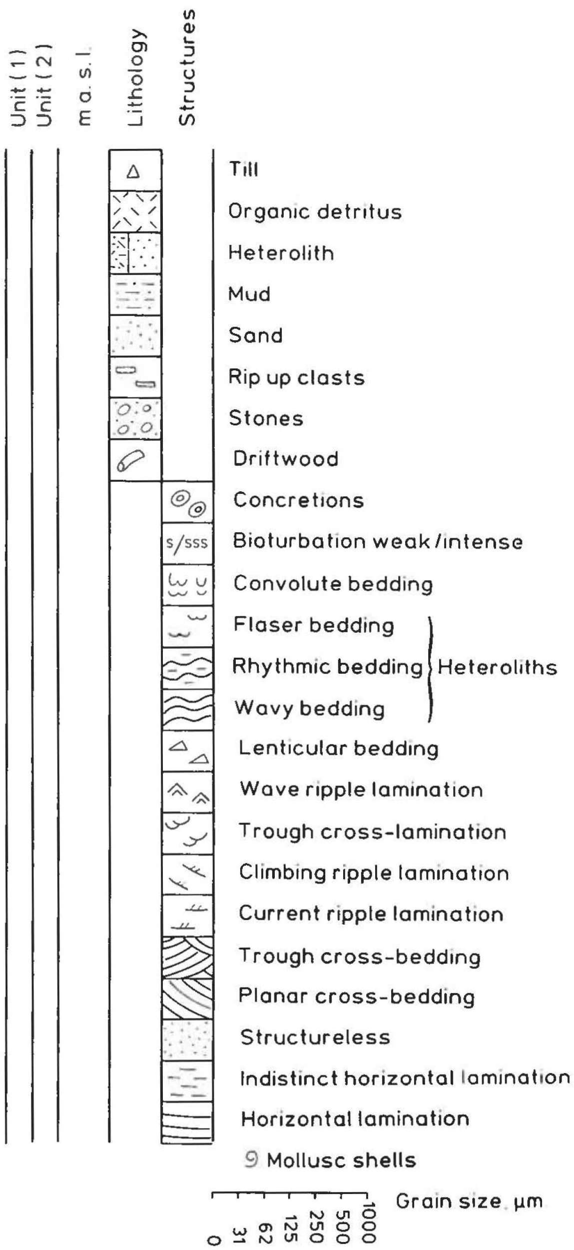


Fig. 3. Legend to sections. Unit (1) designations refer only to sections 50a and 50b, and are those of Funder & Hjort (1980). Unit (2) designations refer to all sections, and are those of Funder et al. (1984).

16 – Smaller sections in member A and unit B3 around 70 m a.s.l. The sections show large scale slump structures (fig. 6 of Funder et al. 1984) and glacio-tectonic structures.

17 – 40 m high section in unit B3 around 80 m a.s.l. Sedimentological log shown in Fig. 4. For legend see Fig. 3.

25 – *C.* 10 m high, poorly exposed section in unit B3 around 110 m a.s.l.

27 – Northward-facing, *c.* 20 m high and 300 m long section in unit B2 around 90 m a.s.l. (Fig. 5a). The sediments

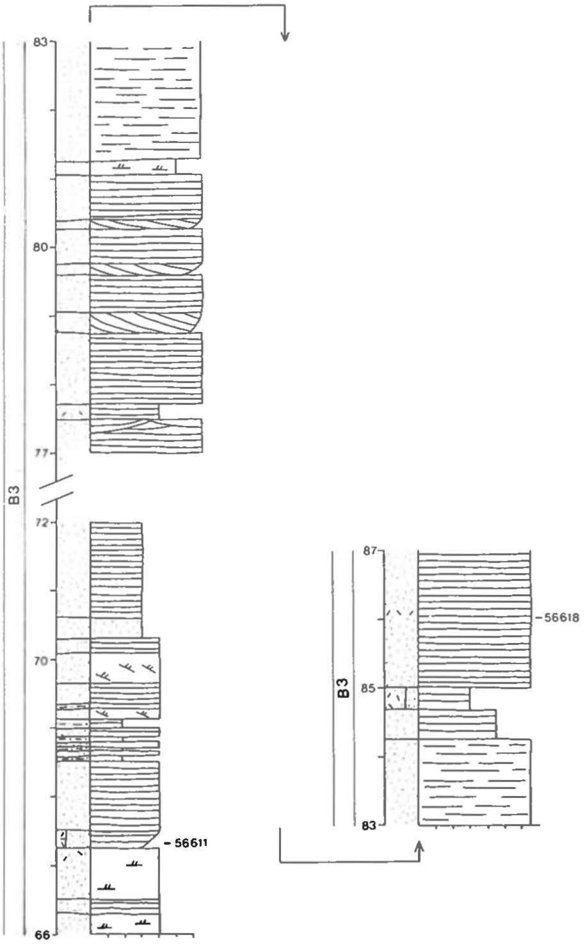


Fig. 4. Detailed sedimentological log from locality 17. For location see Fig. 2.

contain notable amounts of organic detritus throughout, including *Salix* branches near the bottom. This unit is underlain by poorly exposed member A and unit B1 sediments. Sedimentological log shown in Fig. 6.

38 – *C.* 15 m high section in unit B3 around 110 m a.s.l. Overlain by diamicton which contains a member A Foraminifera assemblage (R. W. Feyling-Hanssen, pers. comm.). Sedimentological log shown in Fig. 7.

39 – Small sections along brook in member A.

50 – This is the locality of the type section of the Kap København Formation. The sediments are exposed in the head walls of small cirques (Fig. 5b, c). The exposures extend from *c.* 65 m a.s.l. to *c.* 125 m a.s.l., and expose the uppermost part of member A and unit B1, B2 and B3. Two sedimentological logs are shown in Figs 8 and 9.

56 – Poor sections in unit B3 in hill around 120 m a.s.l. On this hill is a small collapsed cairn erected by L. Koch who undertook astronomical observations here in 1921.

57 – Poorly exposed sections in hill side, showing unit B3 about 80 m a.s.l.

59 – Sections in member A and lower part of unit B1, around 50 m a.s.l. with glacio-tectonic structures.

69 – *C.* 50 m high section in member A, unit B1, B2 and B3.

70 – 20 m high section in member A and unit B1, around 75 m a.s.l.

72 – Section in small isolated hill. Hill top at 112 m a.s.l. Member A (?), unit B1 and B2 are exposed. The hill is formed from a dislocated glacio-tectonic floe. Unit B2 contains rich mollusc and Foraminifera faunas. At this locality unit B2 is overlain by clast supported gravel, included in the Kap København Formation by Funder et al. 1984. In this paper the gravel layer is referred to the glacio-fluvial gravel which covers the Kap København Formation in this area.

74 – *C.* 20 m high section along brook exposing unit B1 and B2 around 85 m a.s.l. Unit B1 is characterised by a giant scale cross-bedded set. Sedimentological log shown in Fig. 10.

75 – *C.* 30 m high section in member A, unit B1, B2 and B3, from 72 to c. 110 m a.s.l. Sedimentological log shown in Fig. 11.

76 – 8 m high section in unit B3 around 65 m a.s.l.

77 – 8 m high section in unit B3 around 65 m a.s.l. Fig. 12 shows a large moss lens with many insect remains at this locality.

80 – 10 m high section in unit B3 around 85 m a.s.l.

81 – 15 m high section in unit B3 around 105 m a.s.l.

108 – 30 m high section in unit B2 (?) and B3 around 130 m a.s.l. Glacio-tectonic structures disturb the sediments.

119 – 30 m high section in unit B3 around 120 m a.s.l. The few mammal remains in the Kap København Formation come from this locality, from a sample of a lens consisting mostly of small twigs (GCI 56692). This sample also contains a diverse flora of vascular plants.

120 – 10 m high and 50 m long section in member A.

122 – Section in unit B3. Logs and accumulations of organic detritus occur around 105 m a.s.l. The *Thuja* twig shown in Fig. 40 and many *Larix* cones originate from this locality.

124 – 15 m high section in unit B2, around 80 m a.s.l. The Foraminifera faunas correspond to those of locality 72 (R. W. Feyling-Hanssen, pers. comm.). The sediments of this locality appear to be *in situ*, i.e. not disturbed by glacio-tectonics.

127 – Sections in unit B3 around 110 m a.s.l.

128 & 129 – 10 m high sections in an isolated north-easterly occurrence of the Kap København Formation around 80 m a.s.l., exposing sand and silt layers correlated with unit B2, and overlain by *c.* 20 m of glacio-fluvial gravel. The sediments contain a rich mollusc and Foraminifera fauna (Bennike, 1989; R. W. Feyling-Hanssen, pers. comm.).

130 – 30 m high section in member A, unit B1, B2 and B3 around 105 m a.s.l. The sediments are somewhat disturbed by glacio-tectonic structures. Sedimentological log shown in Fig. 13.

131 – Small section in unit B3 around 150 m a.s.l.

132 – Section in unit B1, B2 and B3 around 120 m a.s.l. showing glacio-tectonic structures.

133 – Section in unit B3 around 150 m a.s.l.

134 – Poorly exposed section in member A and B around 175 m a.s.l.

136 – 30 m high section in unit B3 around 115 m a.s.l.

141 – 20 m high section in unit B3 around 100 m a.s.l.

143 – 30 m high section in member A and B. The sediments are strongly disturbed by glacio-tectonic structures.

146 – *c.* 15 m high section in unit B3 around 160 m a.s.l.

150 – 20 m high section in unit B3 around 135 m a.s.l.

151 – 10 m high section in unit B3 around 150 m a.s.l.

152 – 20 m high section in unit B3 around 165 m a.s.l.

154 – 15 m high section in unit B2 and B3 around 90 m a.s.l.

157 – 10 m high section in unit B3 around 115 m a.s.l.

164 – Poor exposures in unit B3 around 100 m a.s.l.

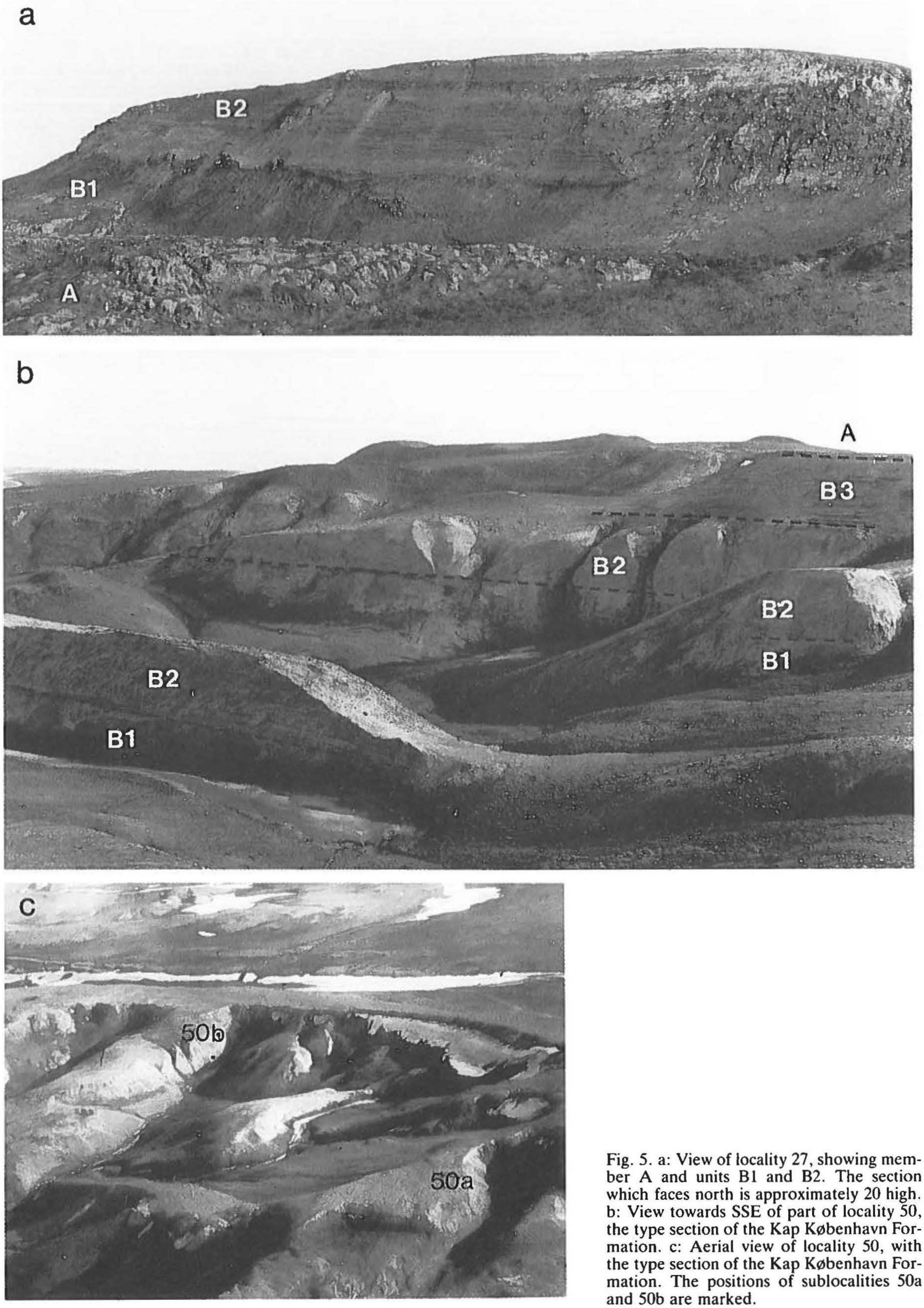


Fig. 5. a: View of locality 27, showing member A and units B1 and B2. The section which faces north is approximately 20 high. b: View towards SSE of part of locality 50, the type section of the Kap København Formation. c: Aerial view of locality 50, with the type section of the Kap København Formation. The positions of sublocalities 50a and 50b are marked.

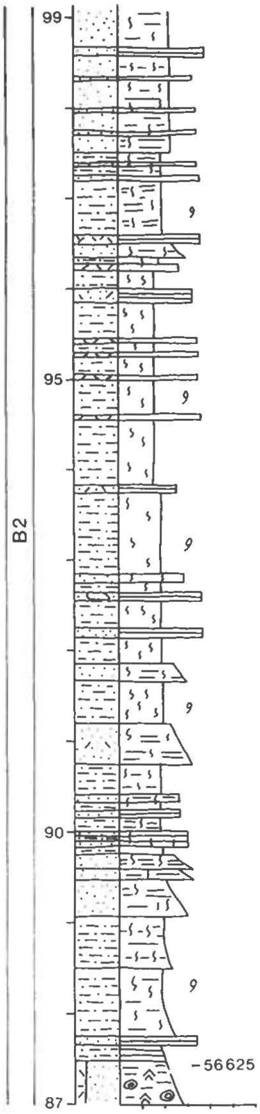


Fig. 6. Detailed sedimentological log from locality 27. For location see Fig. 2.

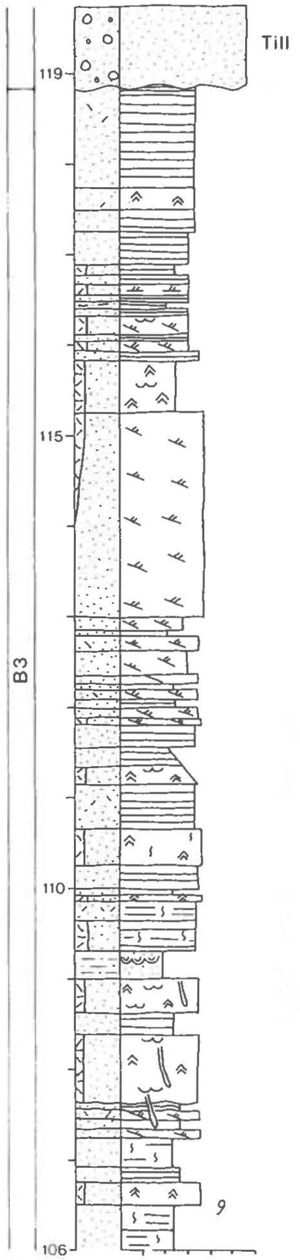


Fig. 7. Detailed sedimentological log from locality 38. For location see Fig. 2.

Stratigraphy and sedimentology

Funder & Hjort (1980) divided the main section of the Kap København sequence into 11 informal units, 1–11. The Kap København Formation was formally erected by Funder et al. (1984) who subdivided it into members A and B. Member B was further subdivided into units B1, B2 and B3. In addition, they designated a type section for the Kap København Formation, which is locality 50 of this paper. The stratigraphical units are mostly defined on the basis of lithology and sedimentary structures.

The Kap København Formation is exposed in many minor and a few major widely separated sections. Correlation from one section to another is made difficult by lateral facies changes and glacio-tectonic disturbances (Fig. 14). Existence of such disturbances means that height above sea level can only be used as a crude guide

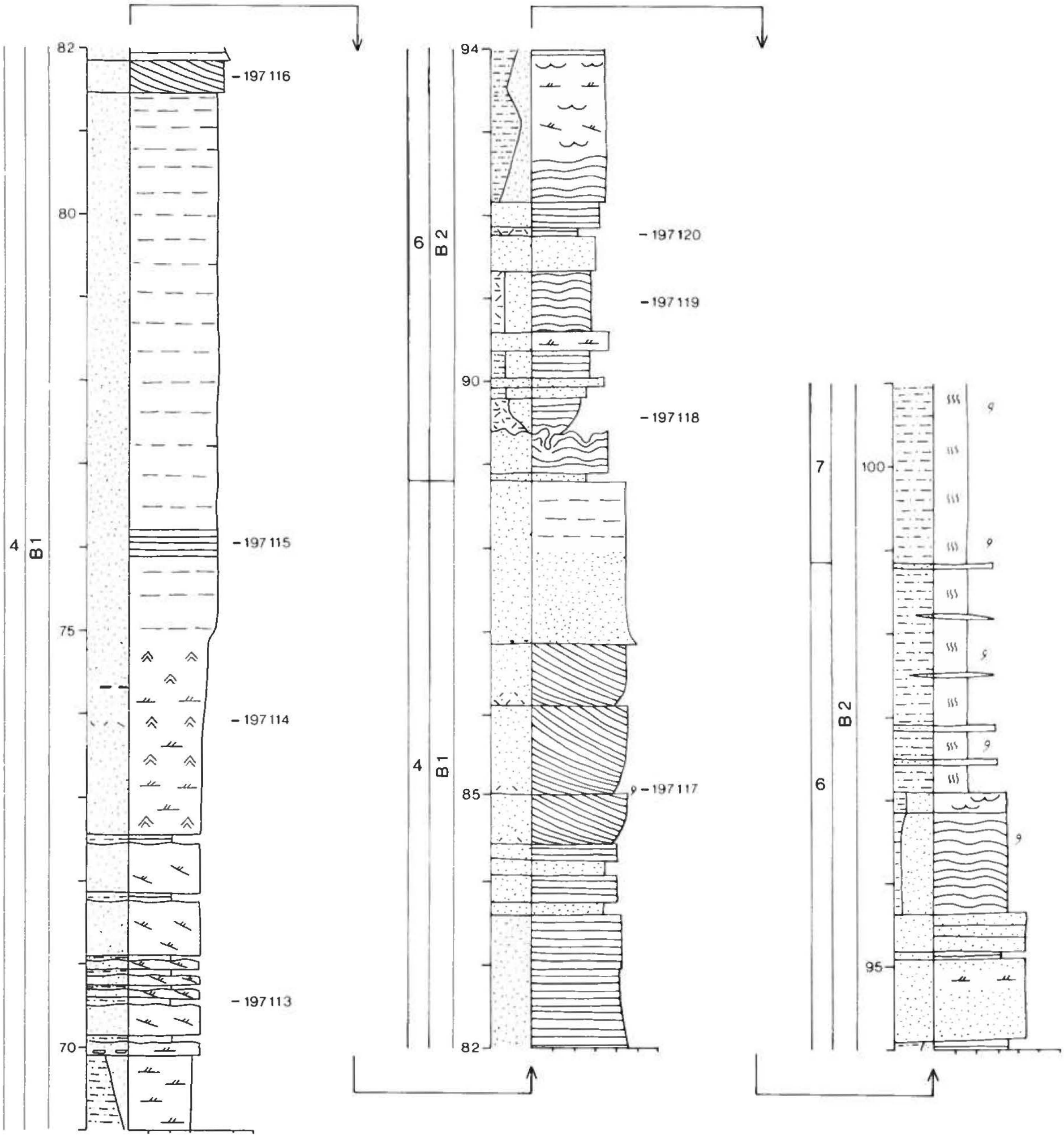


Fig. 8. Detailed sedimentological log from locality 50a. For location see Figs 2 and 5c.

for correlation. The glacio-tectonic structures were caused by a glacier in Independence Fjord which overrode the area (Funder et al. 1984). The orientation of some layers and fold axes is shown on the small geological map in Funder et al. (1985a).

Member A

Thickness. – The total thickness is unknown because the lower boundary is not exposed. The exposed part of the member is up to 50 m thick.

Lithology. – The member is dominated by finely laminated grey or reddish clayey silt (Fig. 15). Fig. 16 shows grain size curves for two samples from the member. These samples contain no less than 26–32 % clay. The dominating layer silicates are illite, chlorite, smectite-chlorite and mica-smectite as determined by XRF analyses. In addition, talc is common (Tables 1 and 2).

The laminae usually show normal grading. Small horizontal burrows occur here and there. In some sections large-scale load structures may be observed. Isolated stones or boulders are common in parts of the member.

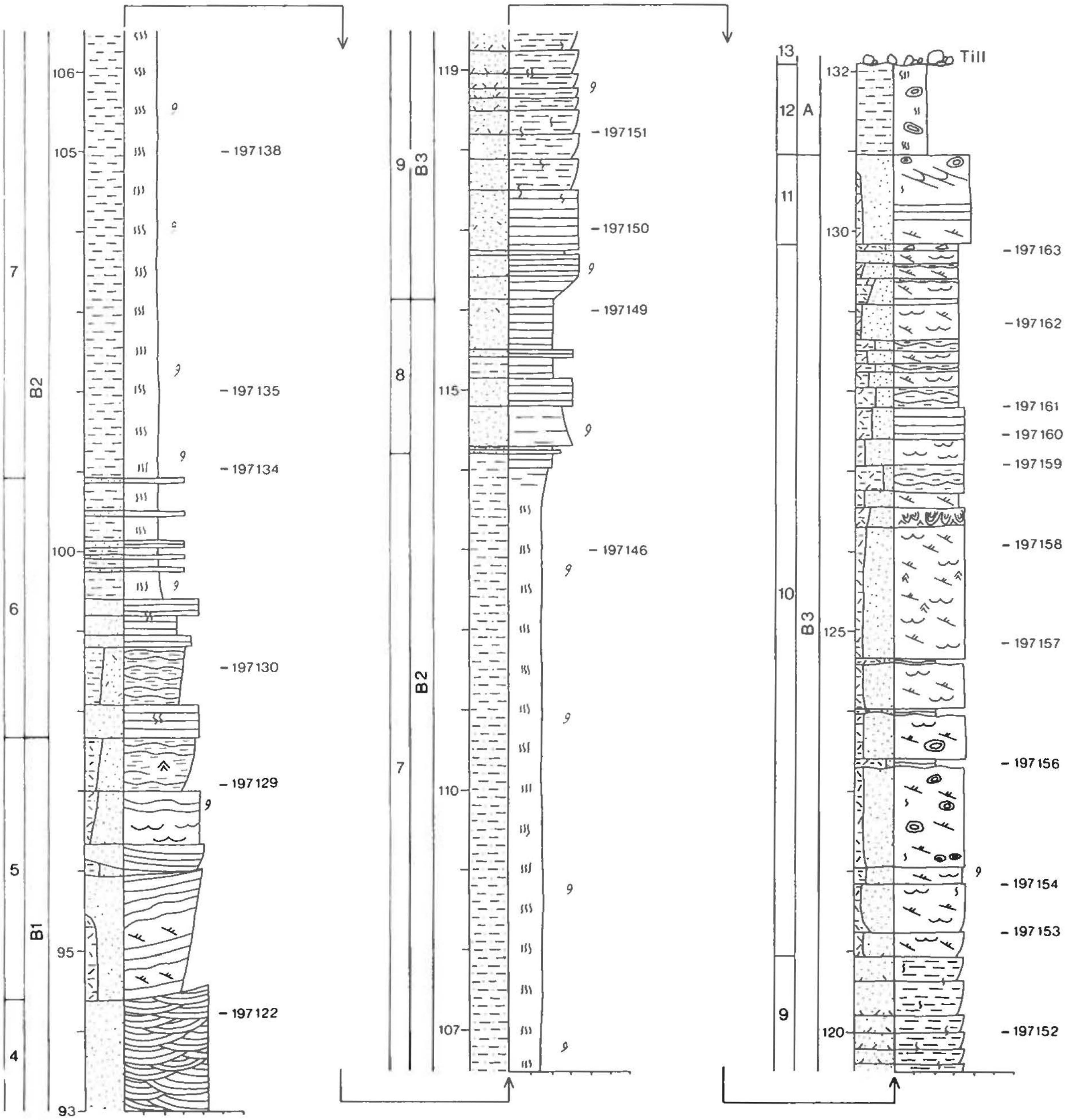


Fig. 9. Detailed sedimentological log from locality 50b. Part of the type section of the Kap København Formation. For location see Figs 2 and 5c.

At two localities (nos 7 and 39) smaller lenses of diamict sediment have been found (Fig. 17).

Marine fauna. – Molluscs are extremely rare. In spite of intensive search only a few paired (i.e. with articulated valves) shells of *Portlandia arctica* and *Musculus nigra* have been found *in situ* (Funder *et al.* 1984). However, fragments of the thick shelled species *Hiatella arctica* (Linné), *Mya truncata* Linné and *Astarte* sp., are commonly seen at the surface in the Kap København area and may come from member A, as suggsted by Funder et al. (1984). Foraminifers usually occur in low concentrations (Feyling-Hanssen 1987).

Depositional environment. – The fine-grained laminated sediment was deposited from suspension. The lack of current and wave generated sedimentary structures shows that sedimentation took place in a low energy environment, which in view of the marine fauna, must have been in the sea and below the storm wave base. The rarity of macrofauna (molluscs) and burrows may be due to a high sedimentation rate.

Table 1. Relative mineral abundances. Analyses by W. Way, University of Lancaster

Unit/loc.	Sample No.	Quartz	Feldspar	Calcite	Dolomite	Gypsum	1.0nm	1.4nm*	Amphibole	Talc
Unit B2										
	GGU									
50	197136	4	3	2	3	–	3	3	1	–
50	197138	4	3	2	3	–	3	3	2	–
50	197140	4	3	1	3	–	3	3	2	–
50	197142	4	3	2	3	–	3	3	1	–
	GCI									
130	53282	4	3	2	3	–	3	3	–	–
130	53284	4	3	2	3	–	3	3	1	–
	GCI									
72	53216	4	3	3	3	2	3	2	–	–
72	53218	4	3	3	3	3	3	2	–	–
72	53220	4	3	3	3	2	3	2	–	–
	GCI									
75	67992	4	3	1	3	2	3	3	1	–
75	67994	4	3	3	3	–	3	3	1	–
Member A										
	GGU									
7	197180	4	3	–	–	–	3	3	1	2
7	197181	4	3	–	–	–	3	3	2	2
	GCI									
120	53208	4	3	–	–	–	3	3	2	2
120	53210	4	3	–	–	–	3	3	2	2
120	53212	4	3	–	–	–	3	3	2	2

*The 1.0 and 1.4 nm peaks represent respectively mica and chlorite group minerals together with expanding clay minerals

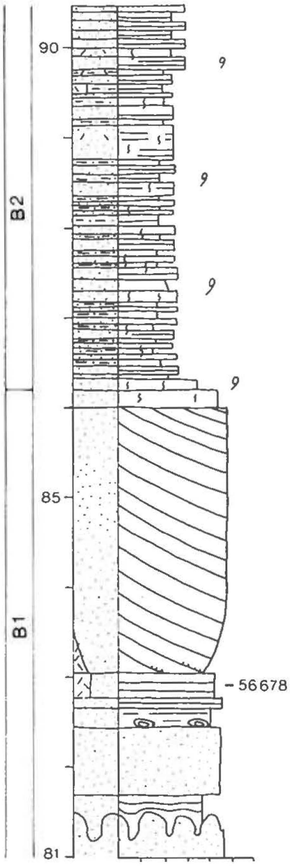


Fig. 10. Detailed sedimentological log from locality 74. For location see Fig. 2.

The scattered stones are interpreted as dropstones, and the lenses of diamicton were probably also dropped from icebergs.

Boundary. – The boundary to the overlying member B is usually erosional. However, at the type section (locality 50) the contact between the members is gradational. In substantial parts of the Kap København area member A forms the topmost unit, being covered only by a thin, discontinuous layer of gravel.

Member B

While member A is homogeneous, member B is heterogeneous. It mostly consists of sand (units B1 and B3), but also contains a muddy unit (B2).

Table 2. Relative percentages of phyllosilicates in representative samples. Analyses by W. Way, University of Lancaster

Unit/ loc.	Sample No.	Mica	Expandables	*Chlorite	Kaolinite
Unit B2					
	GGU				
50	197136	71	19.5	9	<1
	GCI				
72	53218	71	12	8.5	8.5
	GGU				
7	197181	69	15	8	8

*Smectite-chlorite and mica-smectite

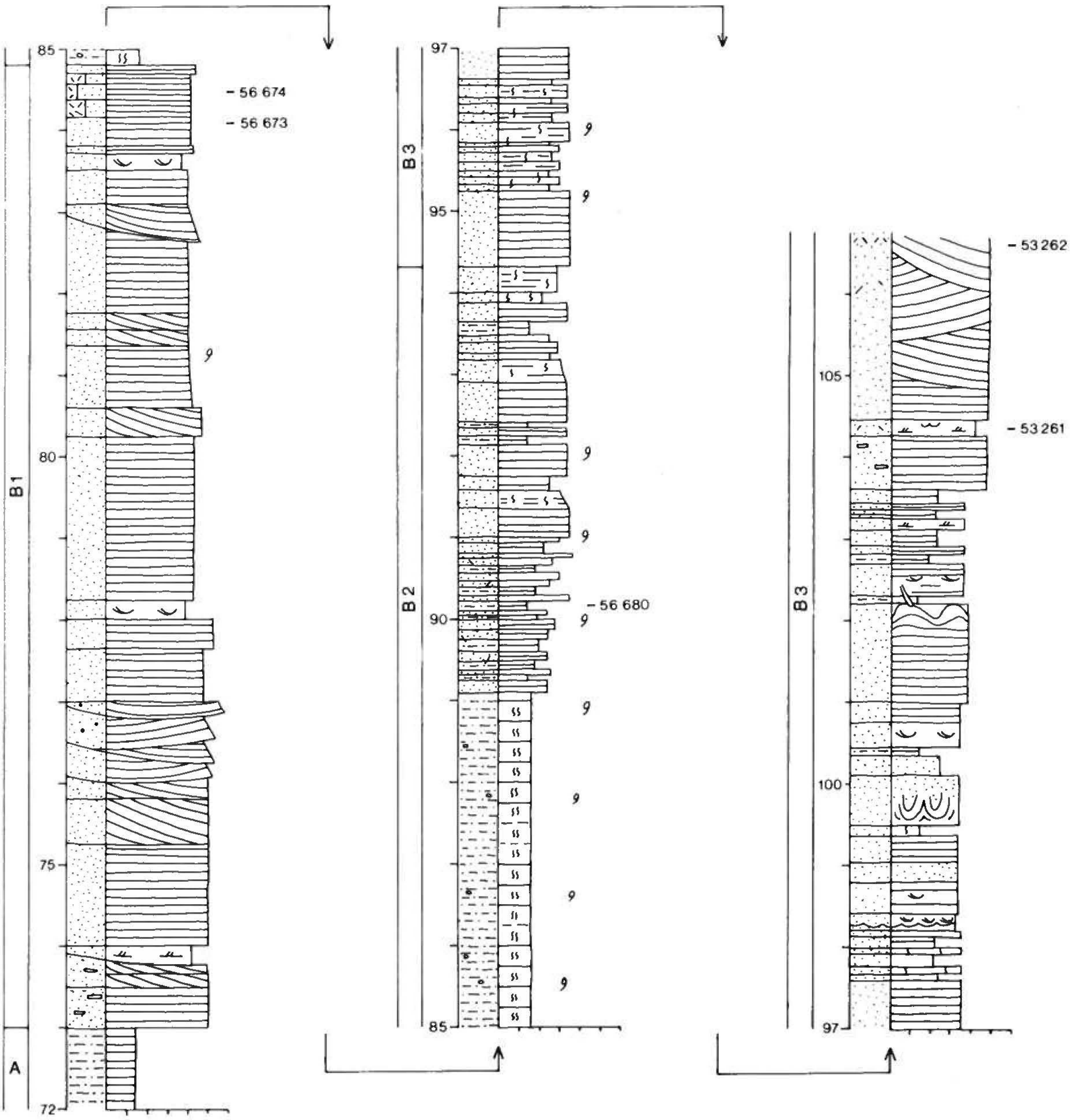


Fig. 11. Detailed sedimentological log from locality 75. For location see Fig. 2.

Fig. 12. Lens of moss rich organic debris which contains many insect remains. Unit B3, locality 77, 100 m a.s.l. Scale: Jens Böcher.

Unit B1

Corresponds to units 4 and 5 of Funder & Hjort (1980).

Thickness. – The thickness of unit B1 varies considerably, attaining a maximum thickness of c. 35 m in the type section, but only 10–15 m in the area of localities 74 and 75 north of Mudderbugten.

Lithology. – This unit is dominated by medium and fine sand, while very fine sand and coarse sand constitute minor parts (Fig. 18). Angular mud clasts of member A occur in the lower part of member B. At a few places thin, discontinuous layers of granules are present. The sand is texturally and mineralogically mature, grey-white quartz sand, with local concentrations of heavy minerals (Fig. 19). Organic detritus occurs rarely in small lenses and layers.

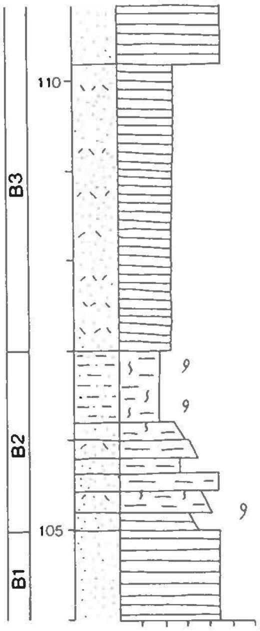


Fig. 13. Detailed sedimentological log from locality 130. For location see Fig. 2.

The dominant structure in this unit is horizontal, parallel lamination – sometimes only faintly visible. Less common are large scale tabular cross-bedding with tangential foresets (low angle (Fig. 20) and high angle), large scale trough cross-bedding, indistinct horizontal parallel lamination, structureless sand and cross-lamination.

At the type section (loc. 50, Figs 8, 9) and in the surrounding area, the upper part of unit B1 shows a fining upward sequence, and large scour-and-fill structures, either isolated or in clusters, occur locally at the transition to unit B2 (unit 5 of Funder & Hjort 1980). The scours are filled by heterolithic sediments (Fig. 21) which contain an abundance of organic detritus – showing up to 30 % loss on ignition. Parallel lamination, wavy and flaser bedding and climbing-ripple lamination are the sedimentary structures present in the scours. A moderate degree of bioturbation is present in some layers.

At locality 74 there is a giant-scale planar cross-bedded set that constitutes part of a fining-upward sequence (Fig. 22). It is 3 m thick; the foresets are tangential and dip towards the west (267°), and the bottomsets and toesets are draped by organic detritus. The foresets of the large-scale tabular cross-bedded sets, in contrast to the giant-scale cross-bedded set, generally dip to the northeast (Fig. 23).

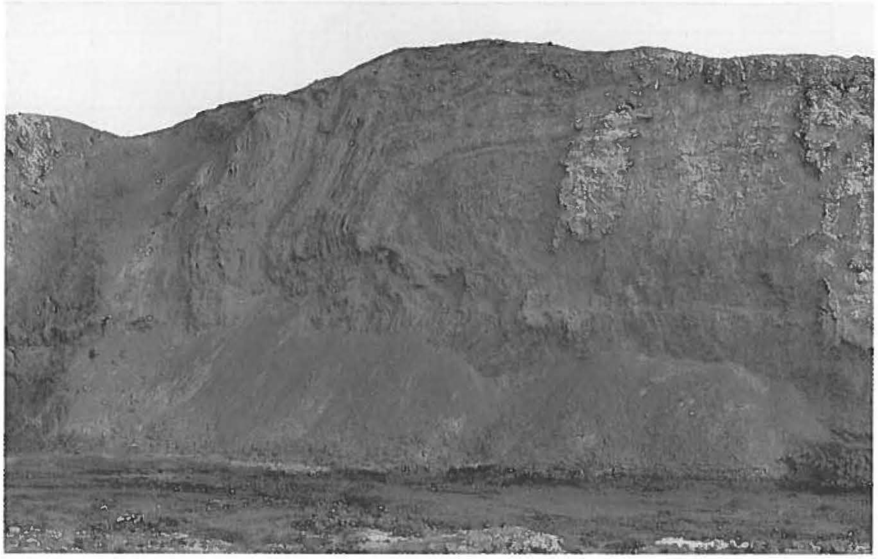


Fig. 14. Typical outcrop of member A, showing folded intercalated mud, silt and fine sand sequence. Locality 135. Height of section about 20 m.

Marine fauna. – At a few localities shells or shell fragments have been located in the upper part of unit B1. They are more or less dissolved and may consequently have been more common. *Cyrtodaria kurriana* shell fragments are quite common in the upper part of the scours of the type section area.

Depositional environment. – The rare occurrence of marine molluscs and the clean, mature quartz sand with heavy mineral concentrations indicate that unit B1 was deposited in a shallow water marine environment of high to medium energy.

Horizontal lamination is the dominant structure in back- and foreshore sediments, and it is also a common structure in shoreface sediments. Large-scale tabular cross-bedding in these environments is mostly formed by migrating longshore bars, which are confined to the shoreface and the foreshore. Heavy mineral placers are produced in the backshore region, mostly near the upper limit of the backshore (Inman & Filloux 1960).

The giant-scale cross-bedded set from locality 74 shown in Fig. 22 was formed by migration of a giant-scale ripple, probably a sandwave.

In summary, unit B1 was therefore deposited in the backshore, foreshore and shoreface of a medium energy coast. The sediments in the upper part of the unit, including those filling the scour structures, were deposited in the transition zone.

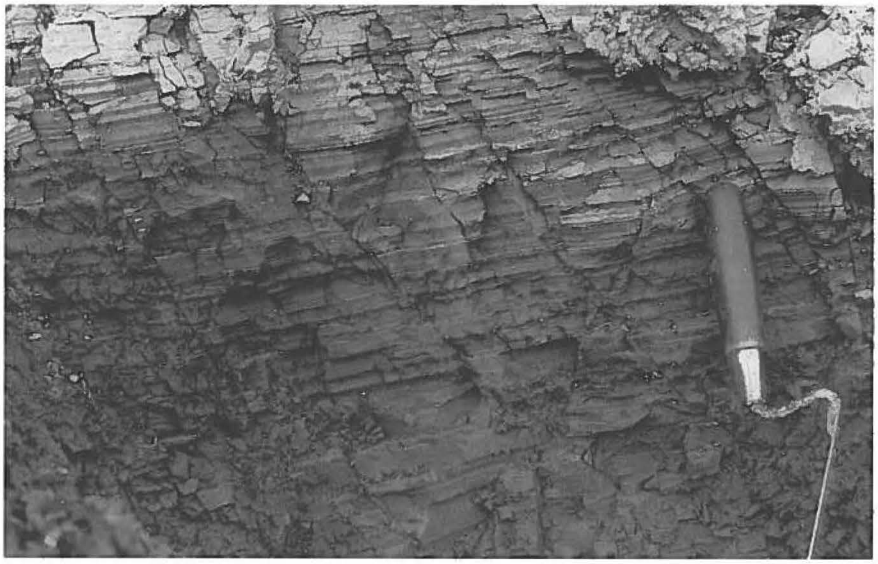


Fig. 15. Finely laminated mud of member A, locality 7, *c.* 30 m a.s.l.

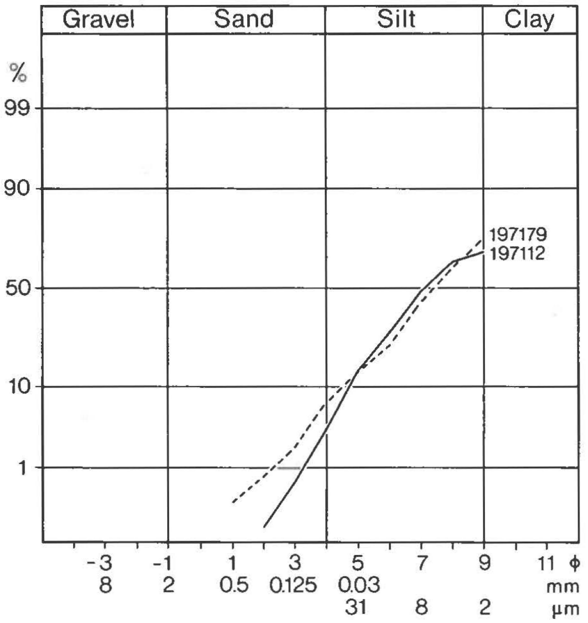


Fig. 16. Cumulative grain size distribution curves from member A plotted on log-probability paper. GGU 197112 is from locality 50a, while GGU 197179 is from locality 7. Each curve is representative of bulk-samples, i.e. both finer and coarser laminae are included. Analyses by H. Bahnson, Geological Survey of Denmark.

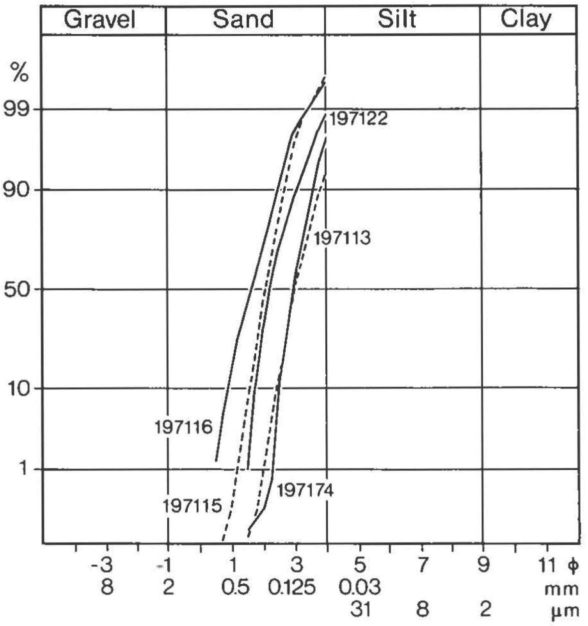


Fig. 18. Cumulative grain size distribution curves from units B1 and B3 plotted on log-probability paper. GGU 197113, 197115 and 197116 are from unit B1, locality 50a, GGU 197122 is from unit B1, locality 50b and GGU 197174 is from unit B3, locality 38.

Unit B2

Unit B2 corresponds to unit 6, 7 and 8 of Funder & Hjort (1980).

Thickness. – The thickness amounts to about 20 m at the type section. North of Mudderbugten this unit only occurs locally and is no more than 9 m thick. In the western part of the area it has not been observed.

Lithology. – At the type section area unit B2 mostly consists of completely bioturbated mud made up of 90% silt with minor amounts of clay and sand (unit 7, Fig. 24). The bioturbation is characterised by small burrows, measuring *c.* 1 mm across.

Some stones have been located in the unit, the largest measured 7 cm. Layer silicates are illite, chlorite, smec-

Fig. 17. Pocket of diamicton overlain by laminated mud. Member A, locality 7, *c.* 30 m a.s.l.

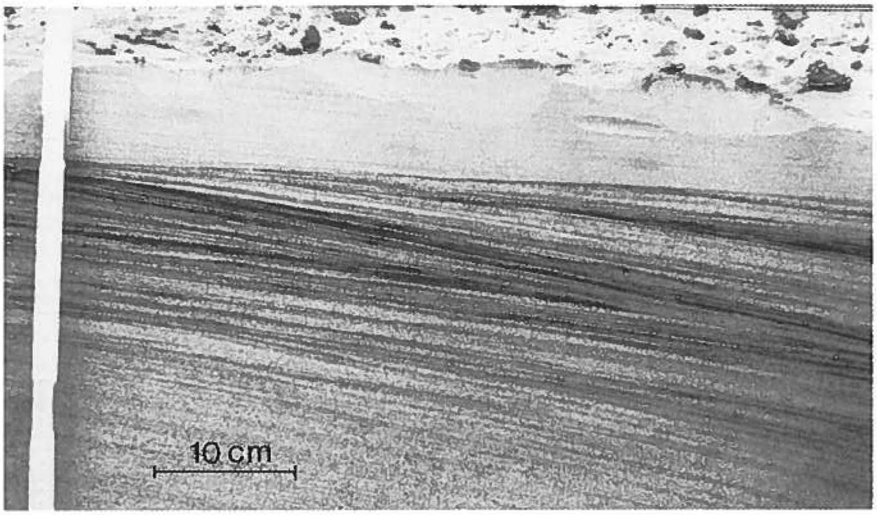


Fig. 19. Low angle cross-bedded medium grained sand with heavy mineral laminae. Note the low angle discordances. Locality 75, unit B1, 102 m a.s.l.

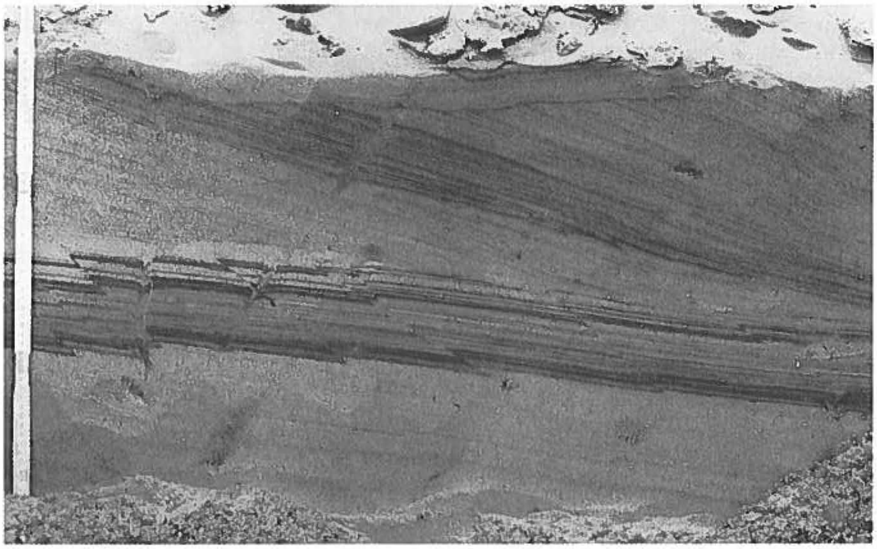


Fig. 20. Low angle cross-bedded quartz sand with heavy mineral laminae, truncated by small reverse faults caused by glacier push. Locality 72, unit B1 (?), *c.* 80 m a.s.l.

Fig. 21. Laminated fine sand and fine grained laminae rich in organic detritus. At the bottom form sets of wave ripples are seen. Upper part of unit B1, locality 50b (unit 5 of Funder & Hjort 1980), 89 m a.s.l.

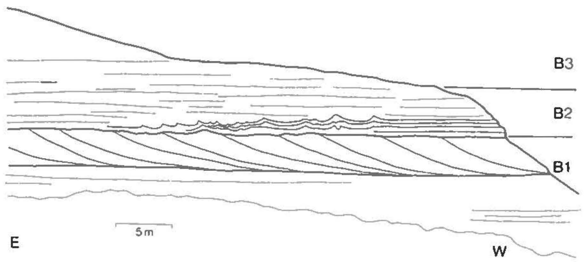


Fig. 22. View of locality 74 showing horizontally laminated sand and a 3 m thick cross-bedded set of unit B1. The foresets are draped by organic detritus in their lower part (not shown). The convolutions are at the bottom of unit B2. Drawn from photo.

tite-chlorite, mica-smectite and kaolinite. Also, calcite, dolomite and gypsum (only some samples) have been identified (Tables 1 and 2), and vivianite, a mineral rare in marine sediments (Postma 1982), is common. The last-named usually forms in anoxic, organic-rich sediments with a high phosphate concentration (Postma 1981, 1982). Small desert roses of portlandite (O. V. Petersen, pers. comm.) were also found in a single sample (GCI 56680).

Unit B2, which weathers to light grey colour, is resistant to erosion and the unit forms small cliffs where exposed (Fig. 25). The completely bioturbated mud facies is under- and overlain by somewhat coarser sediments in which some lamination has survived the bioturbation (unit 6 and 8). These sediments typically consist of an alternation between strongly bioturbated muddy layers and fine sand/silty layers about 5 cm thick. The bases of the fine sand/silty layers are sharp or erosive, the layers are graded, laminated or structureless at the bottom and laminated at the top, and they often contain, especially in their lower part, concentrations of transported shells of the bivalve *Cyrtodaria kurriana*. The shells are usually paired, although not in life position. Some valves are disarticulated or even fragmented.

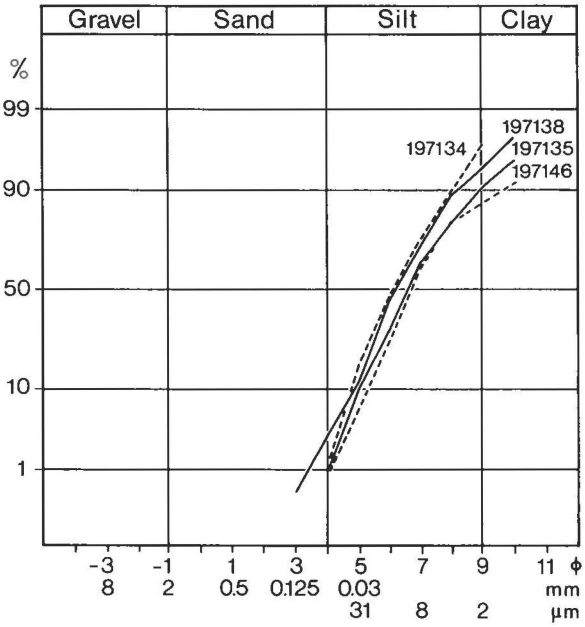


Fig. 24. Cumulative grain size distribution curves from unit B2 plotted on log-probability paper. Analyses by H. Bahnson, Geological Survey of Denmark.

To the north and west of Mudderbugten the bioturbation in unit B2 is less intense, with some sedimentary lamination remaining, and larger amounts of fine sand are present, often as thin graded layers.

Marine fauna. – In the area of the type section the marine macroscopic fauna is diverse, being dominated by small gastropods, notably *Cylichna* spp. (opistobranch), *Oenopota* spp. and *Natica* sp. (prosobranchs) and the bivalve *Astarte borealis*. *Cyrtodaria kurriana* is present in the lower and upper part of the unit. The mollusc shells are extremely thin.

At the stratotype area the Foraminifera fauna of this unit is rich and diverse. *Nonion niveum* dominates the

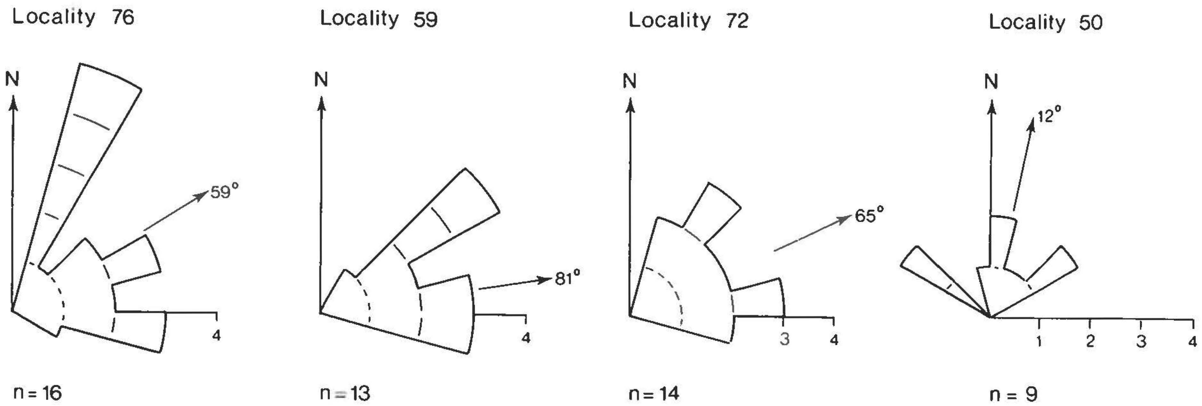


Fig. 23. Palaeocurrent compass roses showing orientation of foreset beds in large scale planar cross-bedded sets of unit B1. The arrows show the vector mean dip direction.

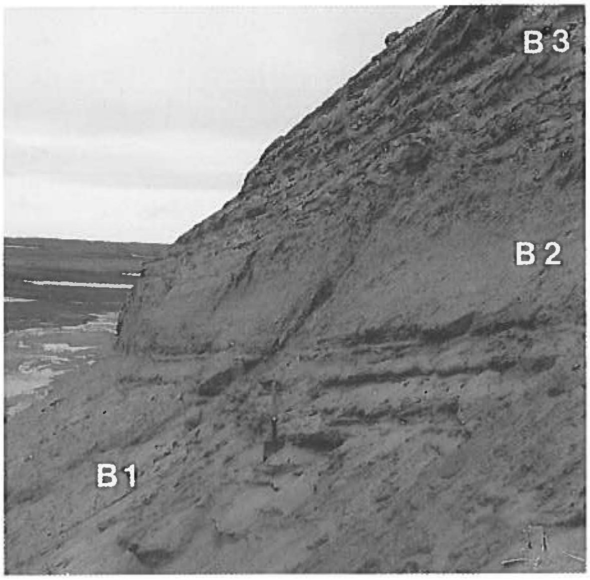


Fig. 25. Outcrop of unit B1, the cliff forming unit B2 and unit B3, locality 130 with Ladegårdsåen to the left (north). Small spade for scale.

assemblages, and other characteristic species are *Elphidiella rolfi* and *Elphidiella hannai* (Feyling-Hanssen 1987).

To the north and west of Mudderbugten the bivalve fauna is more diverse, and includes among others *Macoma balthica*, *Macoma calcarea*, *Serripes groenlandicus* and *Mytilus edulis* Linné (Funder et al. 1985b, 1987). The Foraminifera faunas are distinctly different from that of the type section area, but intermediate assemblages occur at locality 75 (R. W. Feyling-Hanssen, pers. comm.). The assemblages are dominated by *Elphidium excavatum*, and *Elphidiella rolfi* and *E. hannai* are also present (Feyling-Hanssen 1987).

Farthest to the northeast, at locality 128 and 129, the mollusc fauna includes the rare gastropod *Trichotropis bicarinata* (Bennike 1989). The mollusc shells in these two localities are of a normal thickness. Also the Foraminifera fauna in these localities is taxonomically diverse and rich (R. W. Feyling-Hanssen, pers. comm.).

Depositional environment. – The homogeneous, bioturbated silt which makes up the major part of unit B2 was deposited in a low energy environment, below storm wave base on the inner shelf. This interpretation is supported by the evidence from the marine fauna.

The small burrows were produced by soft-bodied deposit-feeding organisms, probably polychaetes, which took advantage of the organic content of the sediment.

The few stones in unit B2 are interpreted as dropstones.

Unit B3

Unit B3 corresponds to unit 9, 10 and 11 of Funder & Hjort (1980).

Thickness. – This unit is typically about 15 m thick, but is poorly exposed and undoubtedly much thicker in the northern and western parts of the area.

Lithology. – The unit is rather heterogeneous, but it is dominated by medium sand (Fig. 18), which is mainly horizontally laminated. At some localities (notably localities 17 and 75) the unit is characterised by a coarsening-upward sequence, from fine sand and silt with horizontal lamination and cross-lamination to medium and coarse sand with horizontal lamination and large scale cross-bedding. Burrows are quite common in the lower and middle part of the unit (Fig. 26).

Logs of small trees are a notable feature for this unit in many areas (Fig. 2). They usually occur at the surface, but in some cases *in situ* pieces have been located. Such pieces are aligned parallel to lamination (Fig. 27) indicating they were deposited as driftwood.

Accumulations of organic detritus are also notable (Fig. 28). They are normally discontinuous, but at the type section organic detritus is dominant, even forming peat-looking layers (Fig. 29b). The inorganic parts of the peat-like layers consist of fine and very fine sand.

At the type section unit B3 is tripartite. The lower part consists of horizontal laminated fine sand with little organic detritus. Burrows are common. The middle part contains most of the organic detritus. Its sediments are heterolithic, with flaser, wavy and lenticular bedding in combination with climbing ripple lamination and wave-ripple lamination. Some of these structures are shown in Fig. 29. Horizontal and draped lamination (Fig. 29a) are also present. The upper part, horizontally laminated with only rare burrows, consists of fine sand with very little organic detritus.

At a level of around 119 m a.s.l. the type section is characterised by fine sand layers showing inverse grading.

At locality 38 the sediments resemble the middle part of unit B3 in the type section, but they contain smaller amounts of organic detritus. Climbing ripple lamination and wave ripple lamination are the most characteristic structures at this locality.

It is also noteworthy that penecontemporaneous deformation structures are found in unit B3 (Fig. 29d).

The boundary between units B2 and B3 is often gradational.

Burrows. – Several types of burrows are present: 1) *c.* 1 mm thick burrows similar to the dominant type in unit B2, 2) *c.* 3 mm thick, more or less vertical burrows which may branch (the most common type) and 3) rare *c.* 10 mm thick vertical burrows up to 20 cm long.

Marine fauna. – Unit B3 at the type section and at localities 38 and 75 (lower part) contains marine molluscs: *Astarte borealis*, *Cyrtodaria kurriana* and *Macoma* spp. The shells are commonly paired but not in life position. Foraminifera are extremely rare. Their thin calcareous tests may have been dissolved by organic acids produced in the organic-rich sediments.

Depositional environment. – The lower part of the

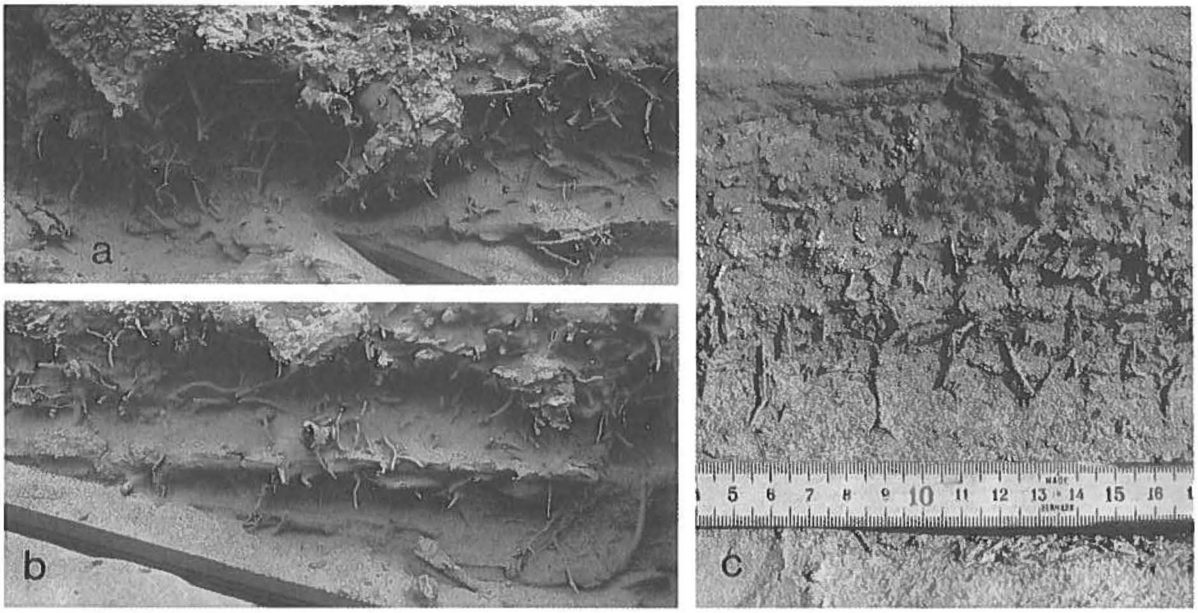


Fig. 26. Examples of burrows which are filled by more cohesive material than the surrounding sediment, which has blown away. a-b: Lower part of unit B3, locality 75, 99.5 m a.s.l. Pencil for scale. c: Unit B3, locality 50b, 116.5 m a.s.l. The burrows were produced by suspension feeding animals.

unit, with marine molluscs and physical as well as biogenic structures is of marine origin, deposited in an environment of medium energy, probably at the shoreface. The upper driftwood-bearing part was deposited at the beach zone, in the foreshore or backshore.

The presence of penecontemporaneous deformation structures may be indicative of rapid sedimentation.

The top of member B is in unconformable contact with overlying deposits which usually consist of a thin gravel layer, representing remains of glacio-fluvial deposits or till deposits. The till contains many erratics, such as gneisses from the Precambrian basement and quartzite and dolerite from the Independence Fjord Group. These rock types must originate in or beyond the inner part of Independence Fjord.

In some areas unit B3 is overlain by a homogeneous silt deposit (unit 12 of Funder & Hjort 1980). In the type section the contact is a thrust plane and the silt is shown to be overthrusted floes of member A by its content of foraminifers (R. W. Feyling-Hanssen, pers. comm.).

Concretions

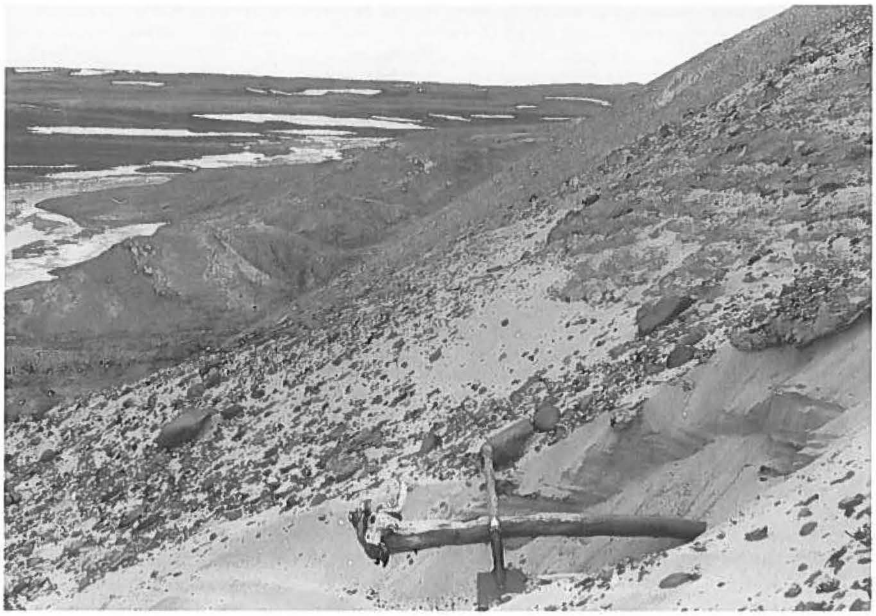
Although the sediments of the Kap København Formation are generally unlithified, certain horizons contain concretions. Two main types are found:

1) The muddy member A at a site *c.* 1 km northeast of locality 7 contains a great concentration of calcareous concretions of a spectacular, perfectly radial symmetry (Fig. 30). Many are of a simple form, but compound forms where two or more concretions have grown together also common. The simple concretions measure 1 to 6 cm across, and 0.5 to 3 cm in thickness. The surface is smooth, and the transition between sediment and concretion is sharp. No nucleus occurs, but the concretions are laminated.

   The concretions are formed by local cementation by $CaCO_3$. They are narrow (as seen in side view) where the sediment is most fine grained, and broader where it is more coarse grained. Apparently the growth rates were higher in the more coarse grained and more permeable laminae.
2) The sandy part of member B contains limonite concretions, mostly in connection with layers rich in plant detritus. These layers must have given rise to iron-rich waters penetrating nearby sand where the iron was precipitated. The concretions are flattened parallel to the lamination, usually elliptical in outline, and 2 to 10 cm long. The colour is reddish or greyish. At locality 57 the concretions are blackish and here they often are formed in connection with mollusc shells, trace fossils or pebbles.

Figs 31–32 show a correlation scheme for some major exposures within the Kap København area. The correlation is mostly based on lithology. The mollusc, Foraminifera and ostracode faunas show marked differences from south to north. Feyling-Hanssen (1987) believes that the change in character of Foraminifera assemblages is due to a substantial age difference, the north-

Fig. 27. Small *in situ* driftwood log of *Larix*. Unit B3, locality 69. Ladegårdsåen to the left (north). Note the shallow roots of the small tree. Member A sediments are exposed near the river.



ern assemblages being younger than the southern. However, intermediate assemblages were found in locality 75, and it is suggested here that the faunal difference is more a question of different, roughly coeval environments. Alternatively, what is here called unit B2 represents a repetition of two lithologically similar units.

Palaeobotany

Laboratory techniques

For macrofossil samples, sediment samples of 1 liter were normally used, but some larger samples of sediments which were particularly promising were also analysed. The sediment was washed through two sieves with meshes of 0.42 and 0.21 mm to remove fine-grained inorganic and organic matter. Tap water was used for washing. Most samples dispersed well in pure water, but some samples had to be soaked in cold 10 % NaOH for some days. Coarse-grained inorganic material was removed by decanting.

A small portion was transferred from the sieve to a petri dish, and a small amount of water was poured into it. Under a Wild M5 dissecting microscope the material was pushed from one end of the dish to the other, and identifiable remains picked out.

The material comprises mosses, seeds, fruits, leaves

Fig. 28. Lens of coarse organic debris with twigs, branches and some cones. The surrounding sediment consists of well sorted quartz sand. The stones on the exposure derive from the till cover. Unit B3, locality 119, *c.* 115 m a.s.l.

Table 4. Vascular plants represented by macroscopic remains in the Kap København Formation

- Equisetaceae
  - *Equisetum* sp.
- Selaginellaceae
  - *Selaginella selaginoides*
- Polypodiaceae
  - gen et sp indet
- Pinaceae
  - *Picea mariana*
  - *Larix groenlandii*
- Cupressaceae
  - *Thuja occidentalis*
- Taxaceae
  - *Taxus* sp.
- Nymphaeaceae
  - *Nuphar lutea* tp.
- Ranunculaceae
  - *Ranunculus hyperboreus* tp.
  - *Ranunculus* cf. *pallasii*
  - *Anemone* sp.
- Papaveraceae
  - *Papaver* sect. *Scapiflora*
- Betulaceae
  - *Betula nana*
  - *Betula alba* s.l.
  - *Alnus* cf. *crispa*
- Polygonaceae
  - *Oxyria digyna*
  - *Polygonum* sp.
  - *Rumex acetosa*
- Caryophyllaceae
  - *Cerastium* cf. *arcticum/alpinum*
  - *Stellaria* sp.
  - ?*Arenaria* sp.
  - *Melandrium affine/angustiflorum*
- Violaceae
  - *Viola* sp.
- Cruciferae
  - *Arabis* cf. *alpina*
- Salicaceae
  - *Salix reticulata*
  - *Salix* spp.
- Myricaceae
  - *Myrica arctogale*
- Ericaceae
  - *Arctostaphylos uva-ursi*
  - *Cassiope tetragona*
  - *Ledum palustre*
  - *Andromeda polifolia*
- Vacciniaceae
  - *Oxycoccus palustris*
  - *Vaccinium uliginosum* ssp. *microphyllum*
- Empetraceae
  - *Empetrum nigrum*
- Crassulaceae
  - *Sedum annuum*
- Fabaceae
  - *Hedysarum* sp.
- Rosaceae
  - *Potentilla* spp.
  - *Potentilla palustris*
  - *Dryas octopetala*
  - *Rubus chamaemorus*
  - *R. arcticus/saxatilis*
- Hippuridaceae
  - *Hippuris vulgaris*
- Geraniaceae
  - *Erodium* sp.
- Cornaceae
  - *Cornus stolonifera*
  - *C. canadensis*
  - *Cornus* sp. A
- Menyanthaceae
  - *Menyanthes trifoliata*
- Caprifoliaceae
  - *Viburnum* cf. *edule*
- Scrophulariaceae
  - ?*Linaria* sp.
- Potamogetonaceae
  - *Potamogeton natans*
  - *P.* cf. *perfoliatus/richardsonii*
  - *P.* cf *gramineus*
  - *P. alpinus*
  - *P.* cf. *vaginatus*
- Juncaceae
  - *Juncus* sp.
  - ?*Luzula* sp.
- Cyperaceae
  - *Carex* spp.
  - *Scirpus microcarpus*
- Gramineae
  - Gen. et sp. indet.
- Sparganiaceae
  - *Sparganium angustifolium* tp.
- Insertae sedis
  - *Aracites globosa*
  - *Carpolithes* sp. A

and twigs of vascular plants, remains of insects and crustaceans, molluscs, foraminifers etc. Because of this broad spectrum of different fossils no flotation technique was tried. The method is tedious and time consuming, but it ensures that all macrofossils are recorded.

The 0.42–0.21 mm fraction only contained few seeds, but oospores, and most remains of midge larvae and cladocerans, oribatids mites and coccoons of worms were found in this fraction.

Some of the SEM specimens were treated with HF to remove adhering mineral grains. They were dried at room temperature, mounted on stubs with double-sided cellophane tape, coated with gold and photographed with a Cambridge S-2 or a Phillips 515 scanning electron microscope.

Some of the results from the study of macroscopic plant remains are presented in Table 3 (in pocket) and Table 4.

Note that 1971XX numbers are GGU numbers (GGU, Geological Survey of Greenland, Grønlands Geologiske Undersøgelse), while 532XX, 566XX, 567XX and 649XX numbers are GCI numbers (Geological Central Institute). The fossils are stored at the Geological Museum, University of Copenhagen. MGUH numbers denote specimens housed in the type collection of the Geological Museum.

Some material of macroscopic plant remains was kindly provided by J. Böcher.

Samples for pollen analysis were prepared by standard methods: boiling with 10% KOH for 10 minutes, treatment with cold 10% HCl, decanting and coarse sieving, boiling with 40% HF for 30 minutes, treatment with hot 10% HCl for 15 minutes, acetolysis for 1 minute in a 9:1 mixture of acetic anhydride and concentrated H_2SO_4 and mounting in silicone oil.

A Leitz Laborlux microscope was used for counting.

For determination of loss on ignition the samples were dried and ignited at 550°C for 3 hours (Dean 1974). In the fine-grained marine sediments of unit B2 a substantial part of the ignition loss probably originates from water associated with clay minerals (Mackereth 1966).

Preservation and taphonomy

Many of the macroscopic plant remains discussed below are slighty carbonised which probably explains why larger, well lignified and more durable plant remains usually are well preserved, whereas small and thin

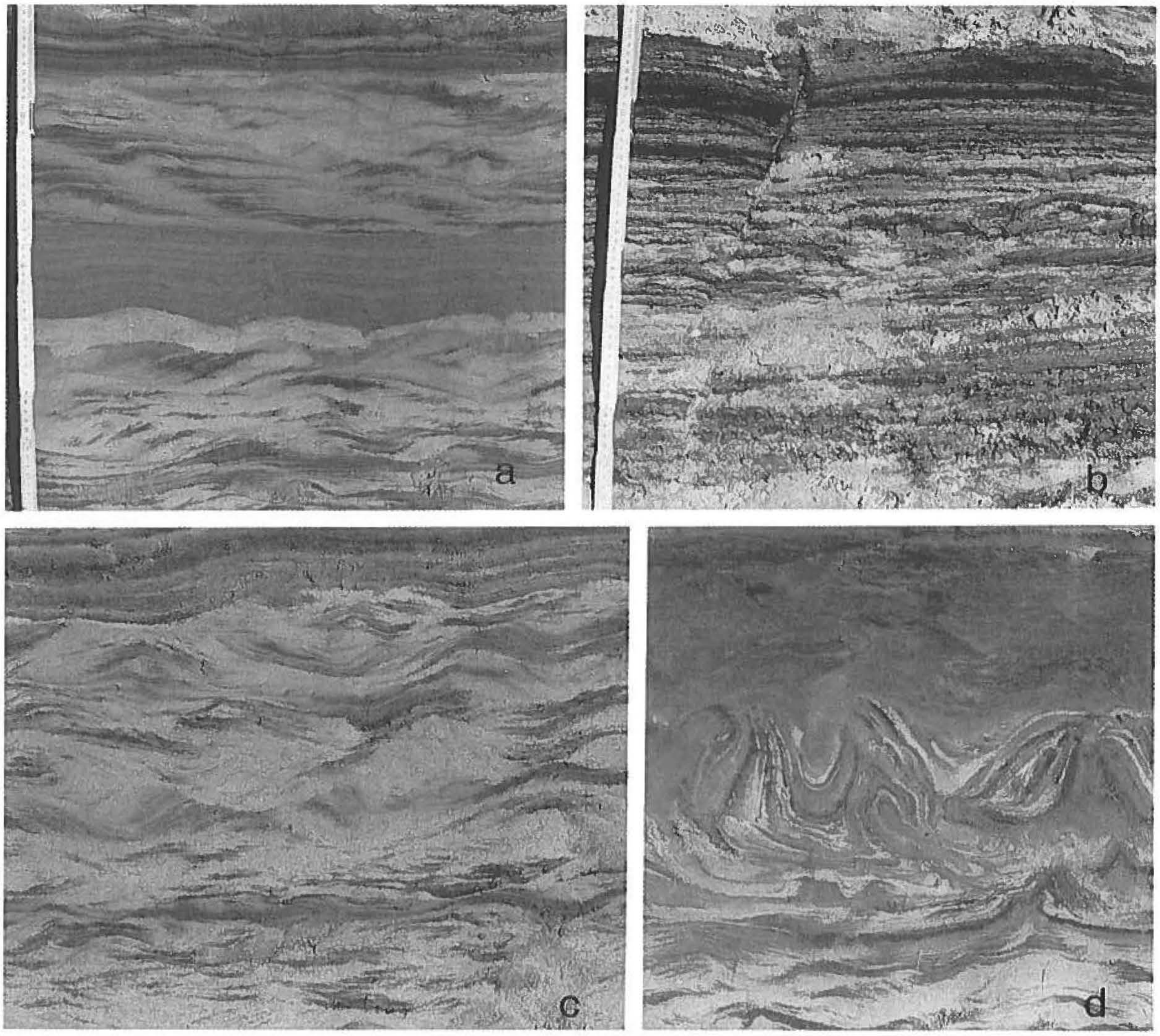


Fig. 29. Unit B3, locality 50b (unit 10 of Funder & Hjort 1980) a: Heterolithic sediments showing climbing ripple lamination and draped lamination, 124.5 m a.s.l. b: The most organic rich sediments of the type section, 127 m a.s.l. c: Heterolithic sediments consisting of fine sand and finer grained, organic rich laminae showing wave ripple lamination except for the top part which show draped lamination, 125.5 m a.s.l. d: Convoluted, heterolithic sediments, 126.5 m a.s.l.

walled degradable seeds and little lignified leaves are poorly preserved. Thus, while fruit stones of *Empetrum nigrum* are common, only one poorly preserved leaf was recovered. The coriaceous leaves of *Vaccinium uliginosum* are abundant, while their thin walled fruit stones were not found. In contrast, *Empetrum nigrum* leaves and *Vaccinium uliginosum* fruit stones are common in Holocene lake sediments of West Greenland (Fredskild 1983).

All of the conifer cones display evidence of transport and abrasion. Some wood fragments are rounded and abraded, perhaps by prolonged to-and-fro rolling due to exposure to wave action on the beach, by long shore transport or by transport in the bed load of rivers. Most plant remains from fine-grained sediments are compressed, e.g. the twigs up to 75 %, and the surface of the softer plant remains show evidence of sand grain impresssions.

Smaller coriaceous leaves and the moss fragments show little sign of wear; they were probably transported in the suspension load of the rivers. Some plant remains are coated by ferruginous matter.

Chitineous remains of animals, such as head capsules, elytra and pronota of beetles, midge larvae head capsules, shells and head shields of cladocerans, oribatid mites and egg cocoons are well preserved, but disarticulated.

The presence of benthonic faunal remains, e.g. molluscs, ostracodes, foraminifers and burrows of polychaetes (?), in the same sediments as plant fossils show

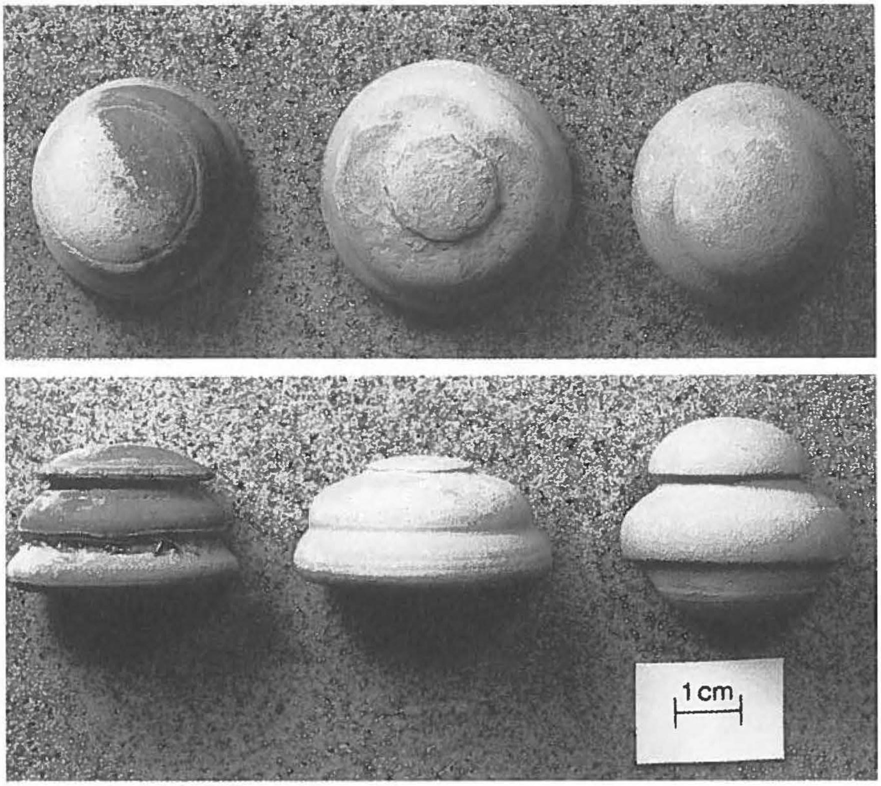


Fig. 30. Three selected carbonate concretions from member A, seen from above and in side view.

that aerobic conditions prevailed at the bottom and in the topmost parts of the sediments during most of the depositional period. The plant remains were therefore not preserved due to anoxic conditions, but rather due to high sedimentation rates, which lead to quick burial of the organic fragments, thereby protecting them from degradation by oxidising bottom waters.

The degree of preservation of the pollen grains is variable but generally poor. The pollen grains show physical and biological degradation, and types such as *Betula*, Lycopodiaceae and *Dryopteris* type may be overrepresented for this reason and because of oxidation effects.

No autochthonous plant remains have been located in the Kap København area. All the plant remains show different degrees of wear and hydraulic sorting.

Most of the cones and many of the fruit types were found in organic detritus dominated by twigs and small wood pieces. Other accumulations consist of virtually nothing but *Scorpidium* type moss fragments, which have a very low settling velocity in water (Spicer 1980). All gradations exist between these two extremes, and it is these less sorted assemblages that contain the greatest variety of plant remains. The more diverse assemblages were probably deposited during relatively high-energy periods, while the less diverse assemblages were formed through non-catastrophic, gradual accumulation (Collinson 1983). Much of the detritus occurs in scours. Once eroded, these scours formed small, local low-energy environments where the organic matter could accumulate.

While Quaternary palaeobotanists usually work on lake, peat or fluviatile deposits, pre-Quaternary students often work on deltaic and nearshore marine deposits. It is well known from studies of recent lake sediments that most plant remains accumulate near the shore (e.g. H. H. Birks 1973). Remains of upland plants are mostly carried to the lake by streams and accumulate near the mouths of inflows (e.g. Drake & Burrows 1980).

The writer believes that transport by streams and rivers was of prime importance with respect to diaspores of water plants and moss fragments in the Kap København Formation, while the small, coriaceous leaves might partly have been transported by wind (Glaser 1981). Little is known about the distances over which diaspores and leaves may be transported. According to Collinson (1983) some material can be transported by rivers up to 80 km without evident wear. The plant remains in the Kap København Formation undoubtedly provide a regional picture of the vegetation and flora.

Small seeds are very sparsely represented among the plant remains. Two explanations for this feature may be offered: 1) Small seeds are very buoyant and might float away to be deposited somewhere else. 2) Most small seeds have a thin testa and are more subject to degrada-

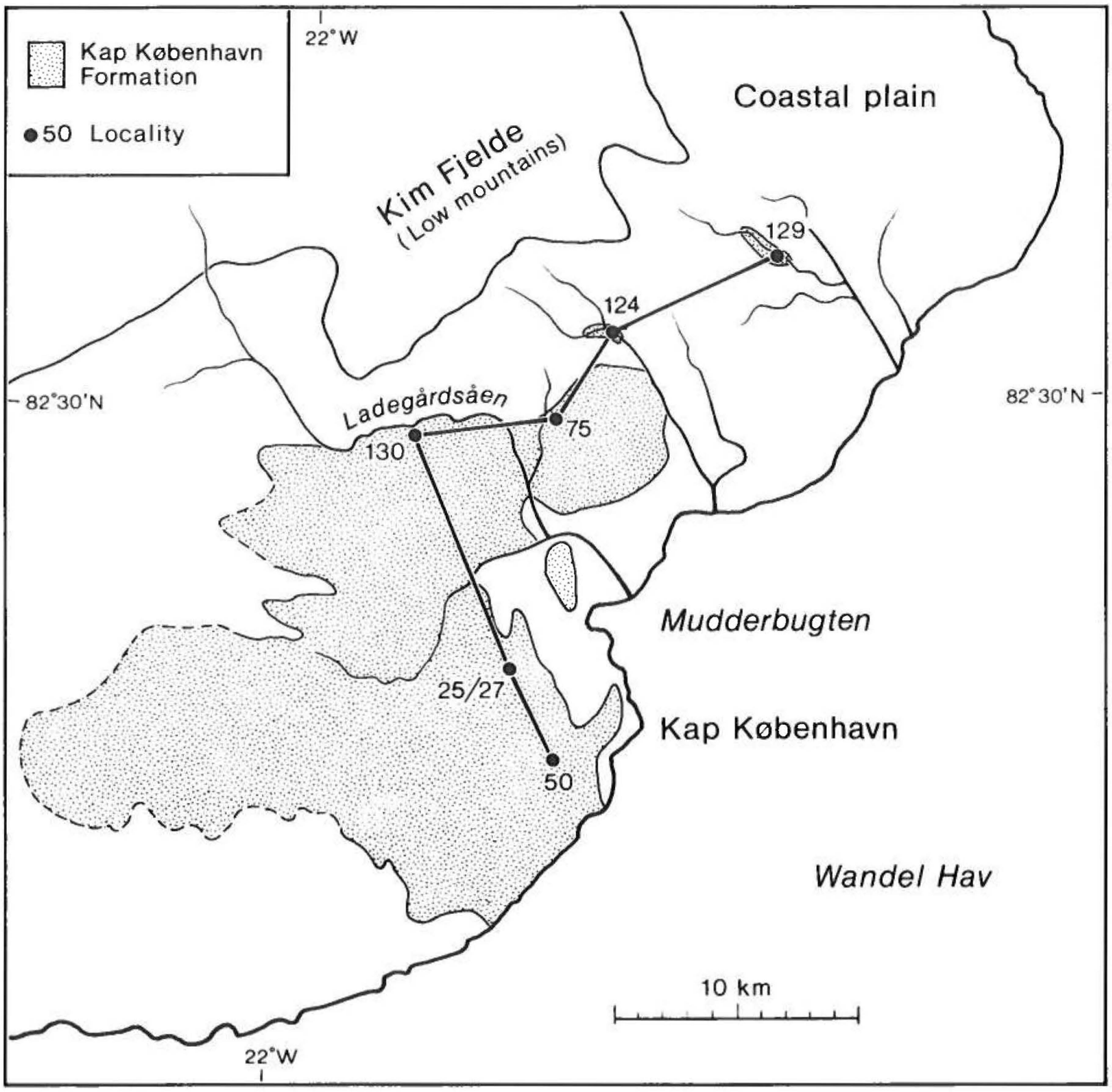


Fig. 31. Distribution of the Kap København Formation, modified from Funder et al. (1984). The Kim Fjelde consists of Carboniferous to Cretaceous sediments which form a landscape of elongate hills and low mountains with a general increase in height to the north, where they reach an altitude of 900 m. The location of the main sections as shown in Fig. 32 is also given.

tion (both physically and biologically) than larger seeds. The generally poor preservation of the small seeds and the common presence of microscopic plant remains (pollen and spores) in the Kap København Formation point to the second explanation.

Pollen grains are hydrodynamically equivalent to fine-grained silt (Muller 1959) and it is obvious from the sedimentology that hydrodynamic sorting was an important process. The silty marine unit B2 contains a fair density of pollen grains, whereas the well sorted sand is devoid of pollen since apparently the pollen grains were winnowed away. Most of the pollen grains were probably flushed into the sea by rivers along with the clastic material, as has been shown in studies of modern marine sediments (e.g. Heusser & Balsam 1977, see also discussion by West (1980)). Unit B2 contains a fair amount of fresh water diatoms and frequent sclerotia of *Cennococcum geophilum*. Dead sclerotia of this fungius can float on water for long periods (Trappe 1969), and some probably floated offshore before finally sinking to the bottom. Some pollen grains were undoubtedly transported to the sea by winds, but the scarcity of bisaccate pollen types, – *Picea* and *Pinus* – may indicate that this was only a minor part of the pollen influx (Mudie 1982).

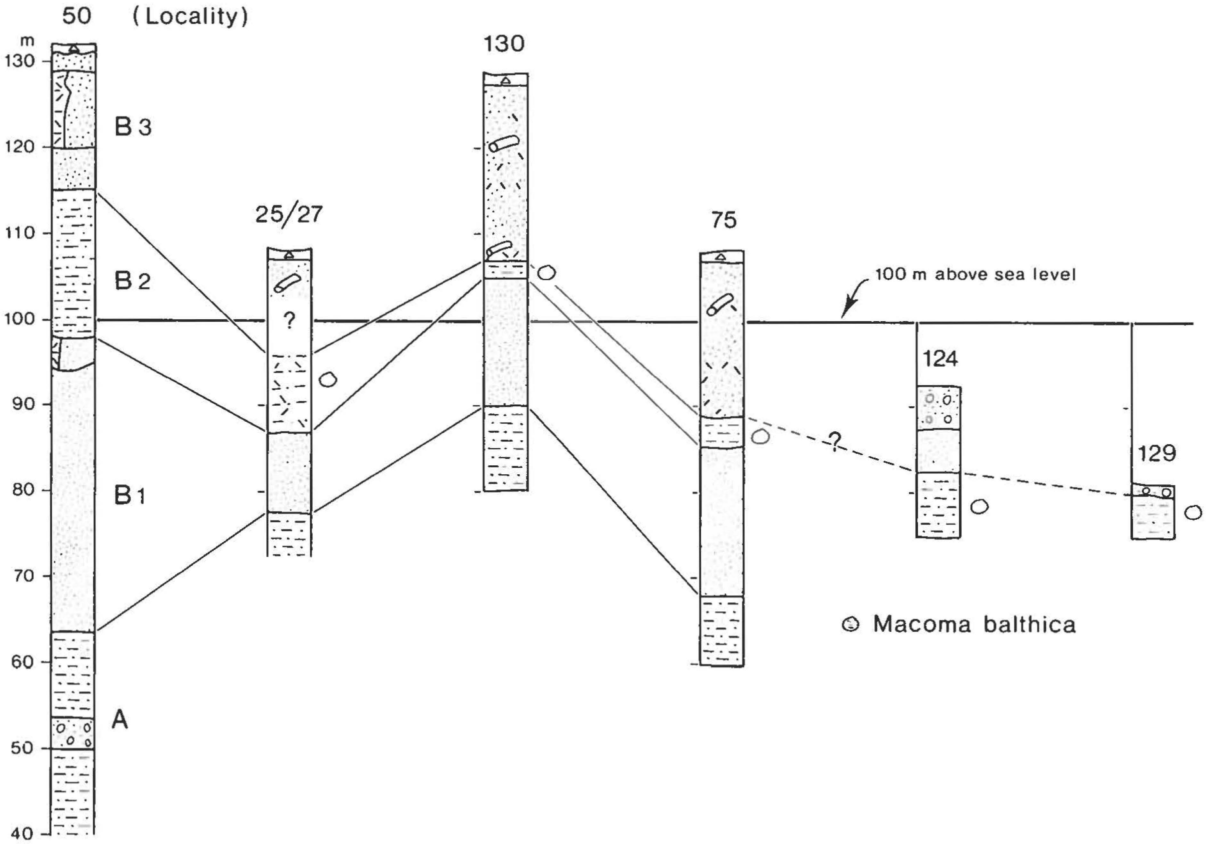


Fig. 32. Lithology and correlation of the Kap København Formation. For legend see Fig. 3. For location of sections see Figs 2 and 31.

Macroscopic plant remains

(seeds, fruits, leaves etc.)

Thallophyta

Remains of thallophytes (Bacteria, Algae and Fungi) were not studied in any detail, but a number of macro- and microscopic remains were noted. Below follows a list of thallophytes represented by macroscopic remains, with some brief notes.

Bacteria: Actinomycetales

Proactinomyces alni (Peklo) Krass
Fig. 33a
Material. – Two nodules.
Remarks. – The figured nodule is hemispherical in shape and measures *c.* 14 mm across. It corresponds closely to modern *Alnus* root nodules (O. G. Petersen 1920, p. 316). The other nodule is much smaller, but it is probably also an *Alnus* root nodule.

Algae: Characeae

Tolypella cf. *nidifica* (O. Müll.) A. Br.
Figs 33b-c
Material. – 21 oospores from GCI 53203, 53214, 64965 and 64991 (unit B3).
Remarks. – The oospores are yellow-brown, subspheric, terete, (265-) 315 (-345) µm long and (230-) 280 (-320) µm broad (n = 15). The membrane is smooth, thin and translucent, with 7 or sometimes 6 thin but prominent ridges; fossa is about 50 µm across (terminology follows Wood & Imahori (1965)).

Because of their small size, non-compressed shape and few ridges the oospores can be referred to *Tolypella* cf. *nidifica*, according to the keys and the broad species concept of Wood & Imahori (1965).

The present day Characeae flora of Greenland comprises three species of *Chara* and two species of *Nitella*, following the taxonomy of Wood & Imahori (1965)(T. Böcher 1954, Lægaard 1960, Molenaar 1976).

Recent distribution. – At present *T. nidifica* is distributed between 45°N and 60°N (Wood & Imahori 1965).

Ecology. The plant which is 2–20 cm high grows in hard water ponds, lakes and streams and in brackish

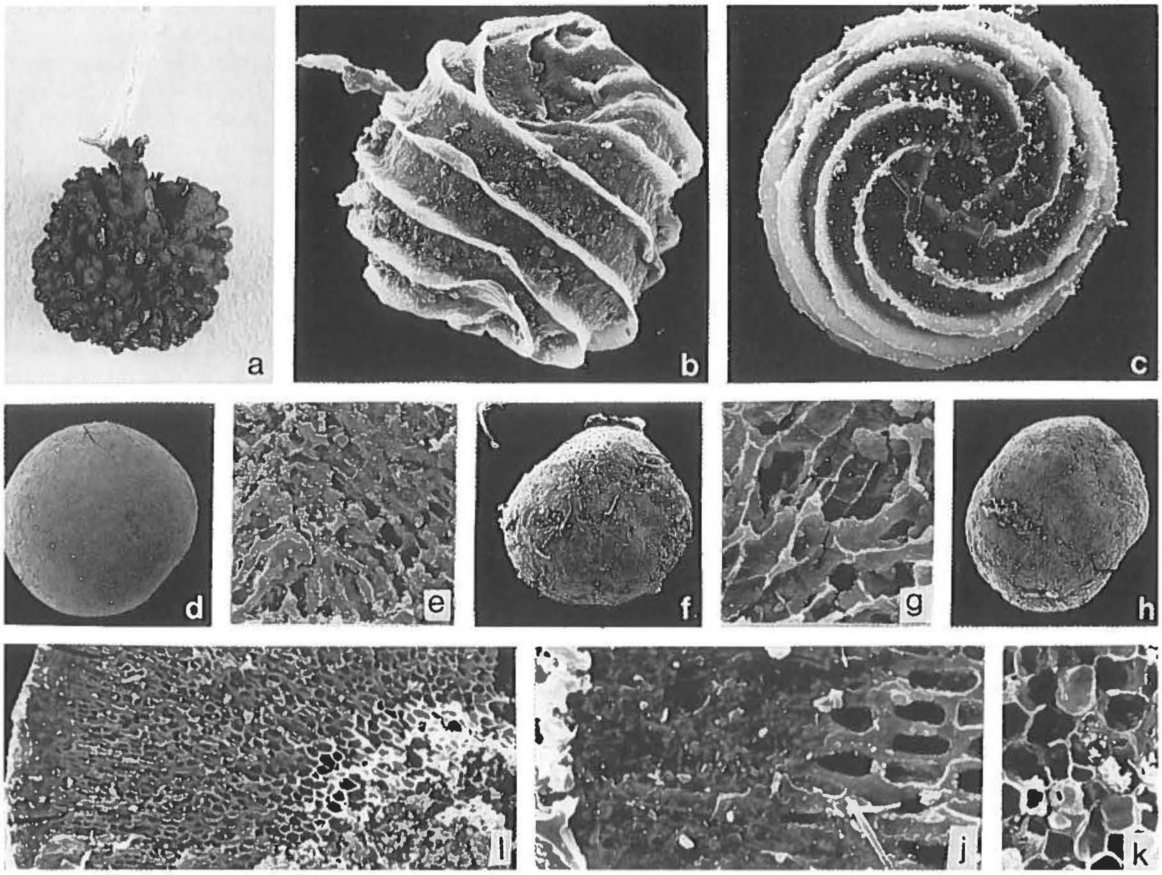


Fig. 33. Thallophyte remains. a: *Alnus* root nodule caused by *Proactinomyces alni*, MGUH 19043, GCI 53214, locality 122, x1.8. b-c: *Tolypella* cf. *nidifica* oospores. b: Side view, MGUH 19044, GCI 64991, locality 77, x160. c: Polar view, MGUH 19045, GCI 64991, locality 77, x14.8. d-k: *Cennococcum geophilum* sclerotia. d: MGUH 19046, GCI 64991, locality 77, x150. e: Surface detail of d, x380. f: MGUH 19047, GCI 64976, locality 157, x60. g: Surface detail of f, x710. h: Sclerotium of irregular shape, MGUH 19048, GCI 64976, locality 157, x53. i: Part of sectioned sclerotium, MGUH 19049, GCI 53214, locality 122, x112. j: Detail of the outer part of i, x810. k: Detail of inner part of sectioned sclerotium, MGUH 19050, GCI 53214, locality 122, x355. All figures are SEM micrographs except a which is a light photograph.

water (Olsen 1944, Wood 1967). Like other Characeae it normally grows on a soft, muddy bottom.

Fungi: ?Pyrenomycetidae

Material. – A number of fruit bodies.
Remarks. – Some leaves of *Salix reticulata* and *Betula nana* bear spherical dark fruit bodies of Fungi, probably perithecia of Pyrenomycetidae (identified by H. Dissing). The fruit bodies do not contain spores, and can therefore not be identified more precisely.

Fungi imperfecti

Cennococcum geophilum Fries
Figs 33d-k
Material. – About 8500 sclerotia.
Remarks. – Sclerotia of the imperfect fungus *C. geophilum* (syn. *C. graniforme* (Sow.) Ferd. & Winge, see Jensen 1974) are extremely common in the macrofossil samples, and they are even found quite commonly in unit B2, where they also occur in the Foraminifera samples (R. W. Feyling-Hanssen, pers. comm.).

The sclerotia are black, and vary in size from 0.1 mm to *c.* 3 mm. The smaller are spherical, the larger are more irregular in shape.

Recent distribution. – *C. geophilum* is common in the northern hemisphere, especially in temperate and arctic climates, and it probably also occurs in the southern hemisphere (Jensen 1975). It has been found in a number of Holocene peat deposits in Greenland (Fredskild 1973, 1983, 1985, Bennike 1983) and it probably occurs throughout the sub-continent.

Ecology. – *C. geophilum* is a common facultative ecto-mycorrhiza forming fungus growing under various ecological conditions. It usually forms mycorrhiza with woody plants, but it may also do so with herbaceous plants. It lives in forests, heaths, meadows, in moss polsters or in arable soil (Ferdinansen & Winge 1925, Mikola 1948, Jensen 1975).

Notes on history. – The sclerotia are frequently encountered in fossil material, but they are often recorded only as sclerotia or fungal sclerotia, especially when dealing with pre-Quaternary floras (e.g. Friis 1976, Szafer 1947, Matthews 1974).

Tracheophyta

Table 3 is a list of vascular plants represented by macroscopic remains. Terminology of family names follows the current "International Code of Botanical Nomenclature" (Greuter et al. 1988). Leaf terminology follows Dilcher (1974). The notes on modern distribution and ecology were primarily extracted from a number of regional floras covering the northern circumpolar area. When the entire range of a species is considered, it often appears that its ecological tolerance is rather large. Therefore the notes on ecology are given only in general terms.

Pteridophyta

Equisetaceae

Equisetum sp.
Figs 34 a-c
Material. – Numerous rhizomes.
Remarks. – The distinctive, shiny, grooved rhizomes are common as are also rootlets. No aerial stem fragments with visible stomata were noted, but they may have been overlooked. No attempt was made to identify the remains.

Recent distribution and ecology. – The genus comprises *c.* 15 extant species, of which seven reach the Arctic today. The genus is very widespread geographically and ecologically. Two species grow at Kap København today.

Selaginellaceae

Selaginella selaginoides (L.) Link
Figs 34d-e
Material. – One megaspore from GCI 56685, locality 74, unit B3.
Remarks. – The megaspore measures 0.46 mm across. The ornamentation is verrucate with bacculae.

The spore is distinguished from *Isoëtes* spores by the absence of an equatorial ridge. It matches the small, tetrahedral spore type of Watts (1959), which was thought to represent immature or perhaps aborted sterile megaspores of *S. selaginoides*. However, the size of mature *S. selaginoides* megaspores may vary considerably, from 0.48 to 0.92 mm according to Minaki (1984).

Recent distribution. – *S. selaginoides* has a disjunct circumpolar range (Fig. 35). It is distributed in the boreal and low arctic zones, most commonly in mountain areas. In Greenland it is confined to the southwesternmost part except for an isolated occurrence in the southeast. Its range as depicted in Fig. 35 has been slightly modified by Hultén & Fries (1986).

Ecology. – *S. selaginoides* is a small moss-like plant with microphyllous leaves which is most common in damp sites, such as mossy areas, grasslands, heaths, fens, open scrubs and open woods. It shows some preference for calcareous soil.

Note on history. – Its fossil record from the Quaternary of Europe closely follows that of *Betula nana* (Tralau 1963). It was very common and widespread during the late glacial in northwestern Europe.

Polypodiaceae s. l.

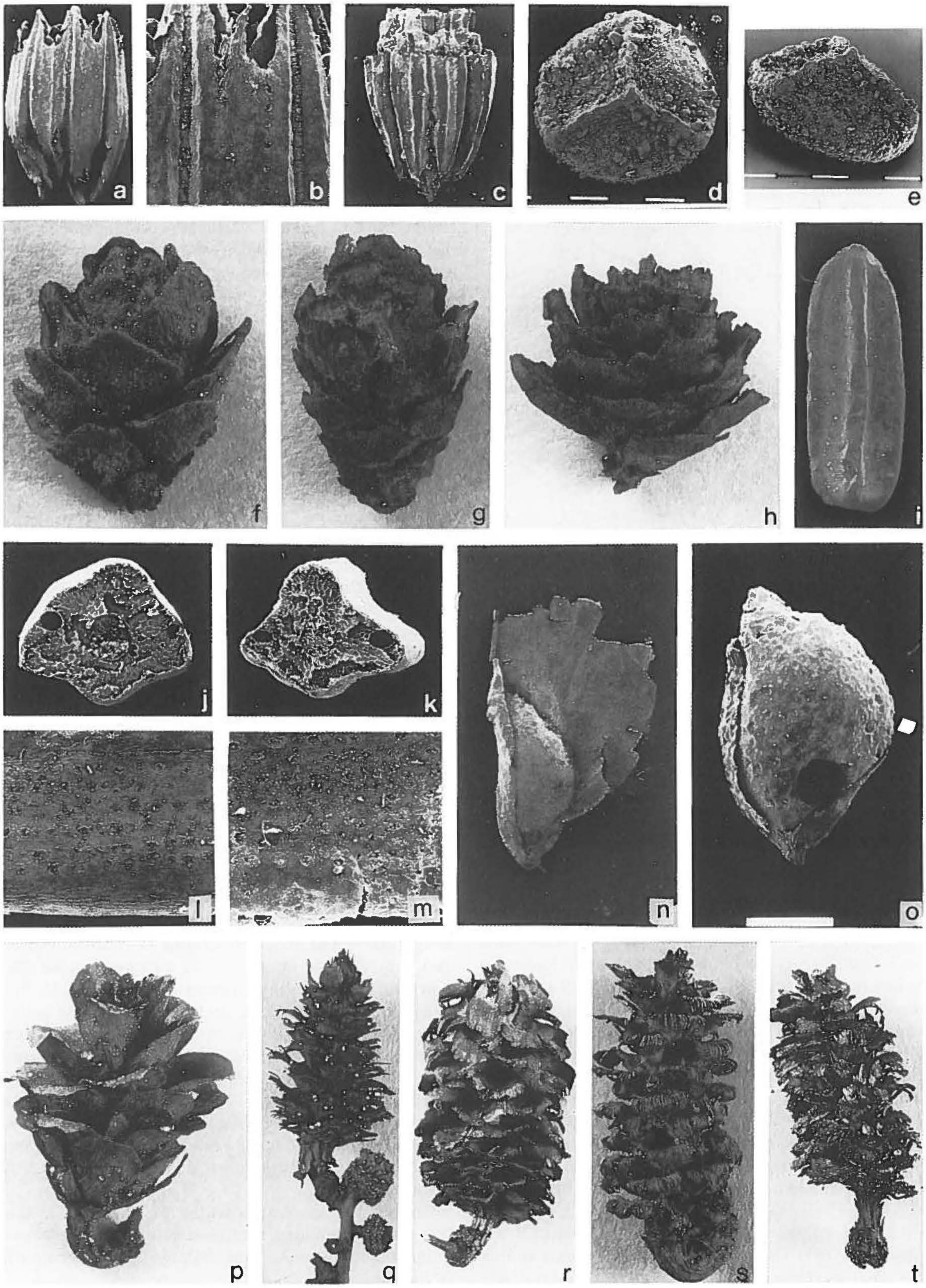
Material. – Two dispersed sporangia from GCI 53203, locality 119, unit B3.
Remarks. – The sporangia are identified as Polypodiaceae s. l. As no spores were found in the sporangia, no further identification was attempted (cf. Collinson 1978).

Gymnospermae

Pinaceae

Picea mariana (Mill.) B.S.P.
Figs 34f-m
Material. – 3 cones (GCI 56567, 64980 and 64990), some cone scales, seeds, about 360 needles and needle fragments, wood, twigs and pollen.
Remarks. – The cones are broadly elliptic in outline. They measure 18x11, 15x12 and 12x10 mm (length x

Fig. 34. a-c: *Equisetum* rhizome remains. a: MGUH 19051, GCI 53267, locality 132, x10.0. b: detail of a, x30. c: MGUH 19052, GCI 53267, locality 132, x11.6. d-e: *Selaginella selaginoides* megaspore, MGUH 19053, GCI 56685, locality 74. d: Proximal face with triradiate laesura and blunt turbercles, x53. e: Oblique side view, x61. f-m: *Picea mariana* remains. f: Cone, MGUH 19054, GCI 64990, locality 77, x3. g: Cone, MGUH 19055, GCI 64980, locality 157, x2.6. h: Cone, MGUH 19056, GCI 56667, locality 77, x2.7. i: Needle, MGUH 19057, GCI 56692, locality 119, x10.6. j-k: Cross sections of needles. j: MGUH 19058, GCI 56692, locality 119, x27. k: MGUH 19059, GCI 56692, locality 119, x24. l-m: Ventral portions of needles with rows of stomata. l: MGUH 19060, GCI 56692, locality 119, x60. m: MGUH 19061, GCI 56692, locality 119, x85. n-o: *Larix groenlandii* seeds. n: MGUH 19062, GCI 53214, locality 122, x8.4. o: Seed with fly hole of *Megastigmus* sp. (Hymenoptera), MGUH 19063, GCI 53267, locality 132, x14.4. p-t: *Larix groenlandii* cones. p: Holotype, MGUH 19064, GCI 53214, locality 122, x2.1. q: MGUH 19065, GCI 56692, locality 119, x1.6. r: MGUH 19066, GCI 53214, locality 122, x1.7. s: MGUH 19067, GCI 53214, locality 122, x2.2. t: MGUH 19068, GCI 56667, locality 77, x1.6. All figures are SEM micrographs except f-h and p-t which are light photographs.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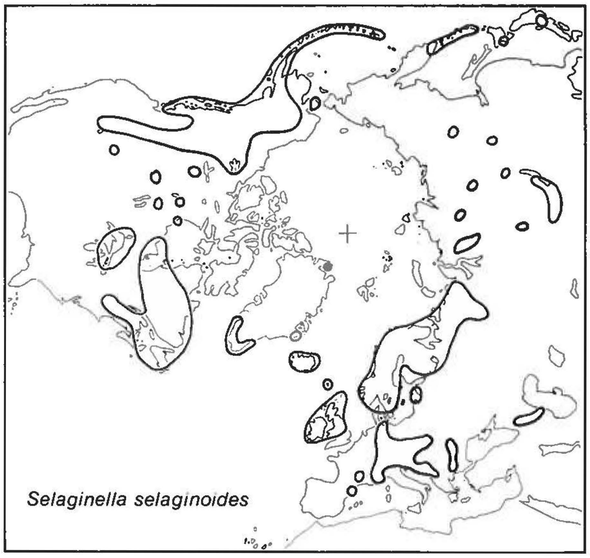


Fig. 35. Modern geographical range of *Selaginella selaginoides* based on Hultén (1958).

breadth). The longest cone bears *c.* 30 cone scales; the thick cone scales are rhombic in shape, up to 9 mm long and 7 mm broad. The bracts are small and thin, up to 3 mm long and 1 mm broad. No stalk is preserved.

The seed body of *Larix* seeds are firmly attached to the seed wing, while in *Picea* the seed body and the seed wing easily separate. Also the seed body of *Larix* is larger than that of *Picea*, but both vary considerably in size and shape. The majority of seeds in the Kap København material were identified as *Larix*, a few as *Picea* and a rather large fraction of worn seed bodies as *Larix* or *Picea*. In Table 3 these three groups are united as are also isolated cone scales of *Larix* and *Picea*.

The size and morphology of the needles vary considerably, from short, robust, dorsi-ventrally compressed needles with rounded apices to long, more slender needles with acute or even acuminate apices, although the first type dominates. The needles most often have 5–6 rows of stomata on each ventral face and 4 on each dorsal face. Twenty leaves of different morphology were studied in serial transverse sections. All had two continuous lateral resin ducts running from base to apex.

There is some disagreement about the identification of *Picea* needles. Some students of macroscopic plant fossils distinguish needles of *P. mariana* and the closely related *P. rubens* Sarg from needles of *P. glauca* (Moench) Voss by the presence of two lateral resin ducts (J. H. McAndrews, pers. comm; H. J. B. Birks 1976). However, many others consider this character unreliable, and do not identify *Picea* needles beyond the generic level (R. G. Baker, pers. comm.; J. V. Matthews, pers. comm.; H. E. Wright, pers. comm.; Watts & Winter 1966). The same disagreement exists among neo-botanists (Durell 1916, Marco 1932, Duman 1957).

In order to clarify the problem the writer has examined a number of needles taken from herbaria specimens at the Botanical Museum in Copenhagen (Table 5). The needles were kept in separate envelopes and probably originate from only a limited part of each tree. *P. mariana* and *P. rubens* frequently hybridise, while hybrids between *P. mariana* and *P. glauca* are rare (Hultén 1968). No needles of hybrids were examined.

In general *P. mariana* needles are short with rounded apices and flattened cross-section, while needles of *P. glauca* are long, slender with acute apex and quadrangular cross-section. *P. rubens* needles (only two collections) are large, flattened with rounded apex. The anatomical results are in complete agreement with Duman (1957): needles of *P. mariana* and *P. rubens* have two continuous resin ducts running from base to apex, while the needles of *P. glauca* may have resin sacs up to 3 mm long. Resin ducts were not observed in *P. glauca* needles, but often two resin sacs are located at the same level, and a cross-section at this level would show two resin cavities resembling true ducts. This is undoubtedly what is figured by Marco (1932, plate 9, fig. 1).

The needles from Kap København have two resin ducts and therefore are not from *P. glauca*. Considering the size of the needles from Kap København (Fig. 36) and the modern range of *P. mariana* and *P. rubens*, it is concluded that they most likely come from *P. mariana*. Also the size of the cones from Kap København corresponds to *P. mariana* cones, while they are smaller than *P. rubens* cones.

Recent distribution. – *Picea mariana* (black spruce) is a major component of the boreal forests of North America (Fig. 37).

Ecology. – This spruce grows primarily on poorly drained sites, such as are found in wet land areas and on permafrost. It reproduces commonly through layering: by rooting of lower branches that are pressed against the ground and produce roots and erect stems (Stanek 1961).

Larix groenlandii Bennike, sp. nov.
Figs 34n-t, 38a-e

Diagnosis. – The cones are elliptic to ovate in outline and very variable in size: 12–32 mm long (mean 22.7 mm) and 8–17 mm broad (mean 12.1 mm) (n=44, Fig. 39). They bear numerous, up to about 60, cone scales, which are broadly obovate, up to 7 mm long and 7 mm broad. Their margin recurves downwards. The cone scales are grooved when eroded, and they bear reddish, brittle hairs at the base. The bracts are more or less broken, but they are strong, large and were undoubtedly longer than the cone scales. The cones are often preserved with a short, thick, curved stalk with leaf-scars.

The seeds (exclusive of wing) are D-shaped in outline, 2.5–3.0 mm long. Some seeds retain the basal part of the membranaceous wing. A few of the seeds are still in the cones.

Table 5. Measurements of *Picea* needles

	Length (mm)	Breadth (mm)	Stomatal rows ventral/dorsal face	Resin ducts
Picea glauca (n=10)				
Nova Scotia, Canada	12(10–14)	1.0(0.9–1.2)	4/3(4/3–3/2)	0
Nova Scotia, Canada	12(10–13)	1.0(0.9–1.1)	4/3(4/4–3/2)	0
Alberta, Canada	10(8–13)	1.6(1.4–1.8)	4/3(5/4–3/2)	0
Michigan, U.S.A.	13(10–15)	1.1(0.9–1.4)	4/3(5/4–4/2)	0
Michigan, U.S.A.	15(13–17)	1.0(0.9–1.2)	4/3(4/3–3/2)	0
Picea mariana (n=10)				
British Columbia, Canada	8 (6–10)	1.6(1.2–2.1)	5/3(7/4–4/2)	2
Wisconsin, U.S.A.	7 (6– 8)	1.1(1.0–1.2)	6/3(6/3–5/3)	2
N.W. Territories, Canada	8 (6– 9)	1.5(1.2–1.9)	6/4(6/5–5/3)	2
Quebec, Canada	11(8–12)	1.8(1.5–2.0)	5/3(6/4–5/2)	2
Alberta, Canada	8 (6– 9)	1.2(1.0–1.5)	5/3(7/3–4/2)	2
Picea rubens (n=10)				
North Carolina, U.S.A.	10(9–12)	1.3(1.2–1.4)	5/2(6/4–4/2)	2
Nova Scotia, Canada	15(12–18)	1.6(1.4–1.8)	6/3(7/4–5/3)	2
Fossil needles from the Kap København Formation (n=44, 56692)				
	6(4–10)	1.4(0.8–2.1)	6/4(8/5–4/2)*	2**

*n=10 **n=20

Most of the thin, flat semi-translucent needles are broken into small pieces. The complete needles measured up to 20 mm in length.

Wood, branches, twigs and trees of *Larix* are common in the upper part of the Kap København Formation. The trees are small and usually of stunted growth form.

Holotype. – MGUH No. 19064, GCI 53214, Fig. 34p

Type locality. – Locality 122, Kap København, North Greenland.

Type stratum. – Unit B3, the Kap København Formation.

Age. – Plio-Pleistocene.

Material. – Numerous twigs, some with cones, *c.* 95 cones, cone scales, seeds, *c.* 1200 needles and needle fragments, wood fragments and tree trunks.

Remarks. – Because the bracts are longer than the cone-scales, the *Larix* cones from Kap København belong in the section *Multiseriales* Patschke which comprises the following extant species according to Ostenfeld & Larsen (1930): *Larix griffithiana* (L. & G.) Carr., *L. mastersiana* Rehd. Wils., *L. potanini* Batal., *L. lyallii* Parl. and *L. occidentalis* Nutt. All species within this section are confined to small mountain areas, the first three in southeast Asia, the last two in the Rocky Mountains. The other species of *Larix* belong in the section *Pauciserialis* Patschke. Many of these species, such as *L. laricina* (Du Roi) K. Koch of North America, *L. sibirica* Ledb. and *L. gmelini* (Rupr.) Gordon of northern Asia are distributed over enormous areas.

The cones of *L. griffithiana*, *L. mastersiana*, *L. potanini*, *L. lyallii* are larger or much larger than the cones from Kap København. The cones of *L. occidentalis*, which bear about 65 cone scales, are 25–35 mm long and 20–30 mm broad, i.e. somewhat larger than the cones from Kap København. In addition, this species which grows well below the local alpine tree line attains heights of 50–80 m, and it is of slender growth form (Simak 1971, Ostenfeld & Larsen 1930).

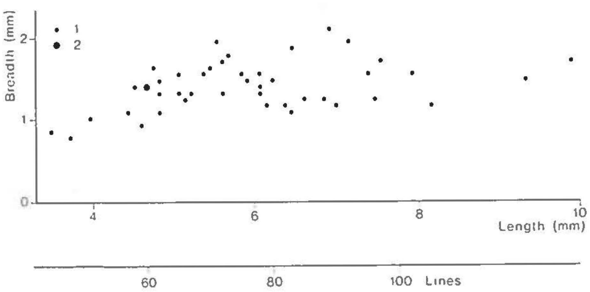


Fig. 36. *Picea mariana*. Relationship between leaf length and breath in 44 leaves from GCI 56692. Large dots indicate two specimens of same size. Mean length is 60 mm, mean breadth is 1.4 mm.

From Siberia a number of extinct *Larix* species have been described, of which *L. omoloica* Dorofeev and *L. minuta* (Vassk.) Dorofeev resemble the *Larix* from Kap København. The cones of *L. minuta*, however, only attain a length of 14 to 18 mm, and the cone-scales are reniform (Vas'kovskij 1956). It should be noted that *Larix minuta* was originally described as *Tsuga minuta*. The new combination *Larix minuta* has not been formally proposed. The cones of *L. omoloica* were described by Dorofeev (1969), and the species was formally established in 1972 (Dorofeev 1972). The species is also described by Bobrov (1972). The cones are elliptic to ovate in outline, 23–36 mm long (usually 26–30 mm) and 16–22 m broad. The numerous, thin cone

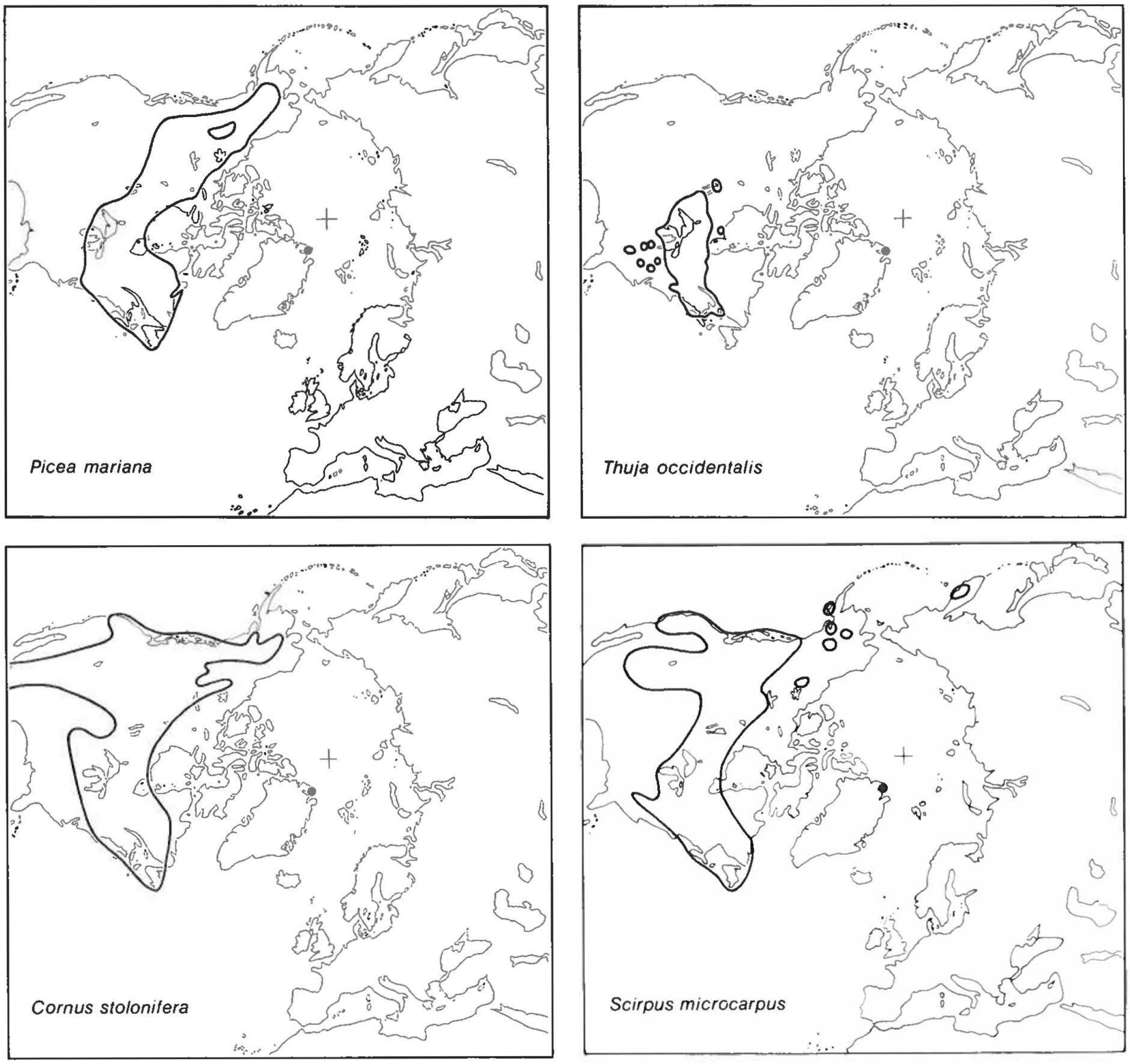


Fig. 37. Modern geographical range of selected species of Nearctic boreal distribution. Range of *Picea mariana* and *Thuja occidentalis* based on Little (1971), range of *Cornus stolonifera* and *Scirpus microcarpus* based on Hultén (1968).

scales are somewhat spoon-shaped. The bracts are broken, but they are probably longer than the cone scales.

The cones from Kap København are variable in size, but generally smaller than the cones of *L. omoloica*. The cone scales are also smaller and more numerous, as compared with the figures of Dorofeev (1972, plate 1, fig. 1–23).

The *Larix* cones from Kap København resemble the cones of *L. omoloica*, but they are sufficiently different from this species and from *L. occidentalis* to be separated as a distinct species named *L. groenlandii*.

Notes on history. – *L. minuta* has tentatively been identified from a number of Neogene floras in northern North America (J. Wolfe, J. V. Matthews, C. Schweger, R. Stockey, pers. comm.).

Larix cf. *omoloica* Dorof. cones were listed from the Beaufort Formation, Duck Hawk Bluffs, southwestern Banks Island by Hills (1975). Unfortunately these cones have not been described. The same applies to a *Larix* sp. cone listed by Hills & Matthews (1974) from the Beaufort Formation on Meighen Island.

Larix groenlandii cones have recently been identified from Late Cainozoic sediments near Strathcona Fjord, eastern Ellesmere Island (O. Bennike & J. V. Matthews, unpublished).

Some wood from the Beaufort Formation, Ballast

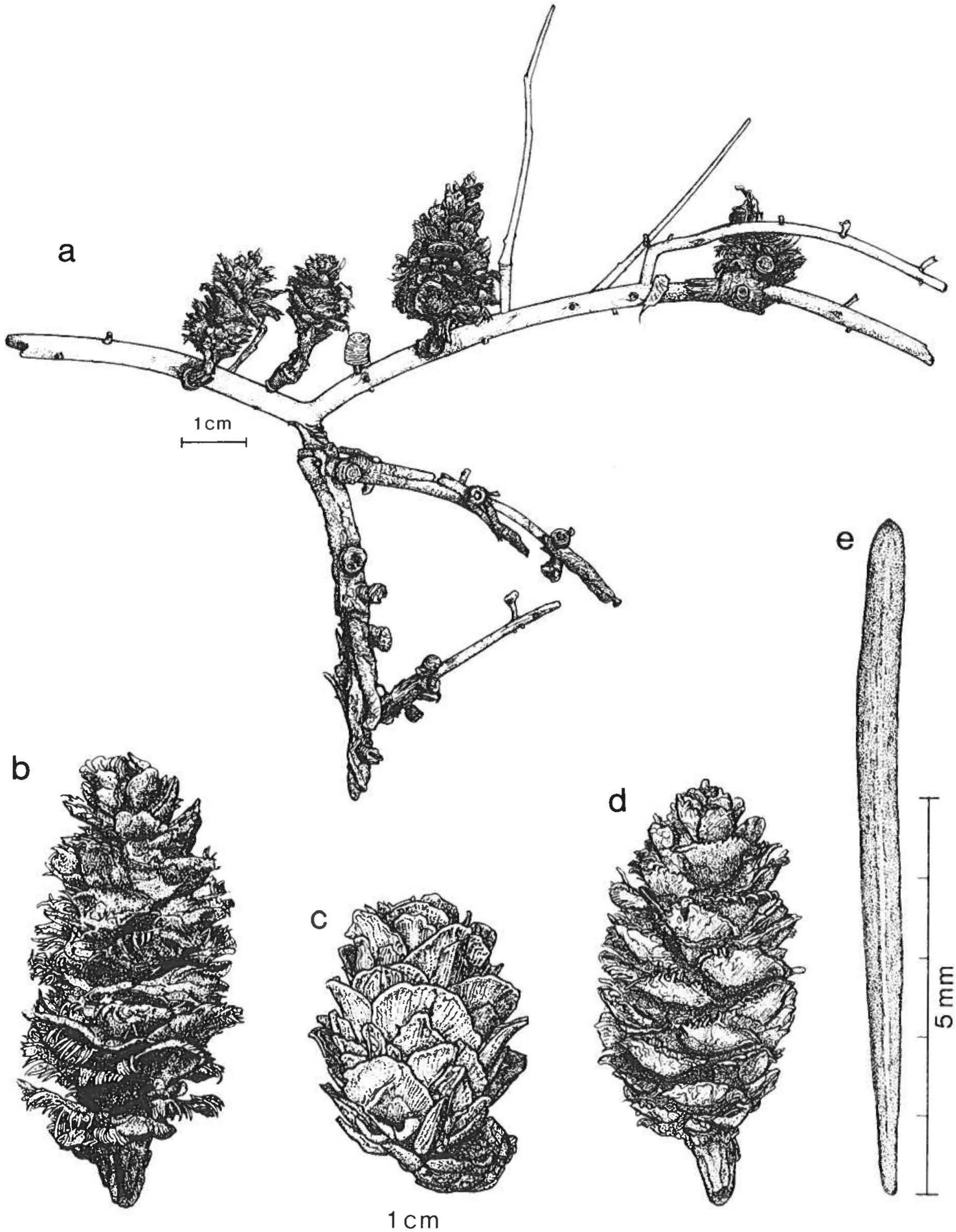


Fig. 38. Remains of *Larix groenlandii*. a: Twig with four wind-eroded cones and several "short" shoots and some bark still adhering, MGUH 19069, GCI 53244, locality 127. b: Cone, MGUH 19070, GCI 56692, locality 119. c: Cone. The large bracts places the cone in the section *Multiseriales*, MGUH 19071, GCI 53214, locality 122. d: Cone, MGUH 19072, GCI 53214, locality 122. e: Dorsal view of needle, MGUH 19073, GCI 56693, locality 119.

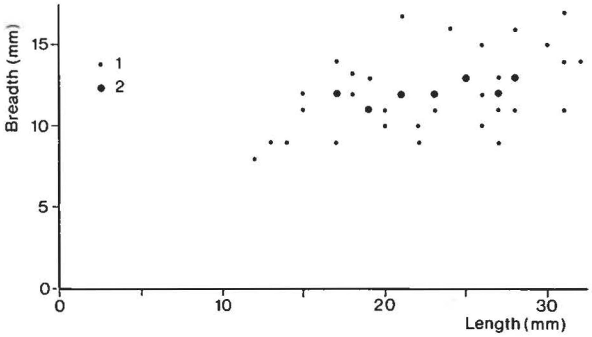


Fig. 39. *Larix groenlandii.* Relationship between length and breadth in 44 measurable cones from 53214, 53300, 56692, 64971 and 64987. Mean length is 22.7 mm, mean breadth is 12.1 mm. The cones were dry when measured.

Brook, northwestern Banks Island, was described by Roy & Hills (1972) and named *Laricioxylon occidentaloides* sp. nov. It was stated that the wood cannot be differentiated from that of *Larix occidentalis.* In fact, wood from the different, extant *Larix* spp. cannot be distinguished anatomically (Budkevich 1955), and the wood from Banks Island might more properly be referred to as *Larix* sp.

According to Matthews & Ovenden (in press) *Larix* needles are the dominant conifer fossils in many Neogene floras from northern North America, in contrast with Late Quaternary samples from the north which often contain only *Picea* needles.

Cupressaceae

Thuja occidentalis L.
Figs 40, 41a-d

Material. – 97 leafy twig fragments, one twig with three cones and three dispersed cones with seeds (from GCI 53214), 1 seed (GCI 53267), one bush with some adhering bark (GCI 64954,2) and one wood fragment (GCI 56667,29).

Remarks. – The twigs, which are flattened, bear opposite, scale-like, pointed leaves. The middle leaves have a distinct gland. The cones are oviform, 6–7 mm long with 8 opposite hard scales, of which only the middle ones are fertile. The seeds (1 dispersed and 7 picked out of the cones) are elliptic with a membranaceous wing and are 2.7–3.5 mm long including the wing.

The bush is of tree growth form but it is too small (75 cm) to qualify as a tree. Its branches have been deformed by heavy snow cover. The bark is thin and fibrous. The specimen was apparently shallowly rooted. The wood fragment has crossfield pits of the cupressoid type and lacks resin channels.

Modern cones of *T. occidentalis* from eastern North America measure 8.5–12 mm in length. The fossil cones are markedly smaller. Perhaps this small cone size is a consequence of the short growing season in North Greenland. Alternatively, the *Thuja* from Kap København may be a different taxon from the modern *Thuja occidentalis*.

Recent distribution. – *T. occidentalis* is found in eastern North America (Fig. 37).

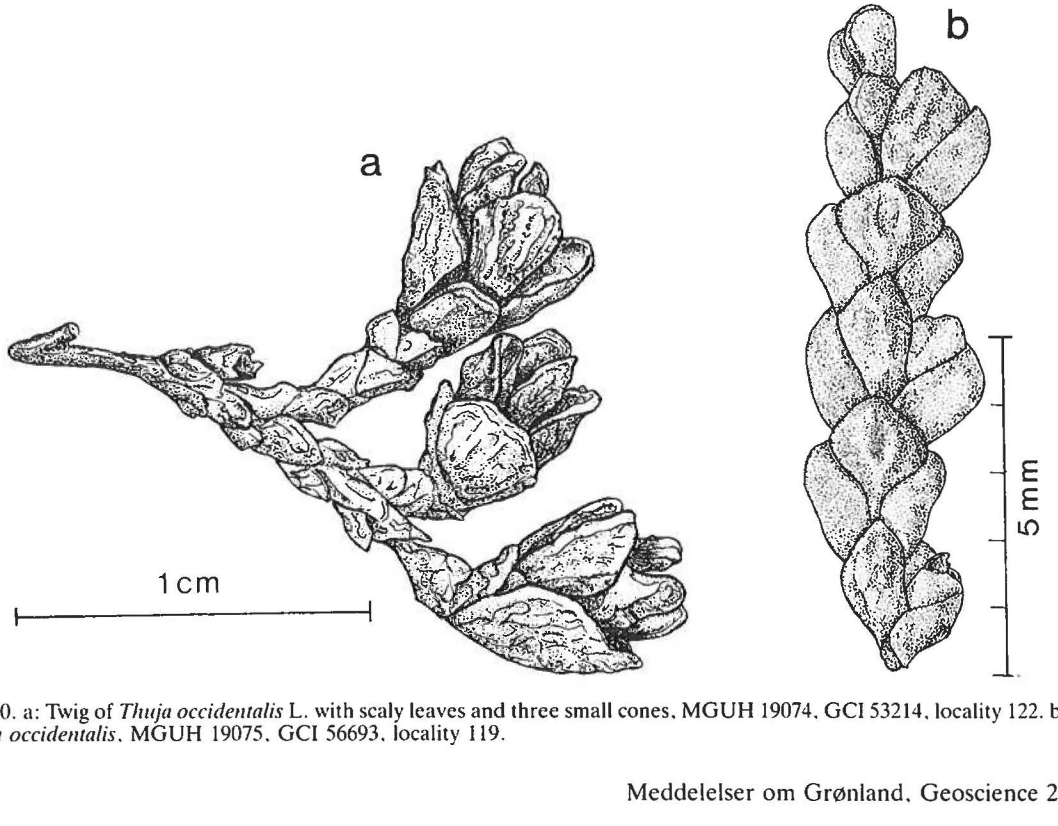


Fig. 40. a: Twig of *Thuja occidentalis* L. with scaly leaves and three small cones, MGUH 19074, GCI 53214, locality 122. b: Twig of *Thuja occidentalis*, MGUH 19075, GCI 56693, locality 119.

Ecology. – *T. occidentalis*, a small to medium sized tree, grows both in swamps, along streams and lakes, and on uplands but not in very wet and very dry sites. It thrives best on moist, well drained, neutral or alkaline soils, and it usually grows in forests consisting of a mixture of conifers and hardwoods, or in the boreal forest. Common tree associates include *Picea glauca*, *P. mariana*, *Larix laricina*, *Fraxinus nigra* Marsh., *Acer rubrum* L., *A. saccharum* Marsh., *Ulmus americanus* L. and *Betula papyrifera* Marsh (Fowells 1965).

Notes on history. – *Thuja occidentalis* and *Thuja* cf. *occidentalis* have been reported from Miocene and Pliocene deposits in Poland (Kolakovskij 1954, Łańcucka-Środoniowa 1966). These records from Europe, which are based on compressed twigs with leaves, are in need of revision. *Thuja* cf. *occidentalis* twigs and/or leaves and cones are reported from the Beaufort Formation on Meighen Island, and at several other Beaufort Formation localities, including Duck Hawk Bluffs (Hills & Matthews 1974, Matthews et al. 1990). Wood of ?*Thuja* sp. reported from northern Ellesmere Island, which has been radiocarbon dated to > 37 000 years B.P., probably also originates from the Beaufort Formation (GSC-1206, Lowdon et al. 1971). The oldest records of the species from its present range are in interglacial deposits of probably Sangamonian (last interglacial) age (Terasmae 1960, McAndrews 1972).

Taxaceae

Taxus sp.
Fig. 41e
Material. 1 branch and 1 leaf (GCI 56618, locality 17, unit B3).
Remarks. – The branch was sampled and identified by G. S. Mogensen (pers. comm). The wood, which is easily recognisable, is typical gymnosperm wood without resin ducts. The tracheids are characterised by well developed distinct spiral thickenings on the internal walls. The needle is 4.3 mm long and 1.5 mm wide, it is narrow elliptic with acute apex. The lamina is thin.

Some students of *Taxus* regard the numerous forms as a single species, *T. baccata* L. (Pilger 1926), comprising seven geographically separated subspecies. Most taxonomists, however, give these closely related taxa specific rank, but knowledge of the geographic province may be the only reliable means of separating the species (Ferguson 1978). Bearing these uncertainties in mind, no identification to the species level was attempted for the fossils.

Recent distribution. – The range of *Taxus* spp. is discontinuous circumpolar, boreal.

Ecology. – *Taxus* is a small evergreen tree or bush. It is most commonly found on upland sites, but also thrives in boggy areas (Godwin 1975). It shows some preference for alkaline soil. The species usually occur as undergrowth of forests and thickets.

Notes on history. – The evidence from the Kap København Formation suggests that *Taxus* had a circumpolar range as late as the Late Pliocene. The present discontinuities are probably due to ecological factors: *Taxus* does not grow in the continental climate of the interior parts of the continents. Apparently the *Taxus* forms have not been geographically isolated for sufficient time to allow well defined species to evolve.

Angiospermae

Nymphaceae

Nuphar lutea tp.
Fig. 41f
Material. – 1 seed (GCI 53214).
Remarks. – The seed which is slightly fragmented is 4.2 mm long, 2.1 mm broad and ovate in outline. A circular aperture indicates the position of the operculum. The raphe ridge is indistinct. The hilum is situated at the margin of the aperture. The external surface of the testa is marked by polygonal, isodiametric sclereids. Close to the aperture they become elongated (cf. Dorofeev 1963, fig. 25, 3). The surface of the seed is smooth, black and lustrous.

According to some neo-botanists the genus *Nuphar* consists of only one, polymorphic species, *N. lutea* (L.) Sibth. & Sm., but most specialists assume from 7 to 20 extant species (Li 1955, Tutin et al. 1964–1980) and a number of extinct species (Dorofeev 1974).

Recent distribution. – The genus is widely distributed in the northern hemisphere. Only the three closely related species: *N. lutea* of Eurasia, *N. variegatum* Engelm. of eastern and central North America and *N. polysepalum* Engelm. of western North America (the *Nuphar luteum* complex of Hultén (1971), reach the Subarctic. No species extend into the Arctic.

Ecology. – *Nuphar lutea* is a water plant with big floating, long-petioled leaves which rise from a submerged rhizome. The fruit is ovoid and contains numerous seeds. The plant grows in lakes and slow streams, at water depths up to about 3 m. *N. lutea* flourishes in eutrophic water but it also grows in mesotrophic water.

Ranunculaceae

Ranunculus spp.
Rather poor preservation combined with inter- and intraspecific variation posed problems in the identification of *Ranunculus* nutlets. No doubt a number of species are represented.

Ranunculus hyperboreus tp.
Figs 41g-h
Material. – 25 nutlets.
Remarks. – The nutlets are flattish and more or less D-shaped in outline. They measure 1.2–1.6 mm in height. The surface is smooth, the colour is yellowish.

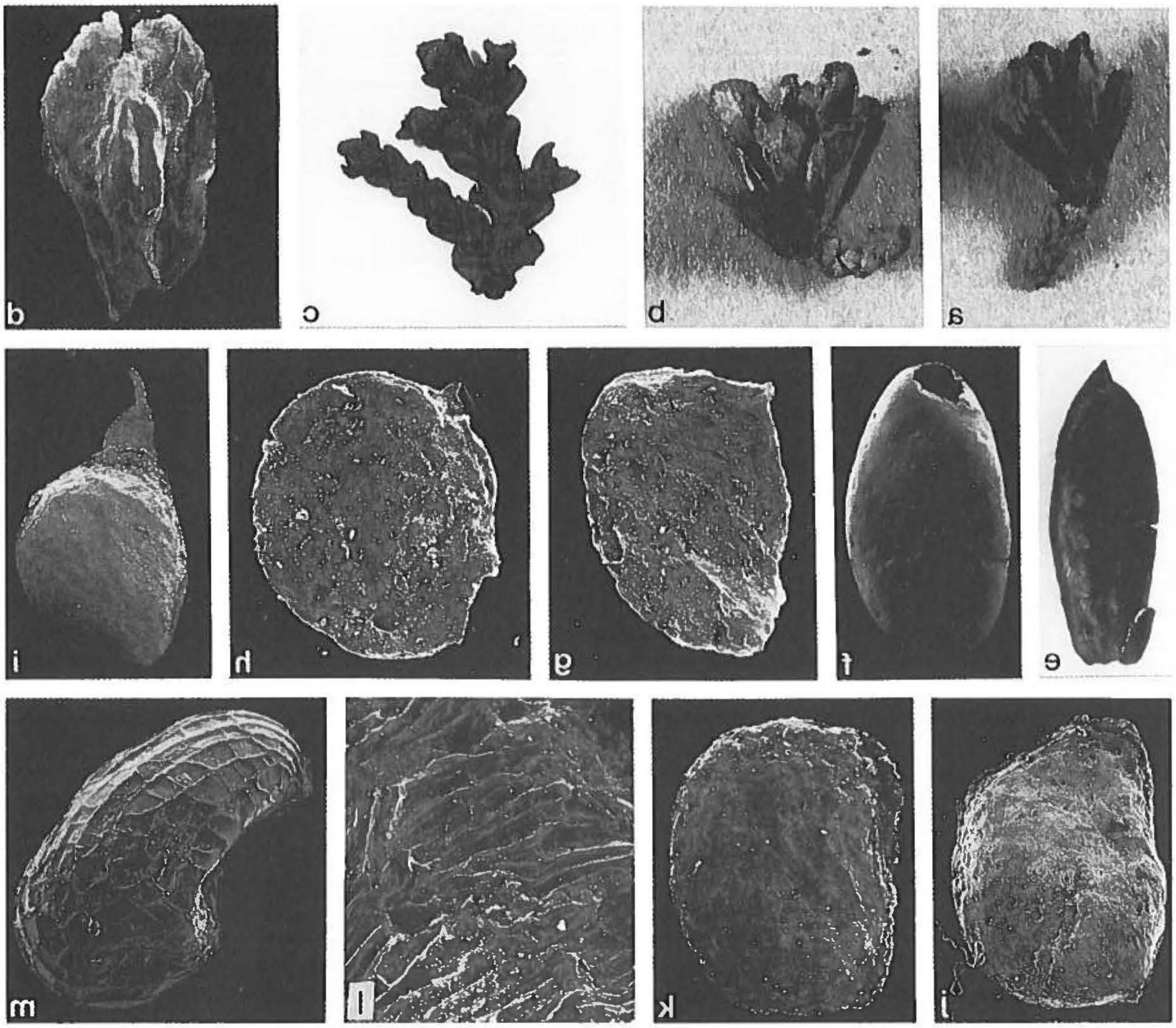


Fig. 41. a-d: *Thuja occidentalis* remains. a-b: Cones. a: MGUH 19076, GCI 53214, locality 122, x3.6. b: MGUH 19077, GCI 53214, locality 122, x3.6. c: Twig, MGUH 19078, GCI 53203, locality 119, x4. d: Seed, MGUH 19079, GCI 53214, locality 122, x13.2. e: *Taxus* sp. leaf, MGUH 19080, GCI 56618, locality 17, x9.6. f: *Nuphar lutea* tp. seed, MGUH 19081, GCI 53214, locality 122, x10.6. g-h: *Ranunculus hyperboreus* tp. nutlets. g: MGUH 19082, GGU 197159, locality 50, x32. h: MGUH 19083, GGU 197158, locality 50, x35. i-l: *Ranunculus* cf. *pallasii* nutlets. i: MGUH 19084, GGU 197124, locality 50, x8.5. j: MGUH 19085, GCI 53266, locality 132, x12.7. k: MGUH 19086, GCI, 56692, locality 119, x12.7. l: Detail of k showing sclereids, x105. m: *Papaver* sect. *Scapiflora* seed, MGUH 19087, GGU 197151, locality 50, x77. All figures are SEM micrographs excepth a-c and e which are light photographs.

This nutlet type, or rather types, compare with nutlets of such extant species as *R. reptans* L., *R. hyperboreus* Rottb. and *R. pygmaeus* Wbg.

Recent distribution. – Widely distributed.

Ecology. – *Ranunculus* spp. are herbs with cauline leaves and usually yellow flowers. Many species, including the three mentioned, grow in moist or wet habitats.

Ranunculus cf. *pallasii* Schlecht
Figs 41i-l
Material. – 10 nutlets.
Remarks. – Nutlets are flattish, the shape in outline is assymetrically obovate, adaxial margin slightly and abaxial margin moderately convex. The nutlets are 3.4–4.0 mm high. The surface is smooth, the colour is yellowish.

This type is mostly distinguisable from the former type by its larger size and thicker wall. It compares in shape with *Ranunculus pallasii*, but the nutlets of that species are larger, 4–5.2 mm high. Part of the difference may however be due to abrasion of the fossil nutlets.

Recent distribution. – *R. pallasii* is discontinously circumpolar in distribution. It is a boreal and low arctic species which does not occur in Greenland today (range map in Hultén 1968).

Ecology. – *R. pallasii* grows in shallow water in ponds, and along the margins of freshwater pools.

Anemone sp.
Material. – 5 nutlets
Remarks. – The nutlets are flattened and somewhat D-shaped in outline and tapered at both ends. The apex bears remains of a style. The surface is smooth. The nutlets are *c.* 3.2 mm high and *c.* 2.0 mm broad.

Most species of *Anemone* have hairy nutlets. The hairs of modern specimens were removed by treatment with a cold 9:1 mixture of acetic anhydride and concentrated H_2SO_4 to enhance comparability with fossil material.

Recent distribution. – *Anemone* is a genus of *c.* 120 species, some of which reach the Arctic today (Polunin 1959).

Ecology. – Most members are perennial herbs. They grow in diverse habitats, such as forests, heaths, rocky areas and grassy areas.

Papaveraceae

Papaver sect. *Scapiflora* Reichenb.
Fig. 41m
Material. – 3 seeds (GGU 197151 & 197163, locality 50, unit B3, GCI 56666, locality 77, unit B3).
Remarks. – The shape of the seed is narrowly reniform in outline, usually somewhat larger at one end than the other. The testa is semi-translucent, with an indistinctly reticulate surface.

It is impossible to separate the many forms of *Papaver* sect. *Scapiflora* by seed characters (Bell & Dickson 1971, Berggren 1981, Gunn & Seldin 1976, Conolly 1958). The section includes a number of species complexes, species and subspecies such as *Papaver alpinum* L., *P. radicatum* Rottb., *P. lapponicum* (Tolm.) Nordh. and *P. nudicaule* L. (see Knaben 1959).

Recent distribution. – The species of the section *Scapiflora* are circumpolar in distribution.

Ecology. – *Scapiflora* species are very common in arctic and alpine regions, especially in open habitats. They become more and more widespread towards the north, and are a dominant member of the most depauperate vegetation which borders the Arctic Ocean and which has been termed the *Papaver dahlianum* Nordh. zone in Svalbard (Brattbakk 1986). In the Low Arctic species of the section are mostly confined to fell-field sites with little snow cover during the winter. In the High Arctic they may grow in areas with a long lasting snow cover. *Scapiflora* species grow in both acidic and alkaline soils, but they show some preference for calcareous soil.

Betulaceae

Betula nana L.
Figs 42, 43, 44a-b
Material. – *c.* 1580 nutlets, 100 catkin scales and 960 leaves.
Remarks. – The fruit is a small, flattened, winged nutlet. The shape (exclusive of wings) is elliptic in outline, the wings are translucent and much narrower than the nutlet body. The catkin scales are small, about 3 mm long, with 3 nearly parallel lobes. The scales lack a resinous hump on the back, a feature characteristic of *B. glandulosa* Michx. However, the hump may not persist during fossilisation (Miller & Thompson 1979). The leaves are orbicular, with truncate base, and usually broader than long. This shape places the leaves in the species *B. nana*.

Remains of *B. nana* are the most common vascular plant fossils in the type section of the Kap København Formation.

Recent distribution. – *B. nana* is a boreal, arctic and alpine plant (Fig. 45). According to most students of the modern dwarf birches, *B. nana* is completely replaced by *B. glandulosa* in central North America (e.g. Scoggan 1978–79), and perhaps also in western North America, although it is regarded by Hultén (1971) as a circumpolar species, extending across the Canadian Low Arctic. According to the range map of Meusel et al. (1965) the distribution of *Betula nana* only extends from western Siberia to Baffin Island.

The species has its main area of distribution in the northern boreal and low arctic regions, but it has outposts in the High Arctic and in more southern areas, where it occurs in low competition areas, presumably as a relict from the late glacial period. In Greenland its northern limit is at 76°N.

B. nana tolerates both oceanic and continental types of climates. In Greenland it is distinctly continental, especially towards the north, while in Scandinavia it grows westwards to Bergen where the climate is extremely oceanic. T. Böcher (1972) proposed that the species survived the last glacial period in Greenland, during which a reduction in its gene-pool took place. However, according to palynological studies by Funder (1978) and Fredskild (1985), the species immigrated to Greenland during the Holocene.

Ecology. – *B. nana* primarily grows in bogs and in moist heaths. In Greenland it is often dominant in dwarf-shrub heaths on moist or dry ground, but it also grows in fell-field areas and in bogs. It prefers acid or neutral soil. In the inner fjord areas of central East and West Greenland *B. nana* is often prevalent. It may form extensive *B. nana* heaths, but usually the heaths consist of a mixture of several dwarf shrubs and herbs.

Notes on history. – Leaves, nutlets and catkin scales of "*Betula* cf. *nana* L. or *glandulosa* Michx." were reported from the Beaufort Formation on Meighen Island by Hills & Matthews (1974). Later, Matthews (1987) reported that a few of the fossils resemble nutlets and catkin scales of *B. glandulosa*. In the taxa list, only *Betula* (low shrub type) was indicated. Bracts of *Betula*

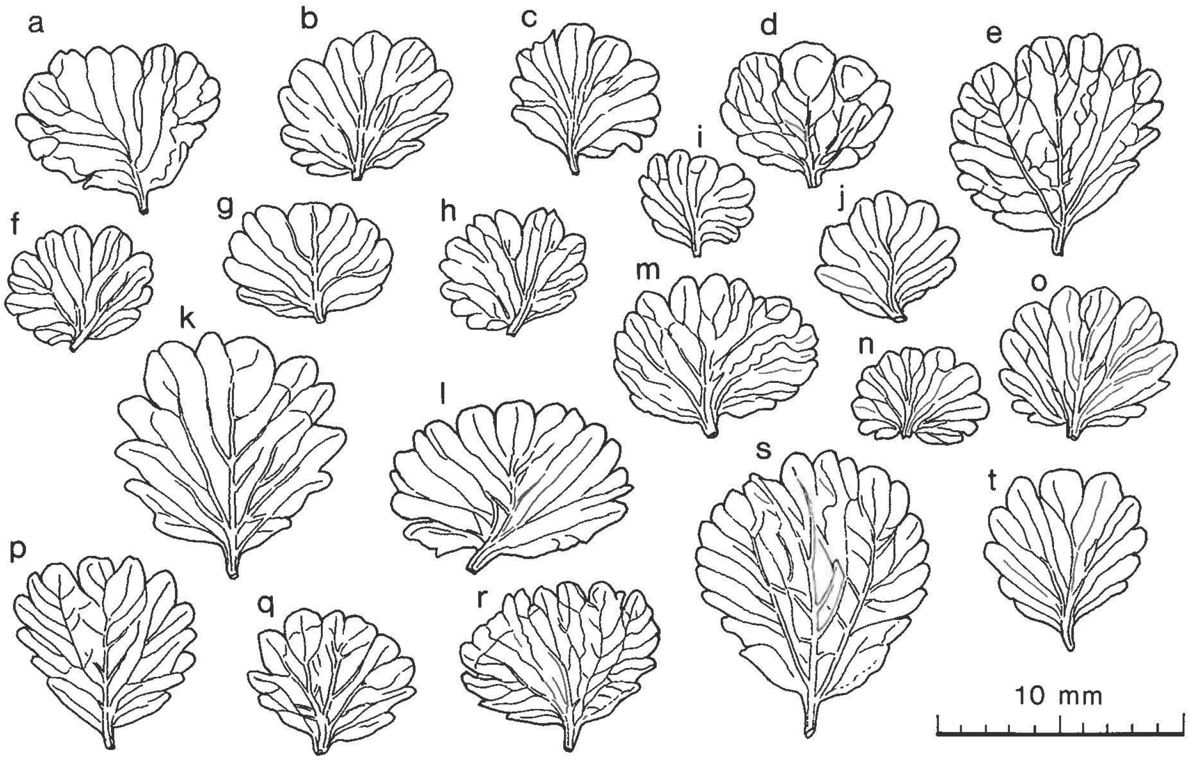


Fig. 42. *Betula nana* leaves. Note that many leaves are broader than long. (MGUH 19088–19107, GCI 56606, locality 15).

dwarf shrub type also occur on Prince Patrick Island Beaufort Formation (Matthews et al. 1990).

Betula nana remains are very common in late Quaternary deposits from Europe (Tralau 1963). The oldest record is from Great Britain, in deposits of Beestonian (middle Pleistocene) age (Godwin 1975).

Betula alba L. sensu lato
Figs 43, 44c-d
Material. – *c.* 175 nutlets and 30 catkin scales.
Remarks. – The fruit is a winged nutlet, with wings of about the same breadth as the nutlet body. The catkin scales are 3-lobed, *c.* 4 to 8 mm long, very variable in size and shape. The lateral lobes are only slightly broader than the central lobe, and the angle between the central and the lateral lobes is rather small. Most scales are longer than broad.

The shape and size of the catkin scales within the different tree birch species are quite variable when samples from the whole range of a species are considered. The catkin scales from the Kap København Formation show closest resemblance to scales of *B. pubescens* ssp. *tortuosa* (Led.) Schneid. (Bialobrzeska & Truchanowiczówna 1960) which grows in northern Europe (map in Hultén 1962). They also resemble scales of some collections of *B. papyrifera* and *B. occidentalis* Hook. which grow in North America (Krüssmann 1960).

These three taxa are regarded by Hultén (1962) as part of *B. alba* s. l. Most taxanomists give this taxon rank of section or subgenus.

Recent distribution. – The range of *B. alba* s.l. is circumpolar, boreal.

Ecology. – The arboral birches are important constituents of the boreal forests, and in northern Europe *B. pubescens* forms the tree line.

Alnus cf. *crispa* (Ait.) Pursh
Figs 44e-f
Material. – 11 female catkins, a few catkin scales and one nutlet, all from unit B3.
Remarks. – The complete catkins measure 11–12 mm in length. The catkin scales compare with *A. crispa* in shape and size. The single recovered nutlet does not retain the wing. The fruits are rather characterless and may have been overlooked.

At present the genus *Alnus* comprises about 30 species distributed in the northern hemisphere. Some of the species may produce fertile hybrids. A number of extinct species have been described from Tertiary deposits. From the Beaufort Formation three *Alnus* taxa have been recorded: *Alnus* (*Alnobetula*) sp. (which includes *A. crispa*), *Alnus* cf. *incana* L. (Moench) and *Alnus* cf. *tertiaria* Dorof. (Matthews 1987).

Recent distribution. – *A. crispa* ranges from central Siberia through North America to western Greenland, where it grows northwards to Evighedsfjord (66°N). It is

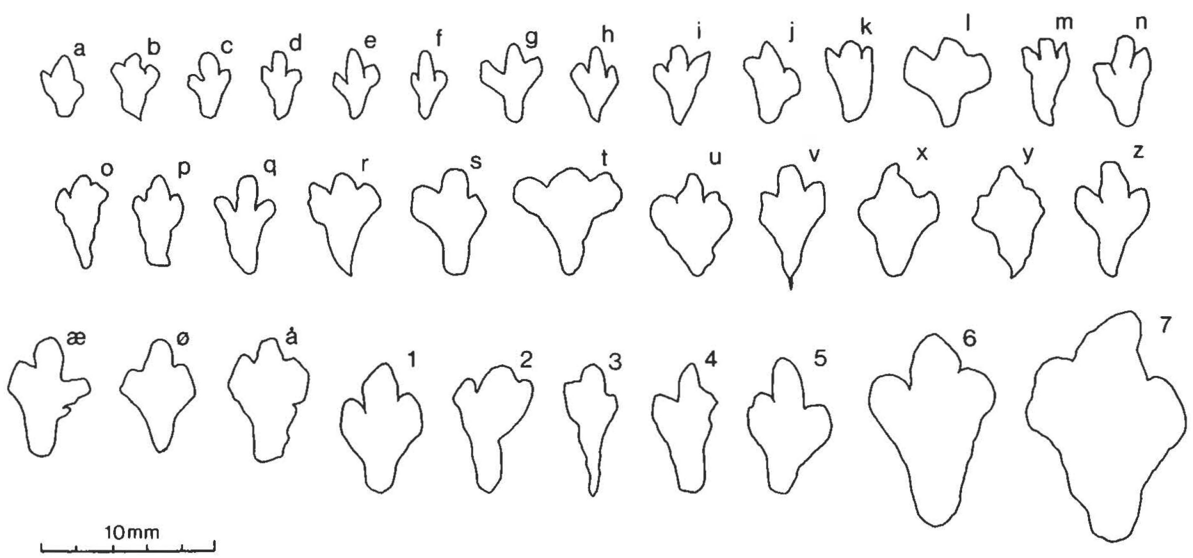


Fig. 43. Variability of catkin scales of *Betula*. There is no abrupt change between small *Betula nana* type scales, and larger *Betula alba* L. s. l. type, suggesting that hybridization took place. a,k,q,u: GCI 53286, locality 130. b,d,h-j,m-p,s,t,å,2: GCI 64956, locality 141. c,e: GCI 56688, locality 119. f,l,3: GCI 56693, locality 119. g,x: GCI 53267, locality 132. r,y,5: GCI 56666, locality 77. v,1: GCI 64972, locality 152. z,6,7: GCI 53265, locality 132. ø: GCI 53263, locality 132. 4: GCI 53266, locality 132. MGUH 19108–19142.

the only *Alnus* species to reach the Arctic today, but it grows most commonly in the boreal forest zone and in the Subarctic.

Ecology. – *A. crispa* is an ascending shrub 1–4 m in height, which forms dense scrubs on wet ground along rivers and lake shores, but it also occurs in upland areas.

Polygonaceae

Oxyria digyna (L.) Hill.
Figs 44g-h
Material. – *c.* 150 nutlets
Remarks. – The nutlets are strongly compressed, broadly winged elliptic, about 3.5 mm long. Usually the outer parts of the lateral wings of the nuts are absent.

Recent distribution. – *Oxyria digyna* is an arctic-alpine monomorphic plant species of circumpolar distribution, but it also occurs as a relict from the late glacial at a few north temperate sites, in areas of low competition. It is common throughout Greenland (Fig. 46).

Ecology. – *Oxyria digyna* is a small perennial herb which is found in a wide range of habitats, from snow-patches, heaths to fell-fields, but it favours open soil.

Polygonum sp.
Figs 44i-k
Material. – 3 nutlets (GCI 53263, 53266, 56666 (unit B3)).
Remarks. – The nutlet is elliptic in outline and flattened in cross section but triangular prior to post-depositional compression. The sides are concave. The surface is smooth and lustrous, and the colour is black. The length of the nutlets is 3.5 mm. Part of the perianth persists at the base of the nutlets.

The only native Greenlandic species within this genus, *Polygonum viviparum* L., which hardly ever produces fruits, lacks persistent perianth at the base of the nutlet (Berggren 1981), and also has a very different shape.

Recent distribution. – The genus is almost cosmopolitan. *P. viviparum* is the only species which is widely distributed within the Arctic, but a few other species reach the southern part of the Arctic.

Ecology. – The genus consists of annual or perennial herbs which often inhabit damp or wet sites.

Rumex acetosa L.
Figs 44l-m
Material. – 4 perianths (GGU 197128, locality 50, unit B1; GCI 53214, locality 122, unit B3; 53288, locality 131, unit B3; 64988, locality 77, unit B3).
Remarks. – The inner perianth segments are cordate at the base, have a small tubercle and are very thin at the margin. These features are characteristic of *R. acetosa*.

Recent distribution. – *R. acetosa* is circumpolar in distribution, but is not native in central and eastern North America. It grows in temperate climates. In southern Europe it is montane. In Eurasia its northern limit is slightly north of the arctic tree line. It occurs in arctic Alaska, in southernmost Greenland, in Iceland and on Spitsbergen.

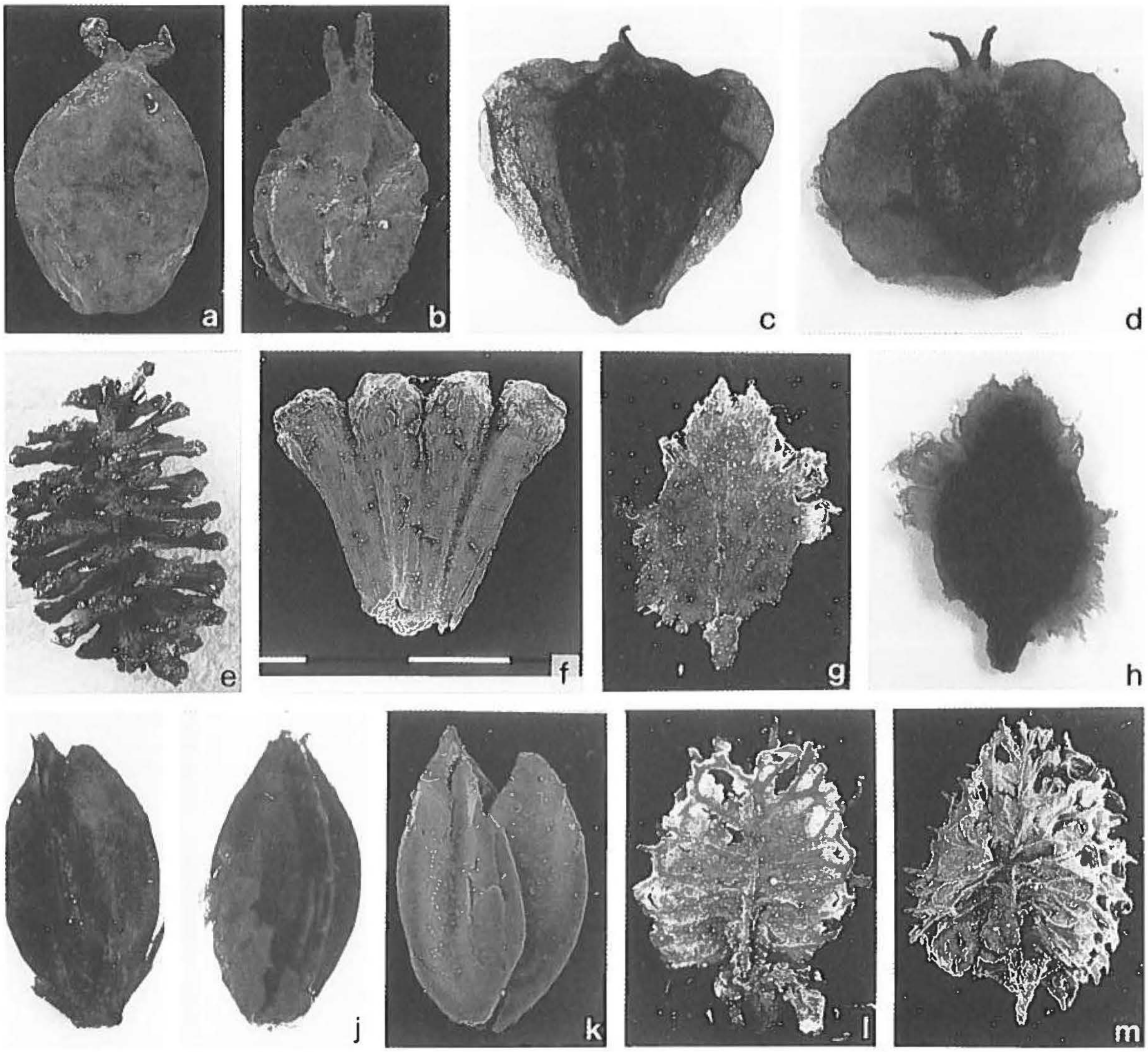


Fig. 44. a-d: *Betula* nutlets. a-b: *Betula nana* tp. a: MGUH 19143, GCI 56692, locality 119, x20. b: MGUH 19144, GCI 56606, locality 15, x18.9. c-d: *Betula alba* s. l. tp. c: MGUH 19145, GCI 56688, locality 119, x17.2. d: MGUH 19146, GCI 53263, locality 132, x13. e: *Alnus* female catkin ("cone"), MGUH 19147, GCI 53262, locality 75, x3.7. f: *Alnus* catkin scale, MGUH 19148, GCI 53290, locality 131, x13.6. g-h: *Oxyria digyna* nutlets. g: MGUH 19149, GCI 53288, locality 131, x12.7. h: MGUH 19150, GCI 53288, locality 131, x5.6. i-k: *Polygonum* sp. nutlets. i: MGUH 19151, GCI 35263, locality 132, x11.4. j: MGUH 19152, GCI 56692, locality 119, x11.4. k: MGUH 19153, GCI 53263, locality 132, x14.6. 1-m: *Rumex acetosa* inner perianths. l: MGUH 19154, GCI 53214, locality 122, x14.5. m: MGUH 19155, GCI 53288, locality 131, x11.1. All figures are SEM micrographs except c-e and h-j which are light photographs.

Ecology. – *R. acetosa* is a coarse herb which chiefly grows in rather damp, sheltered sites, such as in grassy areas, scrubs, woods and heaths.

Caryophyllaceae

Seeds of Caryophyllaceae are rare and badly preserved. Because of this, a restricted reference collection, and intraspecific variation (Wyatt, 1984), identifications within this family are tentative.

Cerastium cf. *arcticum* Lge./*alpinum* L.
Figs 47a-d

Material. – *c*. 5 seeds.

Remarks. – The seeds are semicircular in outline and measure *c*. 1.3 mm across. The epidermal cells of the concave lateral face of the seeds are elongate, with raised centres and strongly undulating anticlinal walls. The epidermal cells of the periphery of the seeds are tuberculate.

The seeds are tentatively referred to either *C. arcti-*

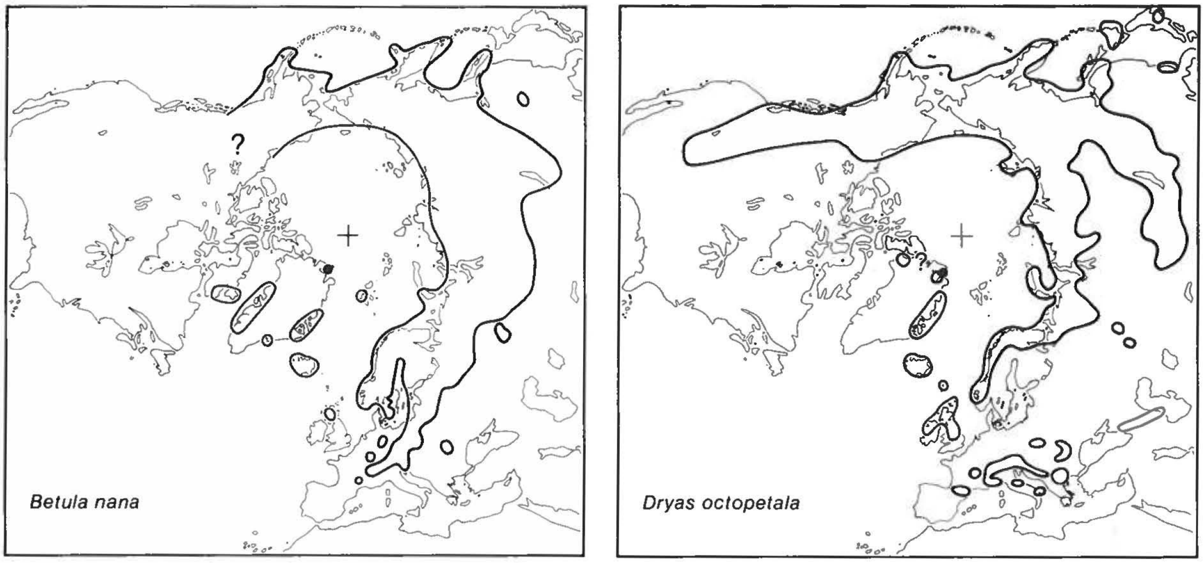


Fig. 45. Modern geographical range of *Betula nana* and *Dryas octopetala*, two species which do not grow in central North America today. Based on Hultén (1970).

cum or *C. alpinum* on account of their large size. These species are closely related and they readily hybridize.

Recent distribution. – The range of the two species is circumpolar. Together they are widely distributed in arctic and alpine regions.

Ecology. – The species, which are small, usually tufted herbs, are most common on dry or slightly moist gravelly soil with open vegetation, but they both tolerate a wide range of habitats.

Stellaria sp.
Figs 47e-f

Material. – *c.* 10 seeds.

Remarks. – The seeds are broadly elliptic in outline. The epidermal cells are elongate with strongly undulating anticlinal walls. The seeds measure about 0.9 × 1.0 mm in outline. They are comparable to seeds of some *Stellaria* species.

Recent distribution and ecology. – The genus is widely distributed both geographically and ecologically.

?*Arenaria* sp.
Fig. 47g
Material. – 1 seed (GCI 53214, locality 122, unit B3).

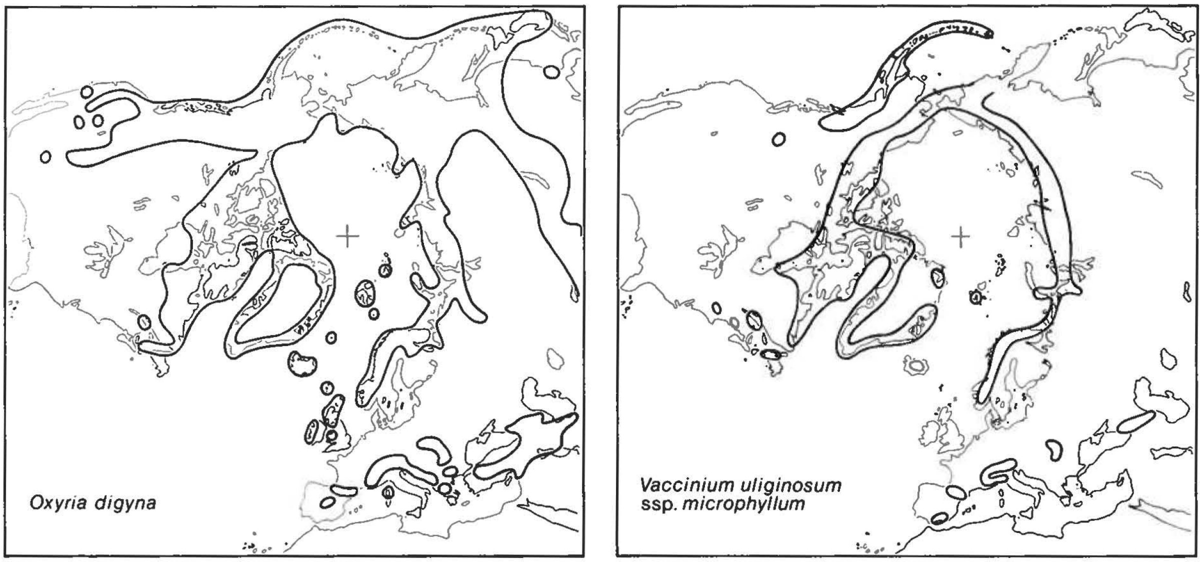


Fig. 46. Modern geographical range of *Oxyria digyna* and *Vaccinium uliginosum*, two plants of arctic/alpine circumpolar range. Based on Hultén (1970).

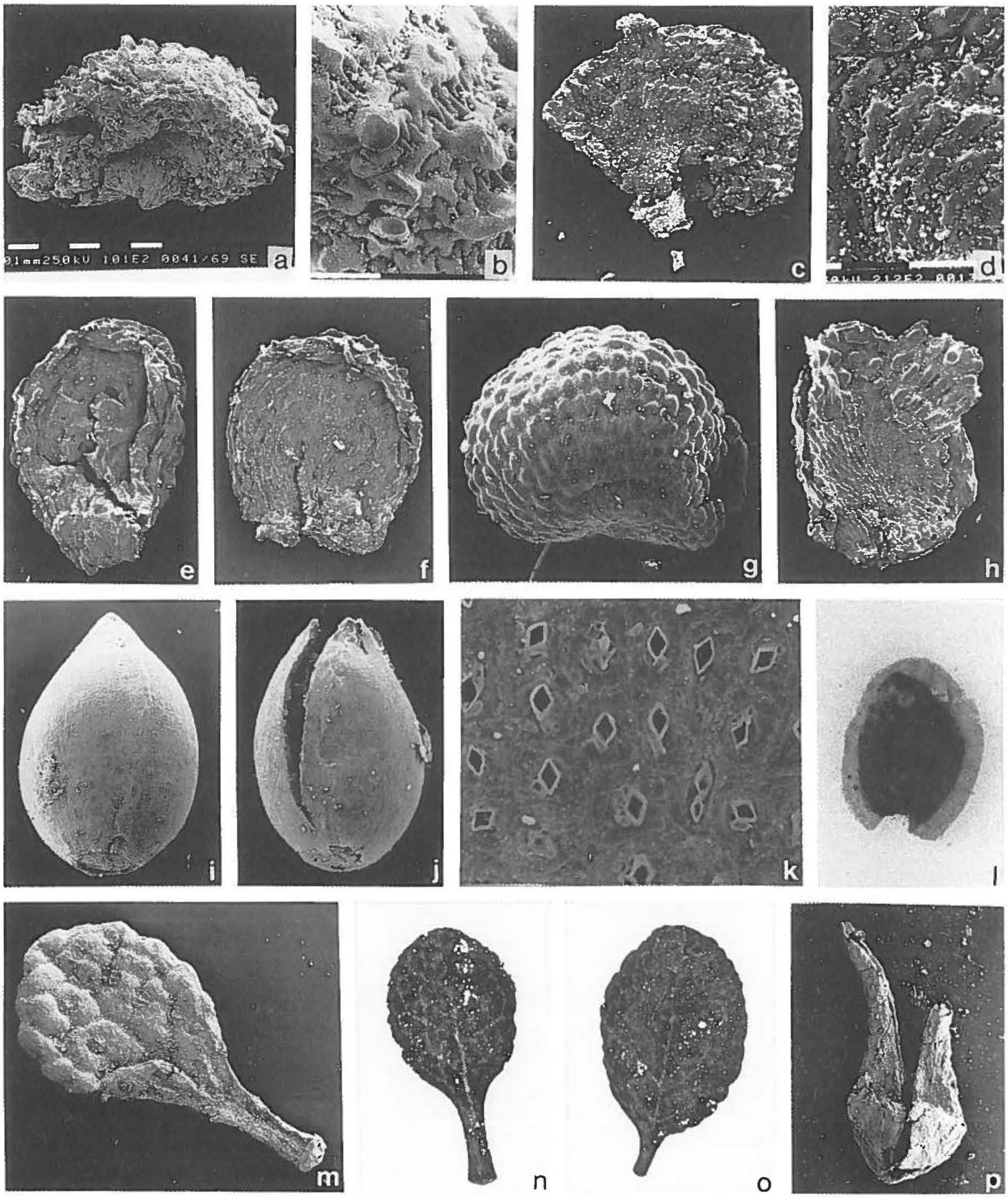


Fig. 47. a-h: Caryophyllaceae seeds. a-d: *Cerastium* cf. *arcticum*/*alpinum*. a: MGUH 19156, GCI 56692, locality 119, x48. b: Detail of a, x200. c: MGUH 19157, GGU 197153, locality 50, x29. d: Detail of c, x105. e-f: *Stellaria* sp. e: MGUH 19158, GGU 197158, locality 50, x30. f: MGUH 19159, GGU 197159, locality 50, x34. g: ?*Arenaria* sp., MGUH 19160, GCI 53214, locality 122, x42. h: *Melandrium affine*/*angustifolium*, MGUH 19161, GGU 197114, locality 50, x31. i-k: *Viola* sp. seeds. i: MGUH 19162, GCI 53263, locality 132, x23. j: MGUH 19163, GCI 56692, locality 119, x27. k: Surface detail of j showing endotestal crystal cells. The outer layers of the testa are eroded away, x510. l: *Arabis* cf. *alpina* seed, MGUH 19164, GGU 197119, locality 50, x30. m-o: *Salix reticulata* leaves. m: MGUH 19165, GCI 56606, locality 15, x16.9. n: MGUH 19166, GCI 56606, locality 15, x7.1. o: MGUH 19167, GCI 56606, locality 15, x6.0. p: *Salix* sp. capsule, MGUH 19168, GCI 56649, locality 57, x13.0. All figures are SEM micrographs except l and n-o which are light photographs.

Remarks. – The shape of the seed is reniform in outline, and the marginal notch is shallow. The outer periclinal wall of the epidermal cells is convex. The anticlinal walls are mostly hidden by debris, but they appear to be strongly undulating. The seed is 1.0 mm long and 0.7 mm high.

Contrary to the other Caryophyllaceae seeds from the Kap København Formation this seed has retained its original shape. The testa is ruptured and seems to be brittle.

Melandrium affine J. Vahl/*angustiflorum* (Rupr.) Walp.
Fig. 47h
Material. – 1 seed (GGU 197114, locality 50, unit B1).
Remarks. – The seed, which is fragmented, is a winged, semicircular Caryophyllaceae seed. The epidermal cells of the wing are elongate as is the case for seeds of *M. affine* and *M. angustiflorum* of Scandinavia. The cells in the wing of the northern species *M. apetalum* (L.) Fenzl are isodiametric in outline. The seed measures *c.* 0.9 × 1.0 mm in outline (excl. wing).

Recent distribution. – The range of this species pair is circumpolar, arctic and alpine, extending southwards to the arctic tree line (Hultén 1968). It does not reach northernmost Greenland and Canada.

Ecology. – The species grow in dry or slightly moist stony, gravelly or sandy soil.

Violaceae

Viola sp.
Figs 47i-k
Materal. – *c.* 15 seeds.
Remarks. – The seeds are ovoid in outline, with a line on one side running from top to bottom. The seeds easily split lengthwise from the top in a characteristic manner. The colour is light brown. The seeds are 1.7–1.8 mm long and 1.1–1.3 mm broad. The outer layers of some of the seeds were eroded away, exposing the endotestal calcium-oxalate(?) crystal-cells (Singh 1963). The crystals are regularly orientated with their long axis parallel to the long axis of the seed (Fig. 47).

Because of the taxonomic complexity of the *Viola* genus (*c.* 300 species (Hutchinson 1967)), and due to the similarity of *Viola* seeds no specific identification was attempted, although it has proved feasible to identify some British *Viola* seeds (Watts 1959, Dickson 1970).

Recent distribution. – The genus is widely distributed in the northern hemisphere. Only seven species reach the Arctic (Polunin 1959), and they are confined to the Low Arctic, and are common only in the southernmost parts.

Ecology. – Violets are predominantly small perennial herbs. In the Arctic they usually grow in sheltered situations. The seeds of some species are dispersed by ants. No ants live on Greenland today, but fossils representing 2–3 species have been recovered from the Kap København Formation (J. Böcher 1989, Bennike & Böcher in press).

Cruciferae

Arabis cf. *alpina* L.
Fig. 47l
Material. – 1 seed (GGU 197119, locality 50, unit B1).
Remarks. – The seed is flattened, broadly elliptic in outline and the margin is winged. There is a marked notch between the tip of the radicle and the tip of the cotyledons. The radicular furrow is indistinct. The seed is 0.9 mm long and 0.7 mm broad inclusive of the translucent wing which is around 90 μm broad all round. The testa is semi-translucent dark brown, and the epidermal cells are quadrangular in outline.

The identification is listed tentative both because only a single fossil was found, and because seeds of some northern *Arabis* species were not available for examination.

Recent distribution. – *A. alpina* is an amphi-atlantic plant which occurs in the Low Arctic and in the mountains of central Europe (map in Hultén 1958). In the Arctic it ranges from the Hudson Bay area eastwards to north-western Asia.

Ecology. – *A. alpina* is a high herb with leaf rosette. It grows in moist but well drained rocky or gravelly sites, often near streams. It often occurs in willow-scrubs, on herb-slopes and in snow-patch communities.

Salicaceae

Salix reticulata L.
Figs 47m-o
Material. – 76 leaves.
Remarks. – The leaves are very small, with a lamina length of around 4 mm and a breadth of around 3 mm. The shape of the lamina, which is coriaceous, is wide elliptic and symmetrical. The apex is rounded and the base is obtuse to rounded, somewhat decurrent in the smallest leaves. The margin is crenate. The petiole is normal and around 1.5 mm long.

The veins, which are deeply impressed on the upper surface, have a pinnate pattern, the primary vein being of moderate size and with a slightly sinuous course. Secondary veins are of moderate thickness and have a moderate to wide angle of divergence and a slightly sinuous course. The tertiary veins form a reticulum between the secondaries. (To enhance the visibility of the venation some leaves were bleached in cold 10 % KOH for two days).

Except for their being smaller, the leaves are similar to modern *S. reticulata* leaves. However, the extant species varies greatly with respect to leaf size, leaf margin and shape of leaves. Several subspecies and varieties have consequently been described.

Recent distribution. – The range of *Salix reticulata* is nearly circumpolar, but the species is missing in Iceland

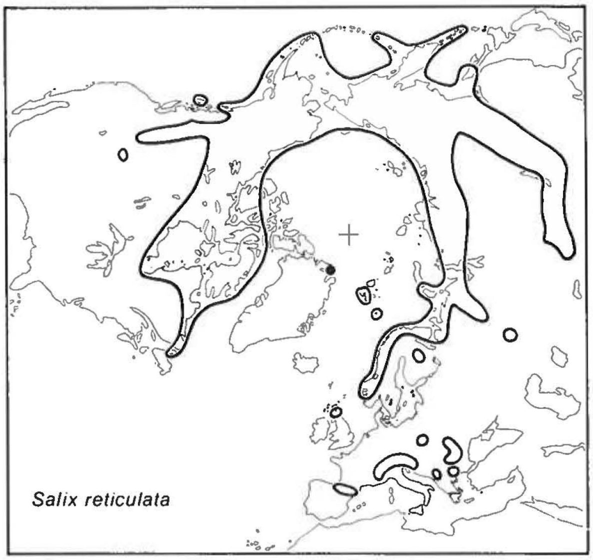


Fig. 48. Modern geographical range of *Salix reticulata* based on Hultén (1970).

and Greenland. It is otherwise widespread in arctic and alpine areas, but it does not occur in the High Arctic (Fig. 48).

Ecology. – *S. reticulata* is a prostrate trailing shrub up to 5 cm tall. It is a common heath plant, both on dry and moist sites, especially in areas that are well covered with snow in winter. It prefers calcareous soil.

Salix spp.
Fig. 47p
Material. – Numerous leaves, capsules, bud scales, twigs and wood.
Remarks. – Include uncharacteristic *Salix* leaves of elliptic shape, pinnate venation up to 4 cm long. Some leaves resemble *Salix glauca* L. leaves or leaves of *Salix arctica*, the only willow species which occurs at Kap København today.

Compressed branches measuring up to 6 cm across occur in the bottom of unit B2 at locality 27. Apparently rather large willow shrubs grew in the area.

Recent distribution. – Widely distributed.

Ecology. – *Salix* is a large genus mostly of shrubs. Its ecological amplitude is very large, from dry to wet soil, although its characteristic habitat is moist soil.

Myricaceae

Myrica arctogale Bennike, sp. nov.
Figs 49a-h
Diagnosis. – The shape of the fruit is ovate in outline, the base is broadly rounded while the apex is pointed. The surface is smooth but resinous glands may be present. The fruit is coalesced with two wing-like, fleshy scales forming a pseudocarp. The mean length of the fruit is 2.16 mm (Fig. 50). The ratio between the length of the fruit inclusive wings and exclusive wings is 1.2–1.5.

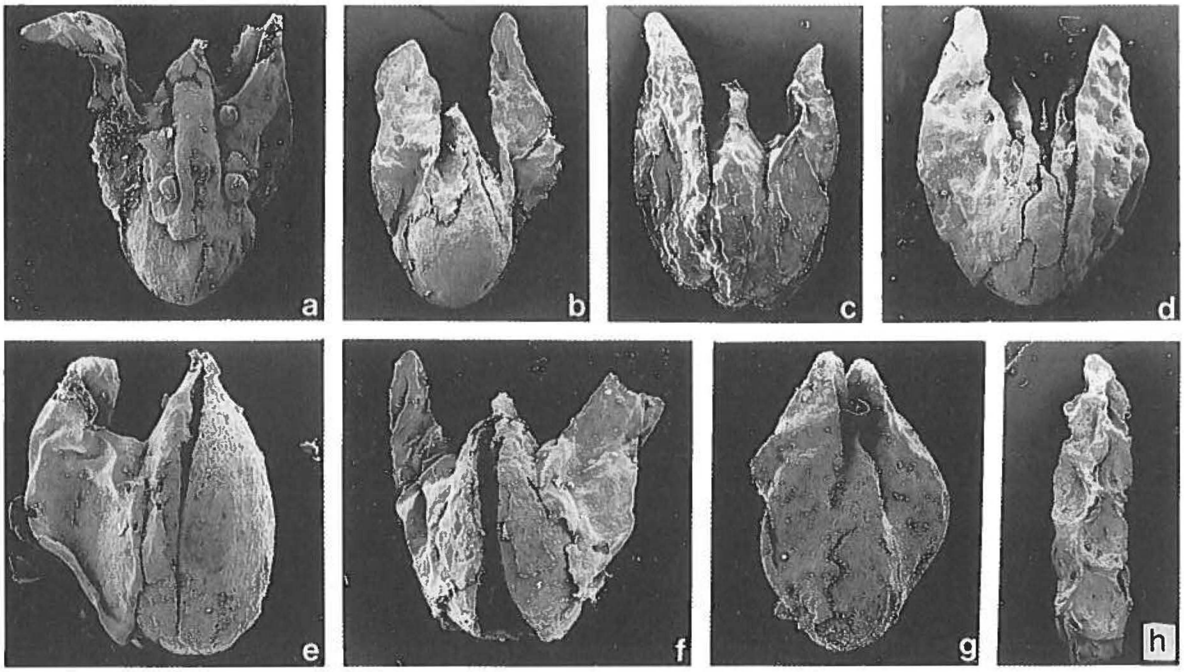


Fig. 49. *Myrica arctogale* remains. a-g: Fruits. a: Holotype, MGUH 19169, GCI 56692, locality 119, x13.3. b: MGUH 19170, GCI 53267, locality 132, x12.5. c: MGUH 19171, GCI 53266, locality 132, x14.0. d: MGUH 19172, GCI 53214, locality 122, x14.0. e: MGUH 19173, GCI 53266, locality 132, x16.7. f: MGUH 19174, 53266, locality 132, x14.7. g: MGUH 19175, GCI 53263, locality 132, x15.3. h: Female catkin axis, MGUH 19176, GCI 56692, locality 119, x7.6. All figures are SEM micrographs.

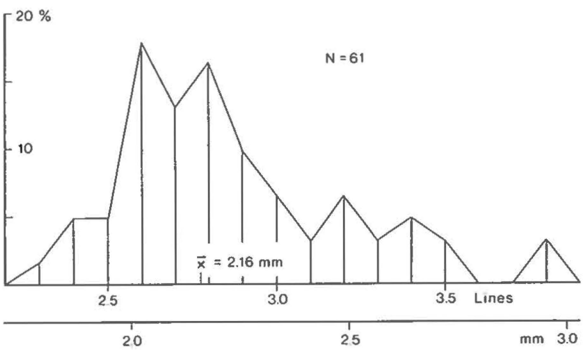


Fig. 50. *Myrica arctogale*. Length of 61 fruits from GCI 53265, 53266 and 53286.

Female catkin axes show that the fossil taxon had an inflorescence similar to that of the extant *M. gale* L.

Holotype. – MGUH 19169, GCI 56692, Fig. 49a.

Type locality. – Locality 119, Kap København, North Greenland.

Type stratum. – Unit B3, the København Formation.

Age. – Plio-Pleistocene.

Material. – *c.* 115 pseudocarps and fruits, 3 female catkin axes, 1 male catkin, 4 fragments of male catkins and a few dispersed male catkin scales.

Remarks. – The mean length of the fruits agree well with reference material of the extant *Myrica gale* and with statements in the literature (Berggren 1981, Montgomery 1977). However, the winglike scales are longer than in the reference material and in any illustrations seen. Thus the ratio between the length of the fruit and the pseudocarp in the fossil material is 1.2–1.5, while in *Myrica gale* it is about 1.1.

The fossil species belong in the subgenus *Gale* (Duham.) Engler which includes the extant species *M. gale*, and the extinct species *M. eogale* V. P. Nikitin and *M. omoloica* Dorof., described from Miocene deposits of Siberia (V. P. Nikitin 1976, Dorofeev 1972).

M. arctogale is probably intermediate between *Myrica gale* and *M. eogale*. The fossil material from Kap København has previously been referred to *Myrica* cf. *eogale* (Bennike 1987).

Notes on history. – It is probably the same species as that called *Myrica* cf. *gale* by Matthews (1987) and *Myrica eogale* by Matthews et al. (1990), both of which occur in the Beaufort Formation of arctic Canada.

Recent distribution of *Myrica gale*. – This species is of discontinuous, circumpolar boreal distribution. It is absent in Greenland and other arctic areas. It is most common in areas with an oceanic type of climate.

Ericaceae

Arctostaphylos uva-ursi (L.) Spreng.
Figs 51a-c
Material. – 12 endocarps.

Remarks. – Shape of endocarp elliptic in outline, ventral margin straight, dorsal margin curved. Length 2.6–3.0 mm, breadth 1.9–2.0 mm. The wall of the endocarp is thick.

The endocarps of *A. uva-ursi* are distinguished from those of *A. alpina* (L.) Spreng. and *A. rubra* (Rehd. & Wilson) Fern. by their larger size and more triangular outline in cross-section.

Recent distribution. – *Arctostaphylos uva-ursi* is placed by Hultén (1962) in the group of boreal-circumpolar plants (Fig. 52). It reaches the Arctic in West Greenland.

Ecology. – *A. uva-ursi* is a prostrate, matted dwarf shrub which is typical of heaths on dry ground.

Cassiope tetragona (L.) D. Don
Material. – 2 leaves (GCI 56606, locality 15).

Remarks. – Although the leaves appeared to be rather well preserved, they, like the single *Empetrum* leaf which was recovered, disintegrated during study. The *Cassiope* leaves are very characteristic, being scale-like with revolute margins and a deep furrow on the upper side.

Recent distribution. – *C. tetragona* is almost circumpolar in distribution, and virtually confined to the Arctic, where it is often abundant. It is missing from the southernmost part of Greenland, but in North America and in western Siberia it extends southwards to the arctic tree line.

Ecology. – The species is a dwarf-shrub up to 25 cm high, which forms *Cassiope* heaths on slightly moist ground such as that which is covered with snow for a fairly long period during the winter. It also occurs on more dry or more moist ground, as a member of different plant communities.

Fossil occurrence. – *Cassiope* cf. *tetragona* twigs have been recovered from the Beaufort Formation on Meighen Island (Hills & Matthews 1974, Matthews 1987).

Ledum palustre L.
Figs 51d-e
Material. – 7 leaves and leaf fragments.

Remarks – The leaves referred to *L. palustre* are linear to oblong with strongly revolute margins, have a reticulate surface and measure 1–2 mm in breadth. Because they are narrower than leaves of *L. groenlandicum* Oeder. they are referred to the narrow-leaved species *L. palustre*, the only other *Ledum* species found in boreal or arctic areas.

Recent distribution. – *L. palustre* is a boreal-low arctic species of circumpolar range (Hultén 1971). In West Greenland it grows between latitude 63° and 78°N.

Ecology. – *L. palustre* is an important component of heaths, especially moist heaths; and bogs. It demands a constant snow cover during the winter and a moist, humus rich, somewhat acidic soil. In the Arctic the plant is decumbent with narrow leaves, while in the

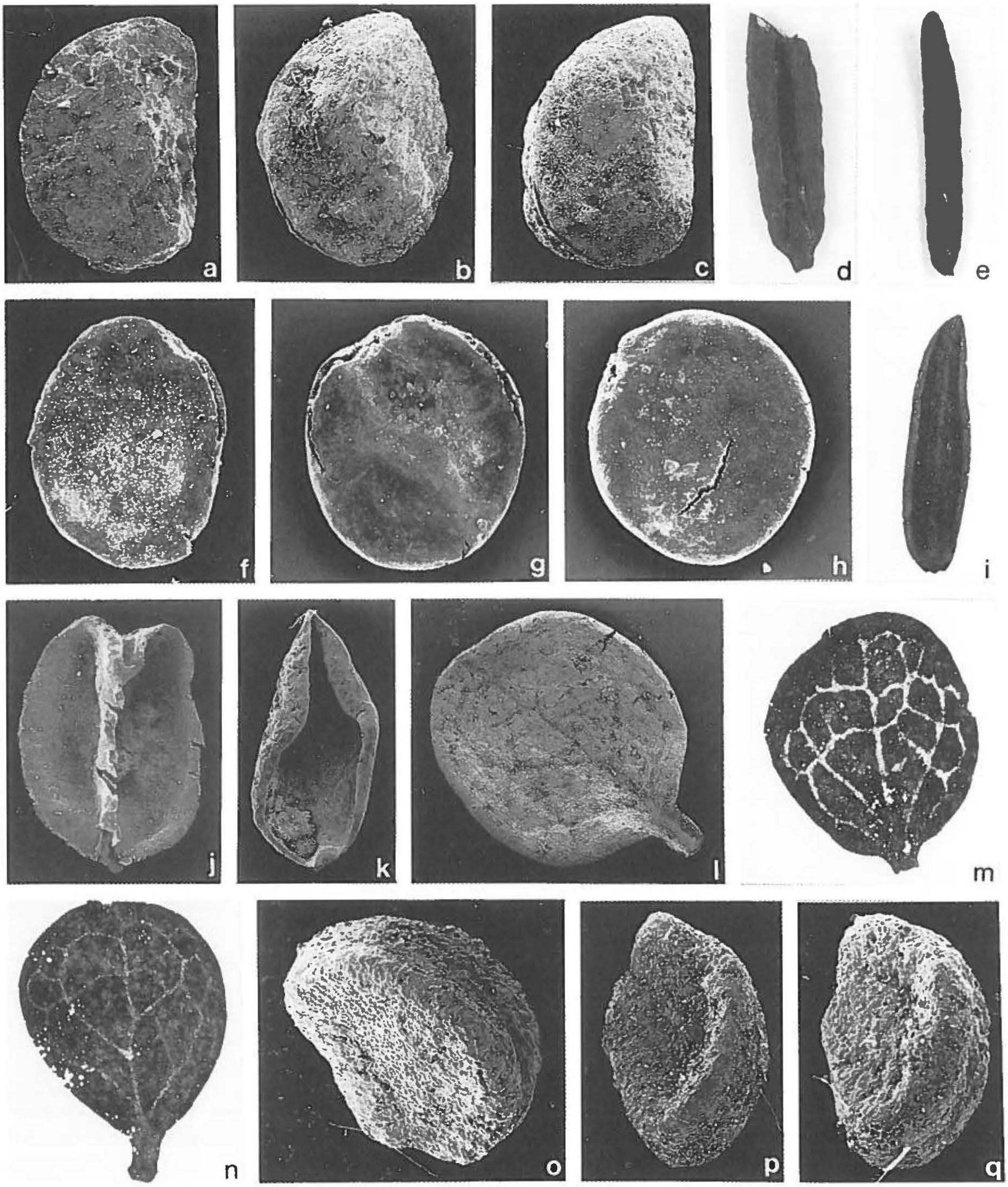


Fig. 51. a-c: *Arctostaphylos uva-ursi* endocarps. a: MGUH 19177, GCI 53261, locality 75, x15.9. b: MGUH 19178, GCI 56692, locality 119, x16.0. c: MGUH 19179, GCI 56692, locality 119, x12.1. d-e: *Ledum palustre* leaves. d: MGUH 19180, GCI 53214, locality 122, x8.3. e: MGUH 19181, GCI 53263, locality 132, x5.0. f-h: *Andromeda polifolia* remains. f-h: seeds. f: MGUH 19182, GGU 197129, locality 50, x44. g: MGUH 19183, GGU 197127, locality 50, x41. h: MGUH 19184, GGU 197127, x50. i: Leaf, MGUH 19185, GCI 53263, locality 132, x3.8. j: Ericaceae carpel, MGUH 19186, GCI 56692, locality 119, x19. k: *Oxycoccus palustris* leaf, MGUH 19187, GCI 56692, locality 119, x11.0. l-n: *Vaccinium uliginosum* ssp. *microphyllum* leaves. l: MGUH 19188, GCI 56606, locality 15, x13.3. m: MGUH 19189, GCI 56606, locality 15, x9.0. n: MGUH 19190, GCI 56606, locality 15, x8.2. o-q: *Empetrum nigrum* s. l. endocarps. o: MGUH 19190, GCI 56691, locality 119, x27. p: MGUH 19192, GCI 56692, locality 119, x25. q: MGUH 19193, GCI 56690, locality 119, x28. All figures are SEM micrographs except d-e, h and m-n which are light photographs.

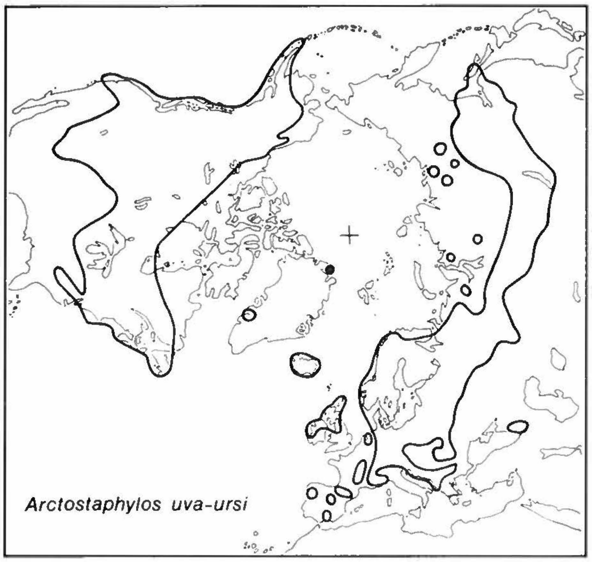


Fig. 52. Modern geographical range of *Arctostaphylos uva-ursi* based on Hultén (1970).

boreal regions it is taller and the leaves are somewhat broader. The species is very common in the forest-tundra region.

Notes on history. – Kuc (1974) reported on leaves of *L. decumbens* (Ait.) Lodd., which is here regarded as the North American *L. palustre*, from the Worth Point site on Banks Island, and leaves identified as *Ledum* cf. *palustre* come from the Beaufort Formation on Meighen Island (Matthews 1987).

Andromeda polifolia L.
Figs 51f-i
Material. – 7 seeds and *c.* 20 leaves.
Remarks. – The seeds are black and obliquely elliptic in outline. The surface is smooth, firm and lustrous, and the hilum is distinct. The length is about 1.0 mm and the breadth is about 0.55 mm. The leaves differ somewhat from *A. polifolia* by having the midvein less distinct on the lower surface than in the modern reference material.

Recent distribution. – *A. polifolia* is primarily a boreal species of circumpolar distribution, but it reaches into the Low Arctic. In Greenland the species occurs in the southwestern part.

Ecology. – The species grows in mossy bogs, in peat bogs, around the margins of pools and in wet, peaty heath areas.

Gen. et sp. indet.
Fig. 51j
Material. – 1 seed (GCI 56606) and some carpels.
Remarks. – The seed which is very small is badly preserved and no identification was attempted. The carpels are similar to those of *A. polifolia*.

Vacciniaceae

Oxycoccus palustris
Fig. 51k
Material. – 3 leaves.
Remarks. – The shape of the leaf lamina is elliptic. The apex is rounded and the margin is revolute. The upper smooth surface is grooved, while the lower surface is characterised by a marked, though not prominent midvein. The leaves are small, up to *c.* 5 mm long and up to *c.* 25 mm wide.

The leaves are with some hesitation referred to *Oxycoccus palustris* Pers., on account of general shape and indistinct midvein. In *O. palustris* leaf size and to some degree shape are rather variable.

No endocarps of this species were recovered, probably because the endocarp wall is rather thin.

Recent distribution. – *O. palustris* is a plant of circumpolar, mostly boreal range. The subspecies *microphyllum* (Lge.) Löve & Löve grows in northeastern North America and in southwest Greenland.

Ecology. – *O. palustris* grows in moist and wet acid soil, in bogs and in woods, and it is often found together with *Sphagnum* or growing in *Sphagnum* bogs.

Vaccinium uliginosum L. *microphyllum* Lange
Figs 51l-n
Material. – *c.* 1700 leaves.
Remarks. – The leaves are broadly elliptic or rarely obovate in form, and less than 1 cm long (Fig. 53). Larger leaves or fragments of larger leaves were not observed.

Small and round-leaved *V. uliginosum* forms a distinct taxonomic unit, usually called *V. uliginosum* ssp. *microphyllum*, but considered a distinct species: *V. gaultheroides* Bigel. by some botanists (D. Löve & Boscaiu 1966). It may be hazardous to assign the fossils to a modern subspecies, but in the present case this is done because the subspecies *microphyllum* is distinct and mainly defined by the leaves – the organs preserved as fossils.

Recent distribution. – According to Hultén (1971) *V. uliginosum* ssp. *microphyllum* is a circumpolar arctic subspecies (Fig. 46). It is very common in the Low Arctic and southern High Arctic, but does not occur in the most northerly parts of the High Arctic. It may grow in Scandinavia, Svalbard, Iceland and perhaps in some of the mountains of central and southern Europe (Hultén 1971, D. Löve & Boscaiu 1966, Hultén & Fries 1986).

Ecology. – The subspecies is a dwarf-shrub rarely more than 15 cm high, with short and dense branches. Ssp. *uliginosum* is distinguished from ssp. *microphyllum* by the latter having leaves less than 1 cm long (Hultén 1968, T. Böcher et al. 1978). *Vaccinium uliginosum microphyllum* grows in heaths and bogs. It is an important constituent of dwarf-shrub heaths, especially *Vaccinium-Empetrum* heaths. It grows in dry gravel or very

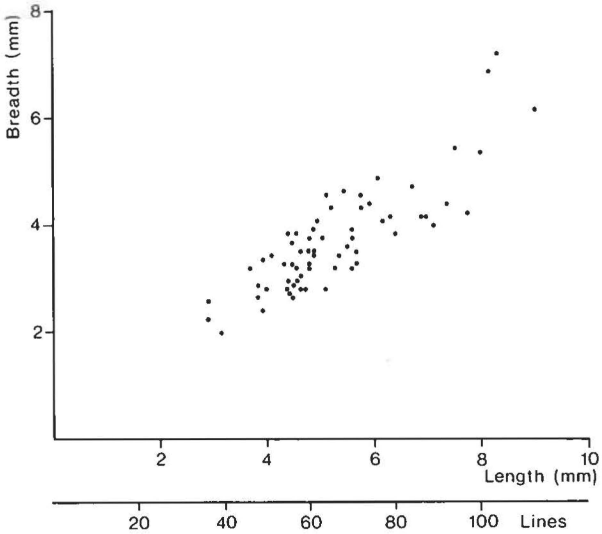


Fig. 53. *Vaccinium uliginosum* spp. *microphyllum*. Relationship between leaf lamina length and breadth in 65 leaves from 56606.
Mean length is 5.1 mm, mean breadth is 3.6 mm.

moist soil, on exposed or protected places; however, it is most commonly encountered in areas with a snow-cover of medium duration during the winter, and with a slightly acid soil.

Note on history. – Kuc (1974) reported this subspecies from the Worth Point site on Banks Island.

Empetraceae

Empetrum nigrum L. sensu lato
Figs 51o-q
Material. – *c.* 175 endocarps and 1 leaf.
Remarks. – The endocarps range in length from 1.3 to 2.1 mm (Fig. 54), have a straight ventral margin and a curved dorsal margin, are triangular in cross-section, and have a distinctive rough surface. They fall within the range of the endocarps of *E. nigrum*, including *E. nigrum* L. ssp. *hermaphroditum* (Hagerup) Böch. Hultén (1968) states that ssp. *hermaphroditum* has "fruit and seed generally larger" than ssp. *nigrum*, but this was not apparent in the available reference material. The single leaf was badly preserved and disintegrated during the study.

Recent distribution. – *E. nigrum* s. l. is of boreal and arctic/alpine circumpolar distribution. It does not occur in the northern part of the High Arctic. In Greenland it occurs as far north as 78°N on the west coast and 77°N on the east coast (Fredskild & Røen 1982).

Ecology. – *E. nigrum* is a dwarf – shrub, which may form large mats. Within the boreal zone it grows primarily in meadows, especially with acid soil, but it is also common in open woods and in heaths. In the Arctic it is common not only in wet soil but also on rather dry, sandy or gravelly ground. It is very common in dwarf shrub heaths, often together with *Vaccinium uliginosum* and *Betula nana*, but also as the only heath species. Such pure *E. nigrum* heaths occur in areas of large precipitation and an oceanic type of climate. *E. nigrum* s. l. does not tolerate areas which are free of snow during the winter period.

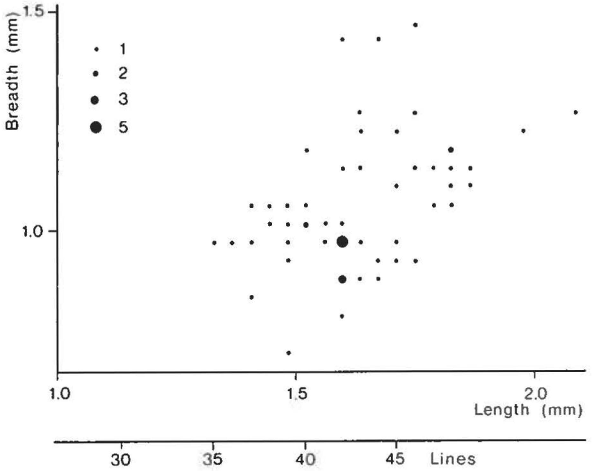


Fig. 54. *Empetrum nigrum* s. l. Relationship between length and breadth in 56 fruit stones from 53286 and 56692. Large dots indicate 2–5 specimens of same size. Mean length is 1.60 mm, mean breadth is 1.10 mm.

Crassulaceae

Sedum annuum L.
Figs 55a-d
Material. – 2 fruits, 1 fragment of a fruit and 7 seeds (GCI 53267, locality 132, unit B3).
Remarks. – The fruit consists of 5 follicles, 3–5 mm long. The two complete specimens have retained the basal part of the tepals, as well as a few stamens. One of the fruits contained some small seeds, about 0.7x0.1 mm, with a thin testa and a smooth surface.

Sedum is a large genus, and the fruits and seeds were only compared with the northern species. Among these the fossils only match specimens of *S. annuum*.

Recent distribution. – The range of *Sedum annuum* is arctic-montane, amphi-atlantic (Fig. 56). The species occurs in southern Greenland, Iceland, Scandinavia and in the mountains of southern Europe.

Ecology. – *S. annuum* is a small herb with succulent leaves which grows in dry rocky, stony or sandy places.

Fabaceae

Hedysarum sp.
Figs 55c-f
Material. – 2 seeds (GCI 53263, locality 132, unit B3 and 56692, locality 119, unit B3).
Remarks. – The seeds measuring 2.3x1.4 and 3.2x2.0 mm respectively are characterised by a distinct hook.

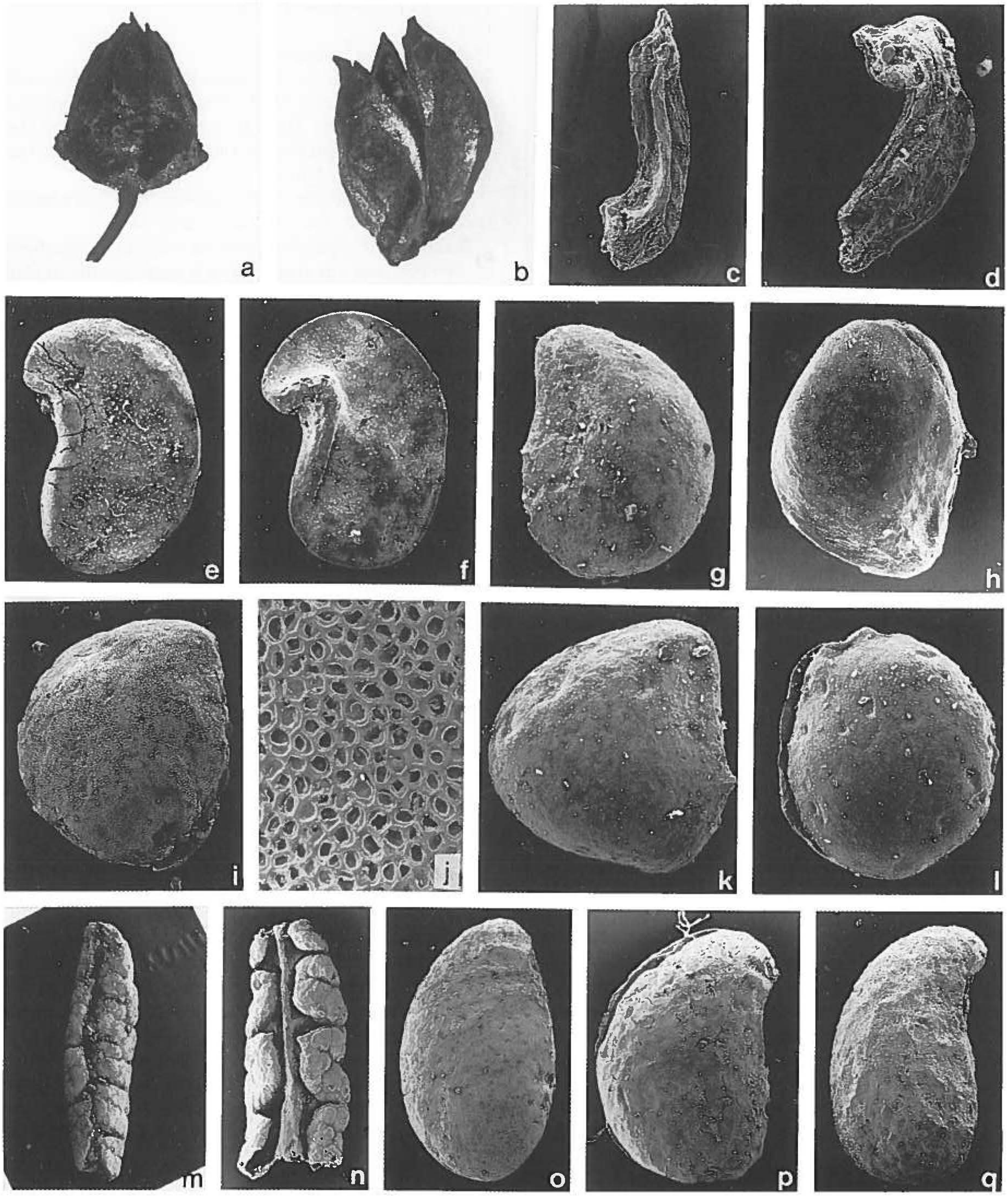


Fig. 55. a-d: *Sedum annuum* remains. a-b: Fruit capsules. a: MGUH 19194, GCI 53267, locality 132, x5.1. b: MGUH 19195, GCI 53267, locality 132, x6.3. c-d: Seeds extracted from the capsules. c: MGUH 19196, GCI 53267, x60. d: MGUH 19197, GCI 53267, locality 132, x78. e-f: *Hedysarum* sp. seeds. e: MGUH 19198, GCI 53263, locality 132, x17.0. f: MGUH 19199, GCI 56692, locality 119, x12.5. g-h: *Potentilla* sp. nutlets. g: MGUH 19200, GCI 56692, locality 119, x35. h: MGUH 19201, GCI 53267, locality 132, x28. i-l: *Potentilla palustris* nutlets. i: MGUH 19202, GCI 64989, locality 77, x30. j: Detail of i, x26. k: MGUH 19203, GCI 56692, locality 119, x34. l: MGUH 19204, GCI 56692, locality 119, x32. m-n: *Dryas octopetala* leaves. m: MGUH 19205, GCI 56605, locality 15, x10.8. n: MGUH 19206, GCI 56692, locality 119, x9.3. o: *Rubus chamaemorus* endocarp, MGUH 19207, GCI 56692, locality 119, x13.0. p-q: *Rubus arcticus/saxatilis* endocarps. p: MGUH 19208, GCI 56692, x18.6. q: MGUH 19209, GCI 53267, locality 132, x17.6. All figures are SEM micrographs except a-b which are light photographs.

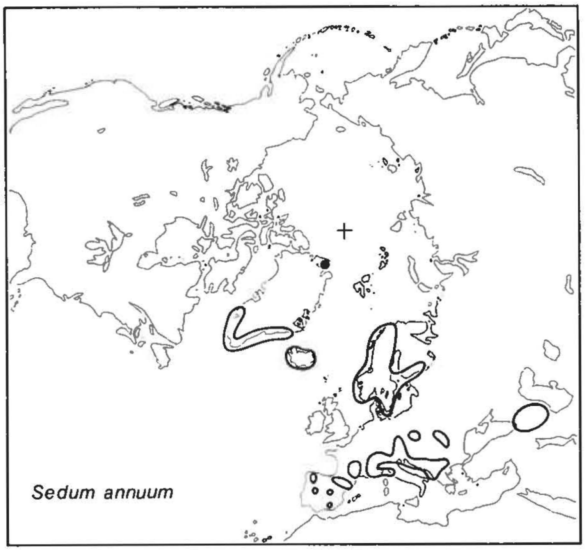


Fig. 56. Modern geographical range of *Sedum annuum* based on Hultén (1958).

Hedysarum includes *c.* 60 species of mostly herbaceous perennials. The fruits are flattened and divided transversely into separable, one-seeded sections.

Recent distribution. – The genus is widely distributed in the northern hemisphere. Three species (*H. alpinum* L., *H. hedysaroides* (L.) Schinz & Thell and *H. mackenzii* Richards) grow in low arctic and alpine areas, but they are most common in subarctic and subalpine regions. At the present day only a single species of Fabaceae, *Lathyrus japonicus* Willd. occurs in Greenland.

Ecology. – The taxon is most common in heathy or open areas, and it prefers calcareous substrates. Gravelly or sandy river banks and lake shores are the most common habitats, but *Hedysarum* may also grow in moist woods.

Rosaceae

Potentilla spp.
Figs 55g-h
Material. – *c.* 140 nutlets.
Remarks. – The nutlets are obliquely obovate in outline, the dorsal margin semi-circular and the ventral margin slightly S-shaped. The nutlets split along the margin. Their surface is smooth with small isodiametric sclereids. They measure 1.1–1.8 mm in length and 0.7–1.5 mm in breadth. This large variation indicates that several species are involved.

Recent distribution. – This large genus is widespread, especially in the northern hemisphere, and *c.* 20 species grow in the arctic region.

Ecology. – Most plants within the genus are perennial herbs. They are primarily members of open vegetation, and many species grow in dry sites.

Potentilla palustris (L.) Scop.
Figs 55i-l
Material. – *c.* 15 nutlets.
Remarks. – Some of the broadly obovate *Potentilla* nutlets 1.20–1.55 × 1.10–1.35 mm probably represent *Potentilla palustris*. However, transitional forms between such roundish nutlets and obovate *Potentilla* nutlets were rather common.

Recent distribution. – *P. palustris* is a circumpolar species in boreal and low arctic climates.

Ecology. – *P. palustris* grows in wet soil in meadows, along lakes and streams, and as a semi-aquatic in shallow water. It prefers acid, oligotrophic water.

Dryas octopetala L.
Figs 55m-n, 57
Material. – *c.* 3240 leaves and some hypanthia.
Remarks. – *Dryas* leaves occur in almost all samples, often in large quantities, and they are amongst the most common macroscopic remains of vascular plants in the Kap København Formation.

The leaves are quite variable but all leaves are crenate along the entire margin, and it is concluded that they represent *D. octopetala*, and not the North American species *D. integrifolia* M. Vahl. The leaves vary in size, shape, dentition and development of revolute margins (Fig. 57). *Dryas octopetala* leaves have two common forms, depending on where the plant grows. Most fossil leaves from Kap København are small and narrow with a strongly revolute margin (the wind-adapted type), while larger leaves (the lee-type) are rare. Although larger leaves are normally fragmented, this factor cannot explain their rarity, because fragments of the larger leaf type are also rare. This is thought to mean that *Dryas octopetala* was a common member of exposed fell-field sites, and rare in sheltered locations where the large leafed form could have grown.

Recent distribution. – Using a broad species concept the genus *Dryas* only comprises three species: *Dryas octopetala*, *D. integrifolia* and *D. drummondii* Richards (Hultén 1959). *D. integrifolia* is found all over arctic North America, in easternmost Siberia and in West, Southeast and North Greenland. *D. octopetala* is of nearly circumpolar arctic and alpine range (Fig. 45), but it does not occur in central and eastern North America, or in West, North and Southeast Greenland. The two species have some scattered boreal outposts in low competition areas, which are regarded as relicts of a former, more widespread distribution (Tralau 1963, Ritchie 1980). The range of *D. drummondii* – unlike the other two, a monomorphic species – is limited to gravelly river beds at scattered sites below the tree line in North America.

D. integrifolia and *D. octopetala* are closely related and hybridise where they occur together. Most *Dryas* specimens in North Greenland are hybrids (C. Bay, pers. comm., Elkington 1965).

Ecology. – *Dryas octopetala* is a very important he-

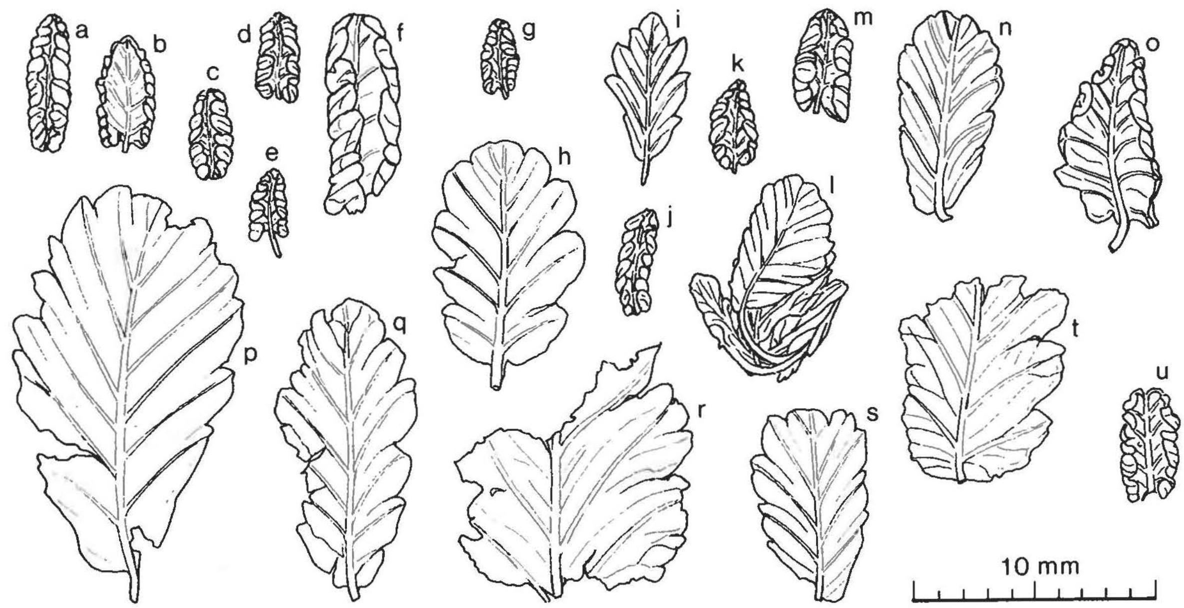


Fig. 57. Ventral view of fossil *Dryas octopetala* leaves from Kap København. Note the large variability. The smaller leaves with recurved margin are from plants adapted to windy sites; whereas the larger ones are presumed to be from plants which grew on protected lee sites. f,i,o,q: GCI 53263, locality 132. n,r,s: GCI 53266, locality 132. l,n,p,t: GCI 64956, locality 141, the others are from GCI 56692, locality 119. MGUH 19210–19230.

liophilous dwarf-shrub in the Arctic. It often dominates (sometimes forming *Dryas* heaths) areas of dry soil which lose their snow early in spring. The species is also characteristic of fell-field sites and areas of moist soil, even sites with rather heavy snow cover. It does not, however, grow in snow-patch communities. Sites with alkaline soil are preferred, but it also grows in neutral or even acid soils.

Rubus chamaemorus L.
Fig. 55o
Material. – 1 endocarp (GCI 56692, locality 119, unit B3).
Remarks. – The endocarp is ovate in outline and slightly flattened laterally. The base and the apex are rounded. The endocarp is *c.* 3.3 mm long and 2.0 mm broad. The surface is smooth except near the apex, where some ridges form an indistinct coarse reticulum.

Recent distribution. – The range of *R. chamaemorus* is boreal/low arctic circumpolar (Fig. 58). In Greenland it is presently confined to the southwesternmost part.

Ecology. – *R. chamaemorus* is a herb-like plant which grows in moist acidic soil, in boggy areas within regions of both open forest and tundra.

Rubus arcticus L./*R. saxatilis* L.
Figs 55p-q
Material. – 4 endocarps (GCI 56692 (3), locality 119, unit B3 and 53267, locality 132, unit B3).
Remarks. – The shape is obliquely ovate in outline, with semi-circular dorsal margin and a ventral margin which is slightly concave. The length of the endocarp is *c.* 2.0 mm, the breadth is *c.* 1.1 mm. The surface is reticulate.

This endocarp type matches modern endocarps of *R. arcticus* and *R. saxatilis*.

Recent distribution. – The range of *R. arcticus*, including some subspecies, is almost circumpolar, but it is missing in Greenland and Iceland. Its distribution is primarily boreal but extending beyond tree line into the arctic zone in some areas (Hultén 1971). Hultén (1958) considers *R. saxatilis* to be an amphi-atlantic species. However, its main range is in Eurasia, although it also occurs in Iceland and in a few places in southernmost Greenland. Like *R. arcticus* it is mainly a boreal species, which reaches the southernmost Arctic.

Ecology. – Both species are herbaceous plants. *R. arcticus* grows in meadows and in thickets. *R. saxatilis* grows in scrubs and open forests.

Hippuridaceae

Hippuris vulgaris L.
Figs 59a-d
Material. – 98 fruits.
Remarks. – The shape of the achene-like fruit is oblong-cylindric, with a line which extends from the bottom to the top of the fruit. The top has a round opening. The colour of the fruit is brown. The fruits measure around 1.6 mm in length and 0.9 mm in breadth (Fig. 60).

The genus *Hippuris* comprises three closely related species (*H. vulgaris* L. s. str., *H. tetraphylla* L. fil. and *H. montana* Ledeb.) or one polymorphic species (*H.*

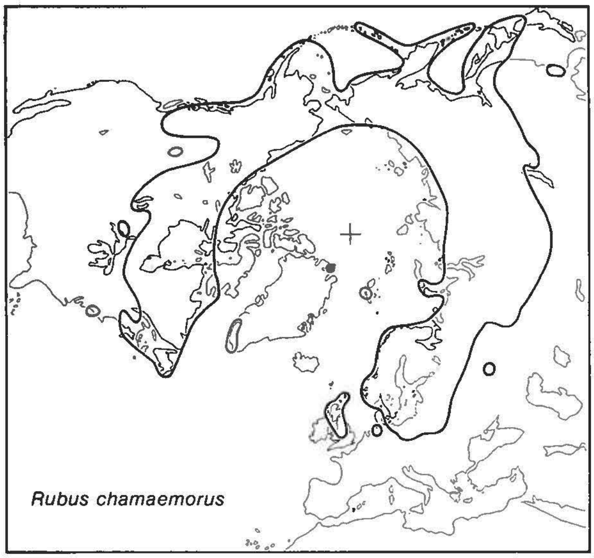


Fig. 58. Modern geographical range of *Rubus chamaemorus*, a species of boreal/low arctic circumpolar range. Based on Hultén (1970).

vulgaris L. s. l.) showing heterophylli (e.g. Hultén 1971, Polunin 1959). According to Welsh (1974) the fruit of *H. montana* is smaller than those of *H. vulgaris* s. str. and *H. tetraphylla*.

The fossil fruits from Kap København are larger than those of *H. montana* fruits, and are referred to *H. vulgaris* s. str./*H. tetraphylla* or *H. vulgaris* s. l.

Recent distribution. – Like many other aquatics, *H. vulgaris* s. str. is widely distributed (Fig. 61), but it is most commonly found in boreal and arctic areas. It grows as far north as Peary Land in Greenland (Fredskild 1966). *H. tetraphylla* is a plant of discontinuous boreal and arctic, circumpolar range (Hultén 1968).

Ecology. – *H. vulgaris* is a perennial aquatic or semi-aquatic herb. *H. vulgaris* s. str. inhabits shallow waters of lakes and ponds or sluggish streams, or wet soil at the margin of lakes or streams. It grows in eutrophic as well as in oligotrophic water. *H. tetraphylla* is characteristic of brackish water.

Geraniaceae

Erodium sp.
Fig. 59e
Material- – 1 fragmented seed (GCI 56692).
Remarks. – The seed is narrowly ovate in shape and 3.9 mm long. Only half of the seed is preserved, but it matches the larger seeds of *Erodium* spp. (Beijerinck 1947, Dayton 1937, Martin & Barkley 1961).

Recent distribution. – *Erodium* grows mainly in temperate regions (Polunin 1959). A single species, *E. cicutarium* (L.) L'Hér. has been introduced to the Arctic (T. Böcher et al. 1978), but the seed from Kap København is larger than seeds of this species.

Ecology. – *Erodium* is a small genus of herbs with pinnate or pinnatified leaves. It grows in open vegetation.

Cornaceae

Cornus stolonifera Michx.
Figs 59f-g, 62a
Material. – 24 endocarps.
Remarks. – The endocarp is hard, woody, smooth and longitudinally grooved. It is obliquely broad elliptic in outline. Length 4–5 mm, breadth 3.5–4.0 mm.

The fruit stones are referred to *C. stolonifera* because of their shape and size.

Recent distribution. – *Cornus stolonifera* is presently confined to North America, where it primarily grows in the boreal forest (Fig. 37). Its northern limit approximately follows the tree line.

Ecology. – *C. stolonifera* is a small to medium sized shrub 1–6 m tall. It is found in wet and moist habitats, in nutrient rich or alkaline soil, where it may form thickets. It usually grows along water courses, in meadows and in moist forests.

Notes on history. – Fossils comparable to *C. stolonifera* have been recorded from the Neogene of Poland (Łańcucka-Środoniowa 1957, Raniecka-Bobrowska 1959, Szafer 1961 (*Cornus* aff. *stolonifera*)), Germany (Burgh 1978, 1983), western Siberia (V. P. Nikitin 1964 (*Cornus* aff. *stolonifera*)) and northern North America (Matthews & Ovenden in press, Matthews et al. 1990).

Cornus canadensis L.
Fig. 62b
Material. – 3 endocarps (GCI 53267, locality 132 and 56692 (2), locality 119, all from unit B3).
Remarks. – The endocarps are hard, smooth and broadly elliptic in outline. They have a lengthwise groove encircling the endocarp parallel to its long axis. They are *c.* 2.2 mm long and *c.* 1.6 mm broad. The fruit stone of the closely related species *C. suecica* L. is broader and larger.

Recent distribution. – *C. canadensis* is found throughout the boreal region of North America, from southernmost Greenland, Newfoundland westwards to Alaska and on to eastern Asia (map in Hultén 1968). Its northern limit in North America almost coincides with the tree line.

Ecology. – *C. canadensis* is a low, up to 30 cm tall, sub-shrub with creeping slender rhizomes. The entire leaves are more or less whorled at the summit of the stem. The fruit is a small red drupe. The species is common in moist, open spruce and birch forests.

Cornus sp. A
Fig. 62c
Material. – 1 endocarp (GCI 56692, locality 119, unit B3).

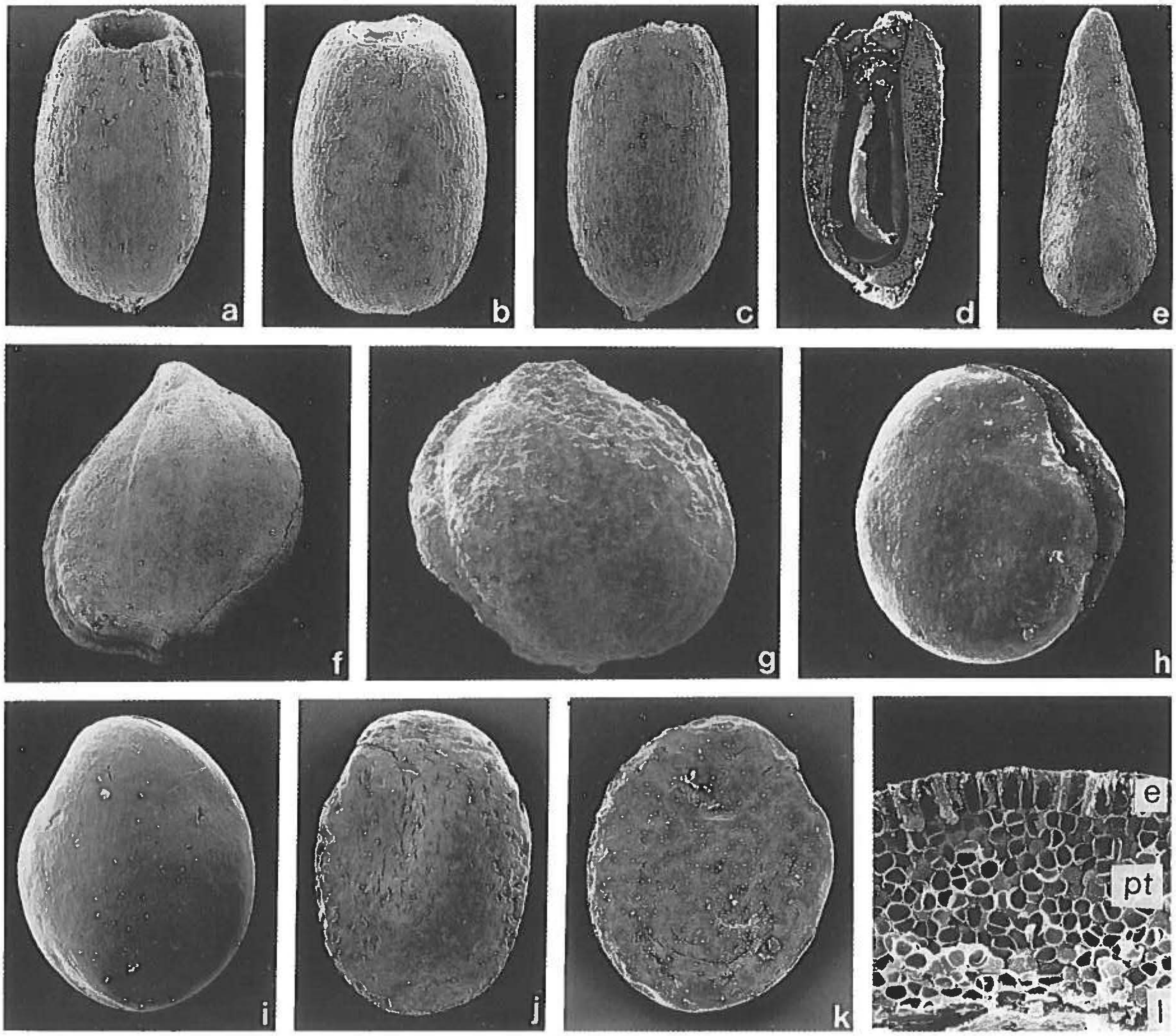


Fig. 59. a-d: *Hippuris vulgaris* fruits. a: MGUH 19231, GCI 53267, locality 132, x25. b: MGUH 19232, GCI 53267, locality 132, x26. c: MGUH 19233, GCI 53267, locality 132, x26. d: Sectioned fruit and seed testa, MGUH 19234, GCI 53267, locality 132, x24. e: *Erodium* sp. seed fragment, MGUH 19235, GCI 56692, locality 119, x11.0. f-g: *Cornus stolonifera* endocarps. f: MGUH 19236, GCI 64965, locality 146, x10.3. g: MGUH 19237, GCI 53267, locality 132, x11.7. h-l: *Menyanthes trifoliata* seeds. h: MGUH 19238, GCI 53261, locality 75, x17.8. i: MGUH 19239, GCI 64976, locality 157, x16.6. j: MGUH 19240, GCI 56692, locality 119, x15.5. k: MGUH 19241, GCI 53214, locality 122, x16.4. l: Transverse section of testa showing parenchymatic tissue (pt) with pits and epidermis (e) consisting of rather narrow and high cells, MGUH 19242, GCI 56692, locality 119, x155. All figures are SEM micrographs.

Remarks. – The endocarp is morphologically similar to those of *C. canadensis*, but much larger: 5 mm long as opposed to *c.* 2 mm in *C. canadensis*. It was compared with a large number of *Cornus* species. It resembles endocarps of *C. florida* L. but is smaller, broader and lacks longitudinal groove. The fossil cannot be referred to any living or fossil species known to the author unless it is an abnormally large specimen of *C. canadensis*.

Menyanthaceae

Menyanthes trifoliata L.
Figs 59h-l

Material. – 540 seeds or half seeds.

Remarks. – The seeds are elliptic in outline, *c.* 2.6 mm long (Fig. 63), with a smooth, shiny surface in well preserved specimens. Some of the seeds are compressed. The seed easily splits into halves, and half seeds were frequently encountered. Four seeds were gnawed, probably by small rodents (B. Bejer-Petersen, pers. comm.).

Menyanthes seeds are perhaps the most common and abundant macroscopic plant fossils in Quaternary sediments (Godwin 1975), and they are also common in Tertiary sediments.

Detailed biometrical analyses on recent and fossil

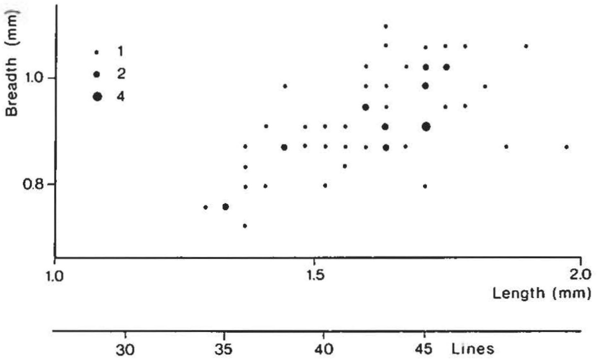


Fig. 60. *Hippuris vulgaris* s. l. Relationship between length and breadth in 55 fruits from GCI 53266, 53267, 53286, 56692 and 64965. Large dots indicate 2 or 4 specimens of same size. Mean length is 1.61 mm, mean breadth is 0.92 mm.

seeds were carried out by Truchanowiczówna (1964, 1967; Jentys-Szaferowa & Truchanowiczówna 1953). According to her work, *Menyanthes* seeds from the Early and Middle Miocene of Germany are comparable to recent *M. trifoliata* seeds. Late Pliocene seeds from Poland are smaller and differ in the anatomy of the testa, justifying separation as a different species – *M. carpatica* Jentys-Szaferowa & Truchanowiczówa. Four other extinct *Menyanthes* species have been described from the Tertiary of Siberia, namely *M. parvula* P. A. Nikitin, *M. minima* Dorofeev, *M. miocenica* Dorofeev (Dorofeev 1963) and *M. orientalis* V. Nikitin (P. V. Nikitin 1979b). Another fossil species, *M. microsperma* Jessen from the Quaternary of Ireland has been reidentified as *Nymphoides* cf. *cordata* (Ell.) Fern (Watts 1971). Fossil seeds from the Pliocene and Quaternary of Japan are somewhat larger than recent seeds (Kokawa 1958, 1959, 1960) but resemble modern seeds in the anatomy of the testa (Truchanowiczówna 1964). As Kokawa suggests, their larger size may be due to post mortem compression.

From the Beaufort Formation and related late Neogene deposits, Matthews (1987) reports both *M. trifoliata* and *Menyanthes* sp. A, the latter being a small form, less than 2 mm in length (J. V. Matthews, pers. comm.).

At present *Menyanthes* is a monotypic genus, and the seeds from Kap København are identical with modern *M. trifoliata* seeds with respect to size (Fig. 63), shape and anatomy of testa. The epidermal cells of the testa are elongated in surface view and narrow-high in cross-section (Fig. 59l).

Recent distribution. – *M. trifoliata* is a widespread circumpolar temperate and low arctic plant (Fig. 61). In West Greenland it is rather common north to latitude *c.* 69°N, while in East Greenland it has only been found in a single lake (Fredskild et al. 1982).

Ecology. – *M. trifoliata* is a herb which grows in shallow water in lakes, ponds, bogs, and in wet meadows. It prefers acidic mesotrophic or oligotrophic water.

Caprifoliaceae

Viburnum cf. *edule* (Michx.) Raf.
Fig. 62d

Material. – 3 endocarps (GCI 53214, locality 122; 56692, locality 119 and 64980, locality 157, all from unit B3).

Remarks – The endocarps are flat, ovate or elliptic in outline. They measure 5.8–6.1 mm in length, 4.5–4.8 mm in breadth and 0.9–1.0 mm in thickness.

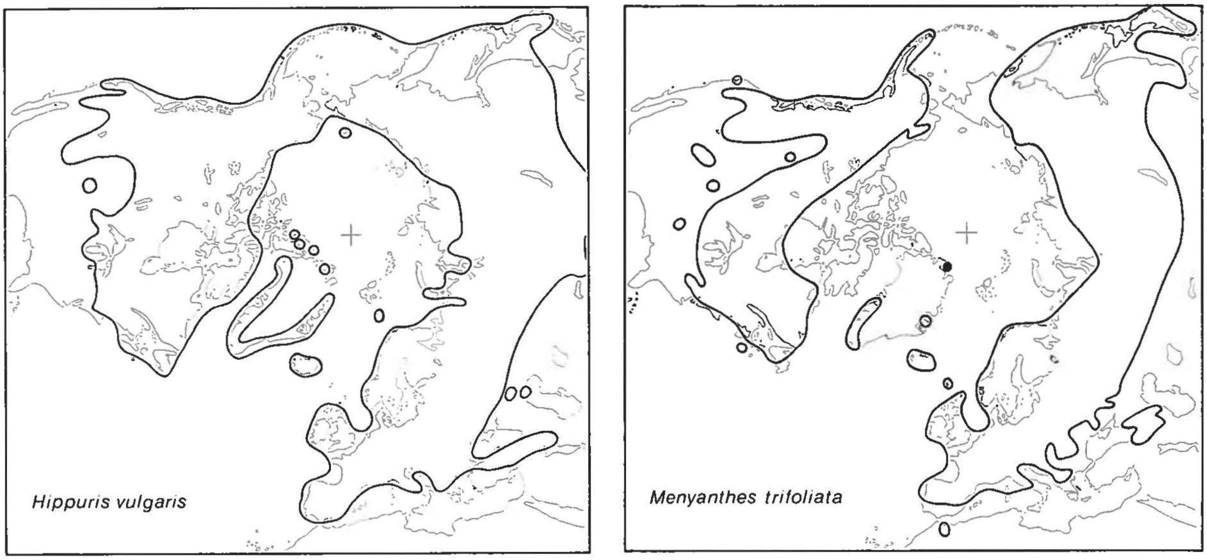


Fig. 61. Modern geographical range of *Hippuris vulgaris* and *Menyanthes trifoliata* based on Hultén (1970).

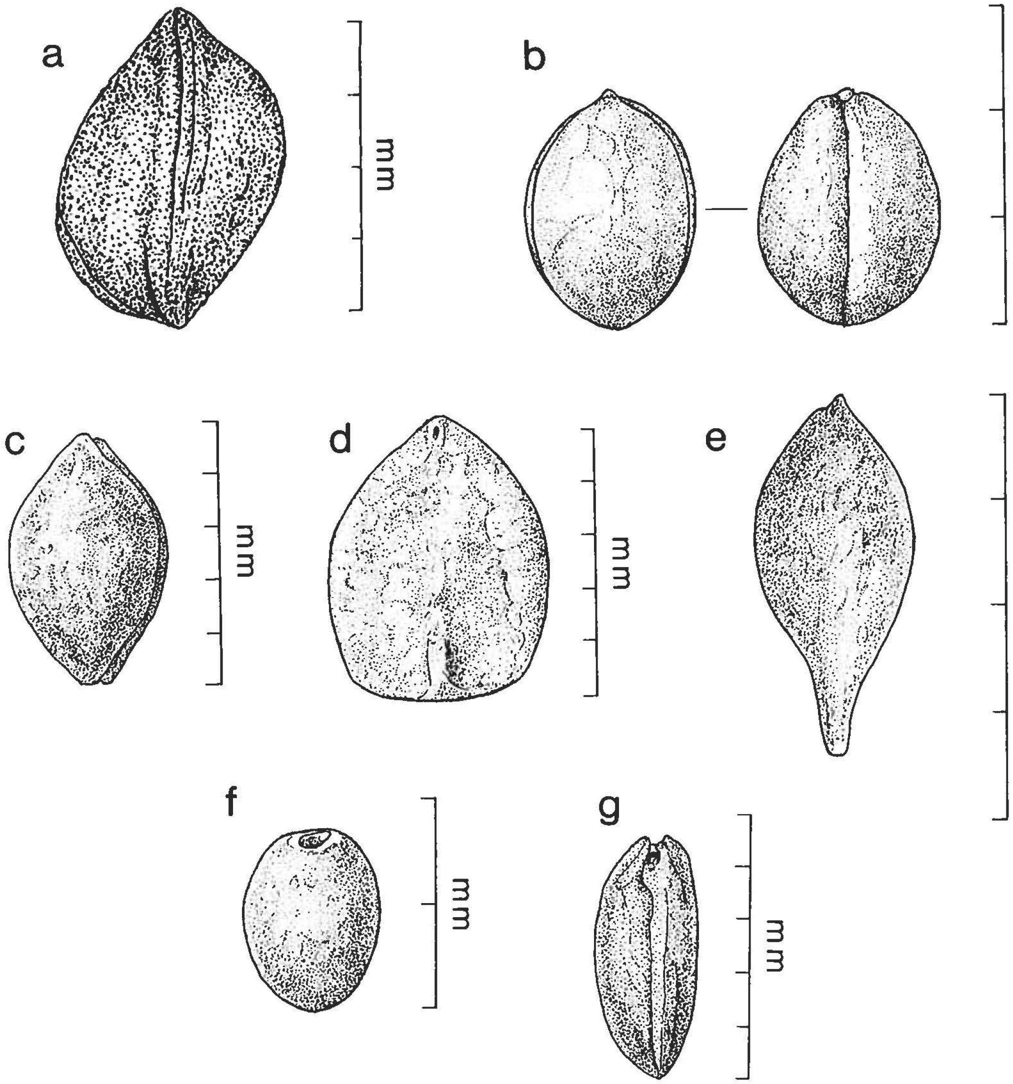


Fig. 62. a: *Cornus stolonifera* endocarp, MGUH 19243, GCI 56692, locality 119. b: *Cornus canadensis* endocarp, MGUH 19244, GCI 53267, locality 132. c: *Cornus* sp. A endocarp, MGUH 19245, GCI 56692, locality 119. d: *Viburnum* cf. *edule* endocarp, MGUH 19246, GCI 56692, locality 119. e: *Sparganium angustifolium* tp. endocarp, MGUH 19247, GCI 53214, locality 122. f: *Aracites globosa*, MGUH 19248, GCI 53214, locality 122. g: *Carpolithes* sp. A, MGUH 19249, GCI 56692, locality 119.

The genus *Viburnum* includes 120 species (Hutchinson 1967) of which the fossil endocarps were compared with 11 northern species. They are quite similar to those of *V. edule*, and smaller than endocarps of *V. opulus* L. var. *americanus* Ait., which are about 9 mm long. However, since all species were not seen and intraspecific variation was large in the reference material that was studied, the identity of the fossils remains tentative.

Recent distribution. – *Virburnum* species are widely distributed in boreal North America where they reach the arctic tree line (Hultén 1968).

Ecology. – Most species are upright shrubs, 1–2.5 m tall. They commonly grow in wet thickets, along brooks, in damp valleys and along the edges of forests.

Scrophulariaceae

?*Linaria* sp.

Material. – 1 seed (GCI 56666, locality 77, unit B3).

Remarks. – The seed is flat, smooth and narrowly winged. It is D-shaped in outline and it measures 1.9 mm in length and 1.4 mm in breadth. The small epidermal cells are polygonal.

Linaria seeds are diverse, but many are winged. Seeds of only a limited number of species were investigated, and the fossil seeds were not strictly comparable to any of these. The genus comprises about 150 species.

Recent distribution. – The genus *Linaria* is widely

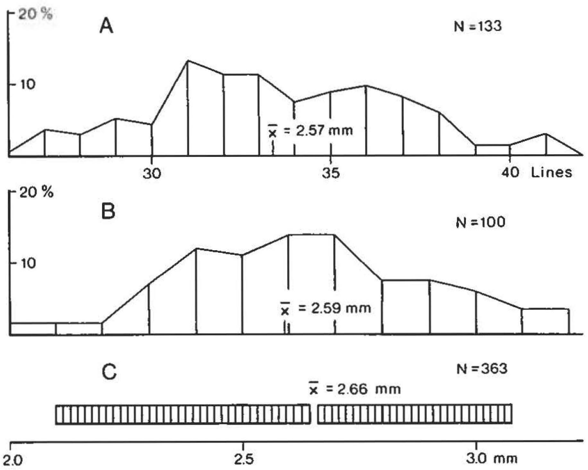


Fig. 63. Length of *Menyanthes trifoliata* seeds. A: fossil seeds from Kap København (56673, 56674 and 56678). B: recent seeds from Eurasia (Jentys-Szaferowa & Truchanówiczowa 1953). C: recent seeds from Japan (Kokawa 1959).

distributed. *L. vulgaris* Hill extends into the European part of the Arctic (map in Hultén (1968)).

Ecology. – The genus consists of herbs which grow in open areas. *L. vulgaris* is characteristic of pastures with dry soil.

Potamogetonaceae

Most of the endocarps of *Potamogeton* were identified to species, although difficulties due to the taxonomic complexity of the genus, intraspecific variation and inadequate preservation posed problems. Also, knowledge and reference material of the North American species is scanty.

The lid was missing in many of the endocarps (terminology follows Aalto (1970)). The outer fleshy layer was partially preserved in two endocarps. Beak and stalk were normally absent.

Potamogeton natans L.
Figs 64a-d
Material. – 13 endocarps
Remarks. – The shape of the endocarp is obovoid. Ventral area in side view S-shaped. The sides are convex with a depression in the center and an indistinct furrow towards the ventral margin. There is a pronounced interval between the apex of the lid and the beak. The beak is ventrally placed. The lid is roof shaped; its apex V-shaped, and base U-shaped. The beak is strong. Length of endocarp: 1.6 (2.24) 2.7 mm, breadth 1.5 (1.78) 2.2 mm (n = 7). This is slightly less than reported by Aalto (1970).

Recent distribution. – The range of *P. natans* is circumpolar, boreal (Fig. 65, see also Porsild & Cody 1980). The species has been recorded from a single inland lake in southernmost Greenland (Polunin 1943) where the climate is subarctic.

Ecology. – *P. natans* grows in lakes, ponds and in streams with slow currents, usually at water depths of less than 1 m, and on a substratum rich in organic material.

Potamogeton cf. *perfoliatus* L./*richardsonii* (Benn.) Rydb.
Figs 64e-f
Material. – 3 endocarps (GCI 56692, locality 119; 64965, locality 146 and 64990, locality 77, all from unit B3).
Remarks. – The shape of the endocarp is oval to roundish in outline. The ventral margin is s-shaped in side view, the dorsal is convex. A prominent boss exists in the middle of the ventral area. The sides are flat with a central depression. Two "warts" are situated near the base. The lid, which is roof-shaped in cross-section, reaches the strongly developed beak. The endocarps are large, 2.5 to 3.1 mm long.

These endocarps are with hesitation referred to either *P. perfoliatus* or *P. richardsonii*, having morphologically variable endocarps. Aalto (1970) discusses the identification of endocarps of *P. perfoliatus* contra *P. richardsonii*. The two species are closely related, and Hultén (1962) considers the latter a subspecies of *P. perfoliatus*. The writer considers them a species pair, the endocarps of which cannot be distinguished.

Recent distribution. – The range of the two species is circumpolar (Hultén 1962). Together they are widely distributed in temperate climates and reach the Low Arctic. The northernmost record is an isolated one from central East Greenland (Lægaard 1960). *P. perfoliatus* occurs in Europe, Asia and Alaska, while *P. richardsonii* occurs in North America, where its northern limit follows the limit of trees (Porsild & Cody 1980).

Ecology. – Both species live in lakes and sluggish streams, usually in calcareous or brackish water, at depths up to 3 m.

Potamogeton cf. *gramineus* L.
Fig. 64g
Material. – 2 endocarps (GCI 56678, locality 74 and 64987, locality 77, both from unit B3).
Remarks. – The endocarps are broadly elliptic in outline. Both the ventral and dorsal margins are convex in side view. The side of the fruit is flat. The lid, which is roof shaped, reaches the base of the beak which is centro-ventral and well developed. The wall of the endocarp seems to be thin for the genus. Length of endocarp: 1.7–2.7 mm, breadth: 1.4–1.9 mm.

Recent distribution. – The range of *P. gramineus* is circumpolar, boreal with outposts in the Arctic. It grows in West Greenland northwards to latitude 68°N.

Ecology. – *P. gramineus* grows in mesotrophic or iron-rich water in lakes, ponds and streams, often at relatively great depths.

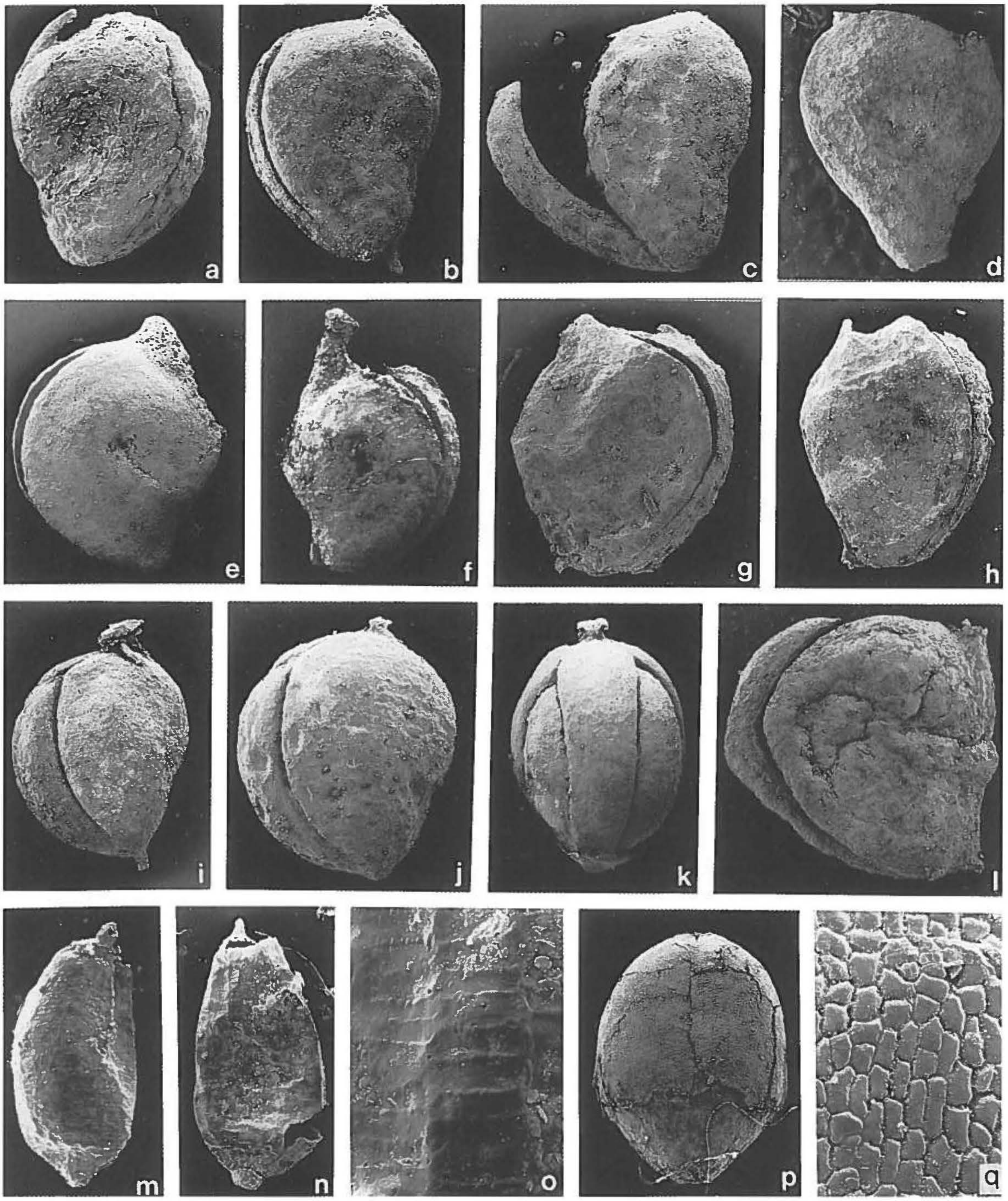


Fig. 64. a-l: *Potamogeton* endocarps. a-d: *P. natans*. a: MGUH 19250, GCI 64965, locality 146, x20. b: MGUH 19251, GCI 64991, locality 77, x16.6. c: MGUH 19252, GCI 64988, locality 77, x15.7. d: MGUH 19253, GGU 197118, locality 50, x17.6. e-f: *P. perfoliatus/ richardsonii*. e: MGUH 19254, GCI 64965, locality 146, x14.3. f: MGUH 19255, GCI 64990, locality 77, x11.6. g: *P.* cf. *gramineus*, MGUH 19256, GCI 56678, locality 74, x23. h: *P. alpinus*, MGUH 19257, GCI 56666, locality 77, x18.4. i-l: *P.* cf. *vaginatus*. i: MGUH 19258, GCI 53214, locality 122, x13.7. j: MGUH 19259, GCI 56692, locality 119, x14.9. k: Anomalous endocarp with two lids, MGUH 19260, GCI 64965, locality 146, x13.7. l: MGUH 19261, GGU 197118, locality 50, x23. m-n: *Juncus* sp. seeds. m: MGUH 19262, GCI 53203, locality 119, x78. n: MGUH 19263, GCI 53286, locality 130, x69. o: Detail of n, x440. p-q: ?*Luzula* sp. seed. p: MGUH 19264, GCI 53214, locality 122, x28. q: Detail of p, x220. All figures are SEM micrographs.

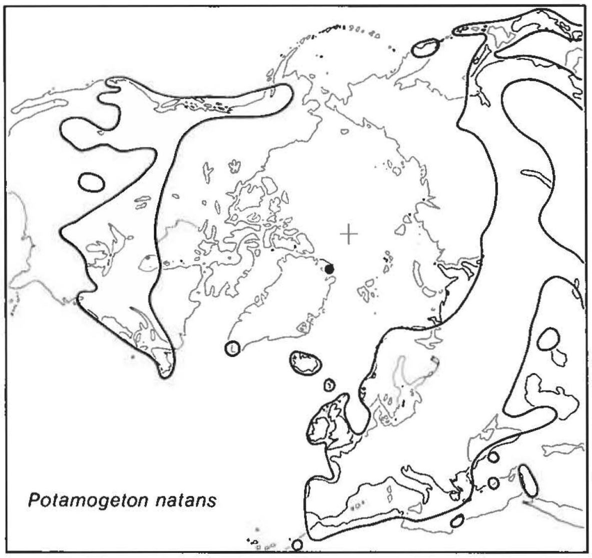


Fig. 65. Modern geographical range of *Potamogeton natans* based on Hultén (1962).

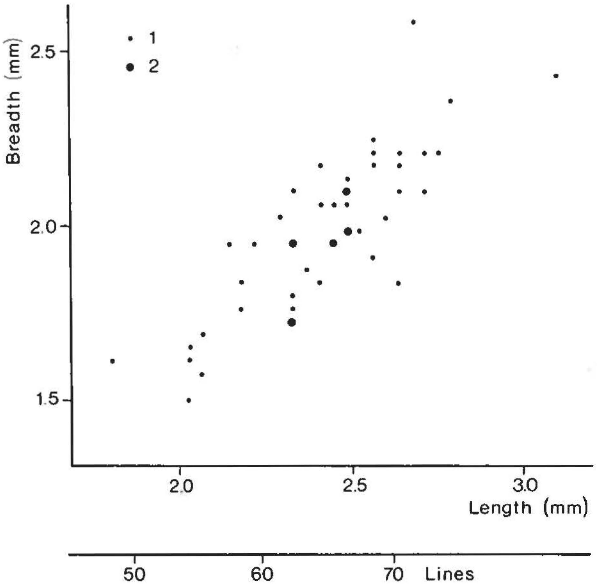


Fig. 66. *Potamogeton* cf. *vaginatus*. Relationship between length and breadth in 46 measurable endocarps from 53214, 53262, 53264, 53266, 53267, 53280, 56692, 64965, 64988, 64990 and 64991. Large dots indicate two specimens of same size. Mean length is 2.41 mm, mean breadth is 1.98 mm.

Potamogeton alpinus Balb.
Fig. 64h
Material. – 1 endocarp (GCI 56666, locality 77, unit B3).
Remarks. – The shape of the endocarp is oval in outline, and it has flat sides. The ventral area is slightly S-shaped in side view. The lid reaches the top of the endocarp but there is a great distance between the top of the lid and the beak. The area between the top of the lid and the beak is almost straight. The endocarp measures 2.21 × 1.73 mm.

Recent distribution. – *P. alpinus* is widely distributed in temperate and low arctic climates of the northern hemisphere (Hultén 1962). It grows in continental Southwest Greenland northwards to latitude 67°N.

Ecology. – The species grows on rich, organic substrates in lakes and ponds with mesotrophic water.

Potamogeton cf. *vaginatus* Turcz.
Figs 64i-l
Material. – 88 endocarps.
Remarks. – Two forms were separated:

1) Shape crescentic. Ventral area in side view almost straight via convex to somewhat S-shaped. Sides convex. There is a long interval between the apex of the lid and the beak. In cross-section the lid is rounded, sometimes with an indistinct keel. The base of the lid is rounded, U-shaped; the apex is V-shaped. The beak is centro-ventrally placed and small. The stalk is usually lacking, when present it is indistinct. The surface of the endocarp is mat, spongy. The mean length of the endocarp is 2.41 mm, the mean breadth is 1.98 mm (Fig. 66).
2) D-shaped endocarps with the ventral area straight in side view and the sides flat. Otherwise as form 1. Length of endocarp 1.7 (1.93) 2.2 mm, breadth 1.2 (1.48) 1.8 mm (n = 13).

The first mentioned form compares rather well with Aalto's (1970) description of *P. vaginatus* although the lid of *P. vaginatus* is described as rounded with a distinct ridge, and with a tapering base.

The second morphotype differs in shape from normal *P. vaginatus* endocarps, and its size is within *P. filiformis* Pers. size range. However, it is believed to derive from the same species as form 1.

These endocarps also show resemblance to related Plio-Pleistocene species, such as *P. praevaginatus* Dorof. *P. vaginatoides* Dorof. and *P. arctovaginatus* Dorof. (Dorofeev 1986).

Recent distribution. – The species has its main areas of distribution in North America and western central Siberia, but it also occurs around the bottom of the Gulf of Bothnia. It extends slightly beyond the arctic tree line.

Ecology. – In Scandinavia *P. vaginatus* is confined to brackish water, but otherwise it grows in fresh or somewhat brackish water. It inhabits rather deep water, up to 2 m deep.

Juncaceae

Juncus sp.
Figs 64m-o
Material. – 1 seed (GCI 53214, locality 122, unit B3).
Remarks. – The seed is narrow elliptic in outline and very small, 0.55–0.61 mm long and 0.27–0.31 mm broad. The testa is thin, with the epidermal cells transversely elongated and arranged in longitudional rows. The anticlinal walls form a reticulum on the seed surface. These seeds are referred to *Juncus* sp. because of their small size and testa structure. Species identifications are not possible until the seeds of the extant, northern *Juncus* species have been studied in detail (cf. Körber-Grohne 1964).

Recent distribution. – *Juncus* is a large genus of wide distribution. 13 species reach the Arctic (Polunin 1959).

Ecology. – *Juncus* are grass-like herbs. Most of the species are characteristic of wet and moist places, though some also occur in upland situations.

?*Luzula* sp.
Figs 64p-q
Material. – 5 seeds (GCI 53214 & 56692 (4)).
Remarks. – The seeds are elliptic in outline, about 1.4 mm long and 1.0 mm wide. The testa, which is rather thin, is missing from the basal part of the seed where the elaiosome probably was placed. The epidermal cells measure 15–20 µm across and their centre is raised.

Recent distribution. – *Luzula* is a rather small but widespread genus mostly of northern regions. Eight species occur in the Arctic (Polunin 1959).

Ecology. – Although some species inhabit bogs and marshes, most species in this genus of grass-like plants grow in dry or moist places.

Cyperaceae

Carex spp.
Figs 67a-g
Material. – *c.* 240 2-sided and *c.* 325 3-sided achenes.
Remarks. – Naked achenes of *Carex* occur abundantly in the material. Many different species are represented, but specific identifications are usually not possible without the enclosing perigynium. Also there are many modern species, many of which exhibit considerable intraspecific variability.

In recent years the taxonomic significance of the micromorphology of the achene surface (after removal of the outer wall of the epidermal cells) have been stressed (e.g. Walter 1975, Thomasson 1983). This technique holds some promise for more secure identifications of fossil achenes, but it depends on a thorough knowledge of the modern species, including their inter- and intraspecific variation.

Ecology. – The genus *Carex* is characteristic of wet and moist soil and it is important in many wet land areas. But some members of the genus grow in upland sites.

Carex cf. *chordorrhiza* Ehrh. in L. fil.
Figs 67h-i
Material. – *c.* 15 achenes with perigynia.
Remarks. – A single *Carex* type often retained the perigynium, which is elliptic in outline and planoconvex in cross-section. The beak is not preserved. The wall is spongy, with distinct nerves 30–65 µm wide. Most of the nerves (9 on the dorsal side and 6–7 on the ventral side) are as long as the perigynium. Size 2.1–2.6 x1.1–1.5 mm (length × breadth).

The achene was studied in two specimens. It is biconvex, obovate in outline, has a short style, and almost fills the perigynium. Size 1.5–1.65x0.8–0.9 mm.

This *Carex* type is identical with *Carex chordorrhiza*, but the identification is tentative because not all modern northern *Carex* species were studied.

Recent distribution. – *C. chordorrhiza* is of circumpolar boreal distribution (map in Hultén 1962). It has been found only once in Greenland, in the very south, but it occurs slightly beyond the arctic tree line through most of its range.

Ecology. – *C. chordorrhiza* often grows in floating mats around the margin of lakes and in raised bogs, but it also grows in wet marshes.

Scirpus microcarpus Presl.
Figs 67j-n
Material. – *c.* 30 achenes, 18 of which from GCI 53265.
Remarks. – The achenes of *Scirpus* are almost flat on the one face, whereas those of biconvex *Carex* are equally convex on both faces. Another distinguishing feature is that a few of the fossil *Scirpus* achenes retained the bristles which are found in *Scirpus* and a few other genera of Cyperaceae.

The shape of the achene is obovate in outline. Its length averages 1 mm, the bristles when present are slightly longer. When the outer wall is missing the epidermal cell pattern is very characteristic in this species (Fig. 67). The cells have strongly undulating anticlinal walls and a central, hemispherical silica (?) body.

The achenes are comparable in size and shape to those of *S. microcarpus*, *S. atrovinctus* Fern., *S. silvaticus* L. and *S. rubrotinctus* Fern. The last is here considered a subspecies of *S. microcarpus* following Hultén (1968) and Scoggan (1978–1980), although Beetle (1943) considered it a distinct species. The central body of the epidermis cell is larger in *S. silvaticus* and *S. atrovinctus* than in the fossil achenes, and the cells are more quadrangular in *S. atrovinctus* than in the fossil achenes from Kap København, according to illustrations in Schuyler (1971) and the writer's observations.

Recent distribution. – Except for an isolated occurrence on Kamchatka, the range of *S. microcarpus* (including ssp. *rubrotinctus*) is in the boreal forests of North America (Fig. 37). Towards the north the species reaches the arctic tree line, but it is not a member of the arctic flora.

Note on history. – The species has recently been

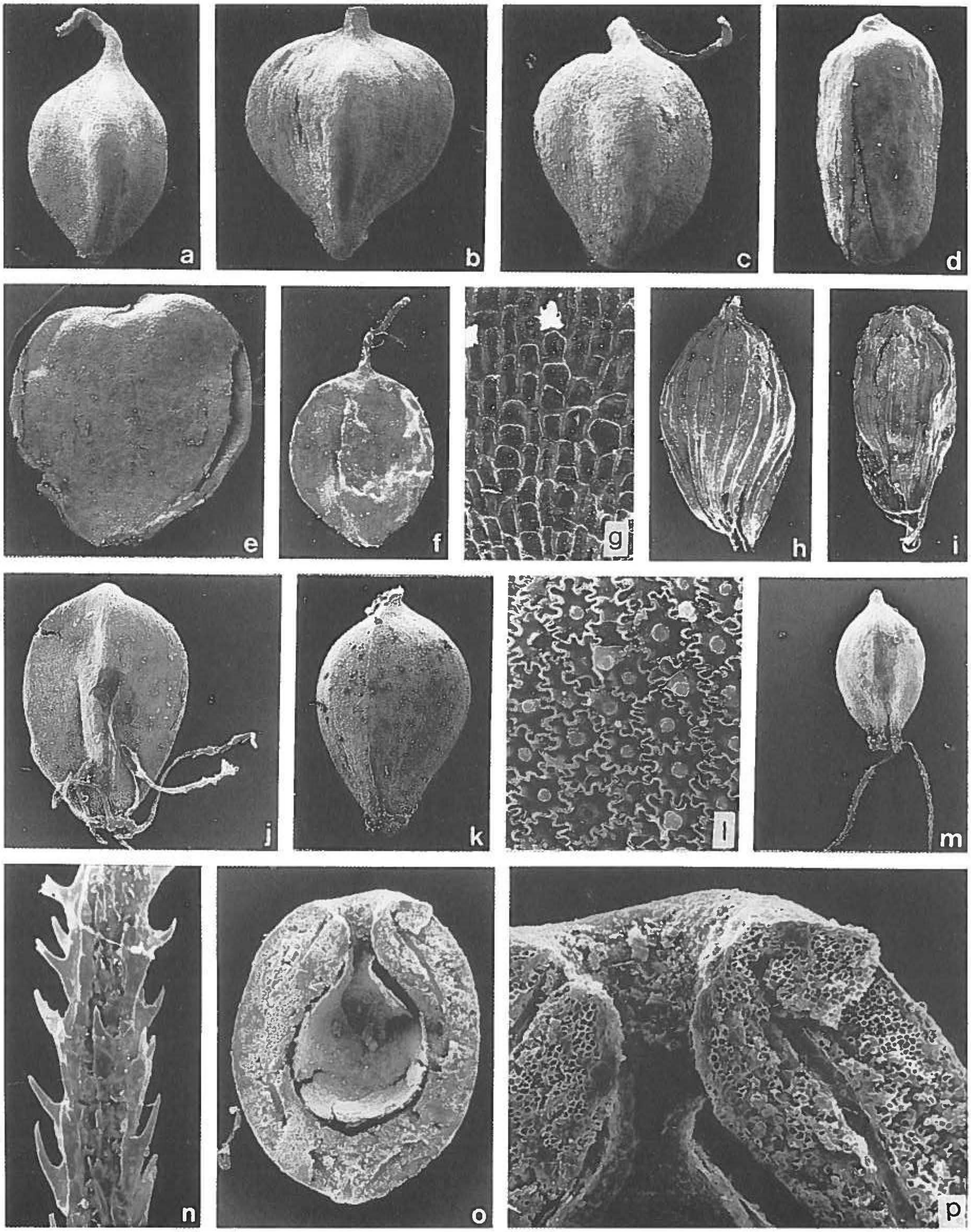


Fig. 67. a-g: *Carex* spp. achenes. a-d: 3-sided types. a: MGUH 19265, GCI 56692, locality 119, x19. b: MGUH 19266, GCI 53202, locality 119, x24. c: MGUH 19267, GCI 56692, locality 119, x24. d: MGUH 19268, GCI 53214, locality 122, x24. e-g: 2-sided types. e: MGUH 19269, GCI 53267, locality 132, x14.9. f: MGUH 19270, GCI 56692, locality 119, x16.4. g: Detail of f, x205. h-i: *Carex* cf. *chordorrhiza* perigynia. h: MGUH 19271, GCI 56693, locality 119, x15.3. i: MGUH 19172, GCI 53214, locality 122, x18.3. j-n: *Scirpus microcarpus* achenes. j: MGUH 19273, GCI 53203, locality 119, x40. k: MGUH 19274, GCI 53266, locality 132, x38. l: Detail of k. The cuticle and outer layer of the epidermal cells are eroded away, exposing the inner periclinal walls of the epidermal cells, x540. m: MGUH 19275, GCI 56692, locality 119, x21. n: Detail of j showing part of bristle with barbellae, x265. o-p: *Aracites globosa* fossil (sectioned), MGUH 19248, GCI 53214, locality 122. o: x34. p: x110. All figures are SEM micrographs.

found in Late Cainozoic near Strathcona Fjord on eastern Ellesmere Island (J. V. Matthews, pers. comm.).

Ecology. – *S. microcarpus* is a tall sedge, up to 1 m tall. The species grows in wet marches and at lake shores (Scoggan 1978–1980).

Gramineae

Gen. et sp. indet.

Material. – 1 caryopsis (GCI 56608).

Remarks. – The only recovered grass fruit was badly preserved and could not be identified.

Sparganiaceae

Sparganium angustifolium tp.

Fig. 62e

Material. – 1 fruit (GCI 53214, locality 122) and 3 endocarps (GCI 56692, locality 119 and 64991 (2), locality 77), all from unit B3).

Remarks. – The fruit, narrowly ovate in outline and yellow in colour, is 3.2 mm long and 1.2 mm broad. The endocarps are ovate in outline and elongated below into a short stalk. They are yellow brown in colour and measure 2.4–3.3 mm in length and 1.4–1.9 mm in breadth. Both the fruit and the endocarps are smooth. The isolated endocarps are bigger than the endocarp of the entire fruit, but this is probably because the fruit is immature.

Because the endocarps are smooth they belong in the subgenus *Xanthosparganium* Holmberg (see Cook & Nicolls 1986, 1987). The same appears to apply to the fruit as it is small and has no indication of an endocarp with ridges. Because of the scanty material a specific identification was not possible. However, the endocarps do not compare with the two species *S. hyperboreum* Beurl. ex Laest. and *S. natans* L., both of which have stalkless endocarps.

Recent distribution. – The subgenus *Xanthosparganium* is widely distributed in the northern hemisphere. The only species which reach the Arctic (including Greenland) today are *S. hyperboreum* and *S. angustifolium* Michx.

Ecology – The subgenus comprises seven species (Cook & Nicolls 1986) of aquatic or semi-aquatic grass-like perennial herbs which grow in shallow water, but *S. angustifolium* may occasionally grow to a depth of 2.5 m or more.

Insertae sedis

?Araceae

Aracites globosa (Reid & Reid) Bennike, comb. nov.

Figs 62f, 67o-p

Material. – Two fossils (MGUH 19248, GCI 53214 (locality 122, unit B3, sectioned) and GCI 56666, locality 77, unit B3).

Lectotype. – This fossil was first described by Reid & Reid (1915). They referred it to *Hippuris* (*H. globosa* sp. nov. (and *Hippuris* sp. 2?)). Unfortunately, the holotype of *H. globosa* has dissapeared (W. H. Zagwijn, pers. comm.), but I propose to designate Reid & Reid's figure (Reid & Reid 1915, plate XIV, fig. 24) as a lectotype.

Remarks. – The fossils are wide elliptic to obovate in outline, the base is rounded and the surface is smooth, black. Both fossils are somewhat flattish. The one measures 1.5x1.2 mm, the other 1.6x1.3 mm. One of the fossils was sectioned; it shows a thick wall and a pear-shaped cavity extending upwards into a canal (micropyle ?) which opens through a pore. The wall is subdivided into two layers; the outer thick one is formed from isodiametric parenchyma cells with smooth walls, and is thickest at the base and top. In the sectioned part of the wall two narrow ducts are seen, they run from base to top. According to P. A. Nikitin (1957) three ducts – called "fibro-vascular fascicles" – are present. Inside the thick wall is a thin layer (integument, cuticula or perhaps testa), partly loosened from the outer layer.

This fossil type was referred by P. A. Nikitin (1957) to seeds of the family Araceae which comprise *c.* 1800 species, mostly in tropical and sub-tropical regions. It may, however, be questioned whether they are seeds or fruits. Reid & Reid (1915), who first described this fossil type, referred it to fruits of *Hippuris*, and Matthews (1987) also proposed that they are fruits, although he retained it in the family Araceae. Katz & Katz (1964) proposed that the fossil is a seed belonging to a member of the family Cucurbitaceae.

P. A. Nikitin (1957) referred the Russian fossils to the species *Aracites johnstrupii* (Hartz) comb. nov. However, the fossils described and named as *Carpolithes johnstrupii* by Hartz (1909) in honour of the Danish professor of geology Fr. Johnstrup, and derived from Miocene brown coal deposits in Jutland and amber-twig beds on Zealand, were reexamined by Kircheimer (1938, 1957 p. 234). He showed that they belong in the genus *Myrica* subgenus *Morella*, and Friis (1985) proposed the new combination *Myrica johnstrupii* (Hartz) Friis nov. comb. for this fruit type which dehisces into two equal valves.

Dorofeev (1963) transferred the species described by P. A. Nikitin (1957) to the form-genus *Aracispermum*. This genus name was used already in 1948 by P. A. Nikitin (P. A. Nikitin 1948), but it was not formally established until 1965 (P. A. Nikitin 1965). Prior to that, however, three species within the genus were established, namely *A. ovale* (Dorofeev 1960), *A. arnense* (Chandler 1962) and *A. compressum* (Dorofeev 1963). The three species *A. jugatum*, *A. canaliculatum* and *A. hippuriformis* formally established by P. A. Nikitin (1965) were also described and figured by Dorofeev (1963). It should be noted that the name *Aracispermum cordiformis* mentioned by P. A. Nikitin (1948) is a *nomen nudum*. In 1979 V. P. Nikitin described a new species of *Aracispermum*: *A. orientalis* (V. P. Nikitin 1979b).

In 1977 Velichkevich erected a new species of *Aracites*: *Aracites interglacialicus* Wieliczk sp. n. (Velichkevich 1977). In 1982 he described this species in more detail and changed the name to *Aracites interglacialis* (Velichkevich 1982). *A. interglacialis* fossils are slightly larger, more elongate and more often have a pointed base (or even a stalked base) than *A. globosa*. However, there is a large overlap between the two species, and the writer proposes to put them in synonomy.

Velichkevich (1982) and V. P. Nikitin (1979b) have argued to maintain *Aracites* and *Aracispermum* as separate genera, as P. A. Nikitin originally proposed. This view is followed here, because the two groups are distinctly different. *A. ovale* should possibly also be referred to *Aracites*.

Notes on history. – *Aracites* sp. has been recovered from Pliocene deposits in Holland (Reid & Reid 1915 – apparently there are no more recent records (W. H. Zagwijn, pers. comm.)), Miocene deposits in Poland (Szafer 1961 – as *Hippuris globosa*)), Pleistocene deposits in Poland (Sobolewska 1977), Pleistocene interglacial deposits in Finland (Aalto & Hirvas 1987), Miocene (?), Pliocene and Pleistocene deposits in Russia (P. A. Nikitin 1957, Dorofeev 1959, 1963, 1969, Velichkevich 1977, 1982), Siberia (Baranova 1978, V. P. Nikitin 1979a, c) and Neogene deposits of northern Canada (Matthews 1987, 1989, Klassen et al. 1988). V. P. Nikitin has proposed to call *Aracispermum jugatum Aracites jugatus*. This species already appeared in the Late Eocene.

Ecology. – According to P. A. Nikitin (1957) fossils of *Aracites* mostly occur in assemblages of mire plants, rather than in assemblages of water plants.

Carpolithes sp. A
Fig. 62g
Material. – 1 fruit (GCI 56692, locality 119, unit B3).
Remarks. – Several unknown fruits were found, of which one should be mentioned. It is ellipsoidal with distinct longitudional ridges and furrows, and show some resemblance to *Ilex* fruits. This fruit type also occurs in the Beaufort Formation on Prince Patrick Island and at one Quaternary site in the northern Yukon (J. V. Matthews, pers. comm.).

Wood

The sandy hills to the north and northwest of Mudderbugten contain an abundance of wood. L. Koch (1928, p. 381) noted the presence of wood in this area at altitudes of 165 m above sea level, but he thought the wood was Holocene driftwood indicating a high Holocene marine limit. Undoubtedly, it was a piece of wood from the same area that was sampled by W. E. Davies and radiocarbon dated to > 32,000 years B.P. (I-371, Trautman & Willis 1966; described as "wood (willow?) from top of terminal moraine of continental glacier, 450 ft above sea level").

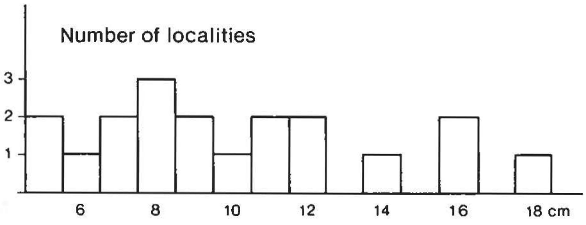


Fig. 68. Maximum tree trunk diameter from 19 localities with wood.

Funder & Hjort (1980) interpreted the wood as driftwood of presumed Siberian origin, but of pre-Holocene age. However, the close association of wood with cones and needles of conifers, and the excellent preservation of the wood, often with branches still attached, shows that the wood is of local origin. However, no rooted trees in growth position have been located, so all of the wood is thought to be local driftwood. Some small pieces of wood from samples of organic detritus have been rounded during transport.

The size of the tree trunks is small to moderate, the largest piece (from locality 75) had a diameter of 18 cm, and was 460 cm long. The second largest piece (also from locality 75) measured 16 cm across and was 335 cm long. Wood pieces measuring more than 10 cm across are rare (Fig. 68), so the trees were small. Many of the trees show stunted growth, and a single almost complete specimen of *Larix* (?) shows decumbent growth. A number of conifers with abandoned top shoots have been noted.

A characteristic feature of the trunks retaining parts of branches are that the branches are usually deflected downwards. This is interpreted as a result of heavy snow load during the winter.

Roots are preserved in a few specimens. They appear to represent shallow root systems and probably did not penetrate far into the soil. This could be due to permafrost conditions or wet soil.

Cross-sections of tree trunks show pronounced growth rings, and ring width series were measured under a dissecting microscope in 15 of the best preserved trunks (12 samples of *Larix*, 2 of *Picea* and one of *Thuja*). The series were measured along radii of intermediate length. Several cases were recorded where trees had been tilted during growth – as evidenced by growth rings formed asymmetrically in the stem after the years of tilting and by compression wood, recognised under the microscope by rounded tracheids and associated intercellular spaces. This hampered the measurements of ring width series. The advantage of ring width measurements is that climatic interpretations are based directly on fossils and are more or less inde-

Table 6. Summary of growth ring analyses

GCI number	MGUH number	Locality	Genus	Number of rings	Mean ring width (mm)
53214,1	19276	122	*Larix*	93	0.31
53214,3	19277	–	–	107	0.23
53214,4	19278	–	–	108	0.44
53287,2	19279	131	–	78	0.49
53299,1	19280	75	–	296	0.28
53300,1	19281	133	–	122	0.35
53300,2	19282	–	–	99	0.41
53300,3	19283	–	–	89	0.20
56620	19284	17	–	107	0.36
56667,25	19285	77	–	73	0.42
56667,26	19286	–	–	126	0.30
64954,1	19287	136	–	165	0.25
Larix total				1463	0.32
53214,2	19288	122	*Picea*	51	0.78
56667,24	19289	77	–	57	0.44
Picea total				108	0.60
64954,2	19290	136	*Thuja*	111	0.20

pendent of species identifications and the present climatic tolerances of the species.

The average growth ring widths were 0.32 mm for *Larix*, 0.60 mm for *Picea* and 0.20 mm for *Thuja* (Table 6). These values indicate that radial growth rates were very low, and imply extreme growth conditions. The maximum ring width is 0.98 mm for *Larix* and 1.05 mm for *Picea*, showing that even during the most favourable summers growth rate was low. The rather large variability in ring width from year to year (Fig. 69) indicates that summer temperatures – the factor which limits growth at the arctic tree line (e.g. Hustich 1949) – also showed pronounced yearly variations.

The common presence of light rings (rings with very few late wood cell layers) also points to low summer temperatures and is especially an indication of shortened growing seasons (Filion et al. 1986).

The extremely narrow growth rings compare with those from the present arctic tree line (e.g. Hustich 1954, Kay 1978, Filion et al. 1986), although this is presently situated far south of Kap København, in a yearly light regime much different from that at Kap København today.

119 pieces of wood have been identified by their anatomy (Table 7). All wood originates from unit B3 exept for some *Salix* wood fragments in the lower part of unit B2, locality 27. The gymnosperm wood is generally well preserved, whereas the angiosperm wood shows some degree of deterioration. *Larix* wood is well known for its resistance to decay, but taphonomic factors (rooting) are not thought to be responsible for the dominance of *Larix* wood.

Larix wood is very difficult to distinguish from *Picea* wood. In this study *Larix* wood was identified by abrupt transition from early wood to late wood, biseriate bordered pits in the radial walls of tracheids and by the dominance of *Larix* type bordered pits in the ray tracheids (Ingvarson 1903, Petersen 1906, Bartholin 1979a, b). Compression wood of *Larix/Picea* (mostly branch wood) was excluded.

Arboreal type growth has only been proved for *Larix* (76 pieces), *Picea* (22 pieces) and *Betula* (one piece). *Taxus* is represented by a single branch, sampled and identified by G. S. Mogensen (pers. comm.). *Thuja* is represented by an almost complete specimen, with root, stem and branches, some of which with adhering bark. Although of tree growth form, the specimen is only 75 cm tall and consequently cannot qualify as a tree. Its branches are deformed by snow load.

Many wood pieces are bored by insect larvae. Most common are borings of Cerambycidae larvae, and fly holes very similar to those produced by *Urocerus gigas* (Funder et al. 1984). Also present in the material are insect galleries produced by Buprestidae and Scolytidae larvae (kindly identified by M. Nuorteva).

About half of the larger wood pieces are glacio-tectonically deformed. The common deformation structures are kink bands and kink folds which form monoclinic and conjugate folds (Fig. 70). The scale of the

Table 7. Subfossil wood identifications

	Log wood	Branch wood
Gymnospermae		
Picea sp.	22	
Larix sp.	76	
Picea/Larix	10	
Thuja sp.	2	
Taxus sp.		1
Angiospermae		
Betula sp.	1	2
Salix sp.		5

Total number of samples: 119

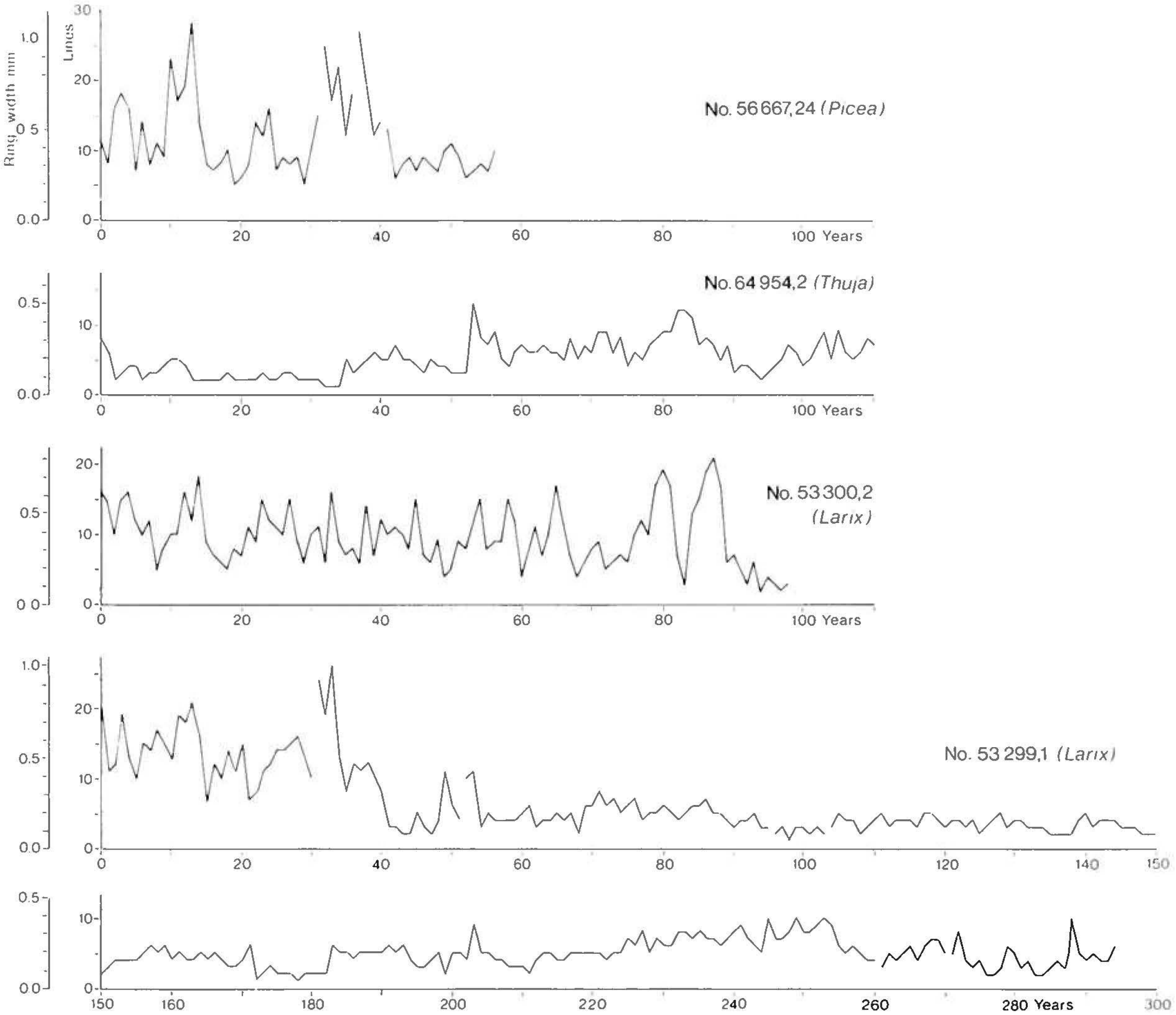


Fig. 69. Selected examples of ring-width series. Broken lines indicate poorly preserved rings. Diameter of 56667,24 is 8.5 cm, of 64954,2 4.6 cm, of 53300,2 8,5 cm and of 53299,1 17 cm.

structures, which must have been formed while the wood pieces were embedded in the frozen sediments, is from *c.* 1 cm to *c.* 10 cm (Bennike 1988).

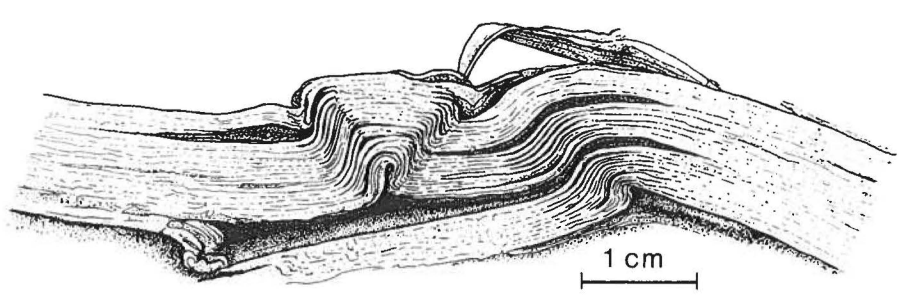
Fossil wood has been reported from the Beaufort Formation in arctic Canada. The Mio-Pliocene sediments on Meighen Island contain transported wood but very few of the tree trunks exceed 18 cm in diameter. On northern Banks Island logs from the lower part of the Beaufort Formation up to 60 cm in cross-section or more are present (J. V. Matthews, pers. comm.). On Prince Patrick Island, north of Banks Island, most trunks from the Beaufort Formation are 10 cm or less in diameter, but isolated logs exceed 40 cm (Fyles 1987). From the Worth Point Formation on Banks Island *Larix laricina* trunks up to 26 cm in diameter have been reported (Kuc 1974).

Pollen

Pollen analyses were performed to supplement the work on macroscopic plant remains, and to investigate if any vegetational time trends could be established. Thus marine silt with hardly any macroscopic plant remains was analysed, along with fine sand containing organic detritus. Another aim was to determine if the pollen assemblages from unit B2 at different localities differ from one another to the same extent as the marine faunas.

The sediments are not well suited to pollen analysis, because of abrupt facies changes, and because large parts of the sequence are virtually devoid of pollen, namely member A and that part of member B which consists of clean, well sorted sand. Also redeposition of pollen grains is likely to be a factor of importance for

Fig. 70. Small conjugate fold in wood. The "laminae" are growth rings, only some of which are shown.



these sediments which were deposited in near-shore marine environments.

Description

The pollen concentration in the laminated silty sediments of member A is extremely low. Four samples were prepared for analysis, but only one to eight pollen and spores were found per slide. A total of 77 pollen grains and spores were counted. *Betula* grains were the most common; other types include *Picea*, *Alnus*, *Salix*, *Lycopodium* and *Huperzia*. One spectrum from a lens of diamicton in member A yielded 128 pollen and spores, dominated by *Betula* (57%), but also including *Salix* (6%), Gramineae (6%) and *Lycopodium* plus *Huperzia* (4% each).

The results of the pollen analysis of member B sediments are shown in Fig. 71. Note that the vertical distance between the samples is highly variable, from 0.2 to 6.7 m. Pollen diagrams from eight separate sections and two isolated pollen spectra are shown. All pollen and spores of tracheophytes are included in the pollen sum.

The pollen spectra are quite variable, but the variation appears to be random, hence the diagrams are not divided into pollen zones. Arboral pollen types (*Larix*, *Picea* and *Pinus*) generally only make up about 10% of the pollen sum. Note that *Larix* pollen grains were not recognised during the counting of the samples from locality 50.

Betula and/or Cyperaceae dominate with the other important non-arboral pollen taxa being Gramineae, *Salix*. Ericales, *Ranunculus*, Caryophyllaceae, *Oxyria*, *Saxifraga* and *Artemisia* are minor, but consistent elements. Spores of tracheophytes are common, especially *Lycopodium*, but also *Huperzia* and *Dryopteris* tp. (monolete, naked fern spores).

Vascular plants represented by pollen or spores, but not by macroscopic remains, comprise *Pinus*, *Polygonum viviparum*, *Saxifraga*, *Chamaenerion*, Liguliflorae, *Artemisia*, *Erigeron*, *Cirsium* (identified according to Stix (1960)), *Botrychium*, *Cystopteris fragilis dickieana*, *Gymnocarpium*, *Lycopodium* and *Huperzia*. Thus the pollen work adds considerably to the flora of the Kap København Formation. In addition, spores of *Zygnema* and fruit bodies of *Microthyrium* are shown in Fig. 71.

Other microfossils in the pollen preparations (not shown in the diagrams) include a few head capsules of midge larvae and various spores of Fungi, Algae and bryophytes. Also rare pre-Quaternary palynomorphs were encountered, as well as some few dinoflagellate cysts.

Notes on some taxa

Pinus. This tree species produces great amounts of pollen grains which are effectively dispersed by wind. As no macroscopic remains of pine were seen, the small percentage of pine in the sediments is attributed to long distance transport.

Larix. As indicated in Table 7, larch was the dominant tree species in the Kap København area. *Larix* is a moderate pollen producer, and is underrepresented in pollen spectra (Ritchie 1987).

Betula. Measurements of *Betula* pollen grains were not carried out, but according to the analyses of macroscopic plant remains (including wood) tree birches were very rare in the Kap København area.

Alnus. This genus attains values of less than 5%, surprisingly low for an arctic tree line site (Ritchie 1987). Presence of *Alnus* macrofossils shows that it grew in the area, but the low pollen values indicate that *Alnus* was rare.

Lycopodium. This plant is a prolific spore producer; nevertheless, it is hard to believe that *Lycopodium* spores constituted up to 27% of the original pollen/spore rain. The wall of *Lycopodium* spores is very resistent to oxidation (e.g. Havinga 1984), and it is believed that differential preservation explains the abundance of this taxon. The same explanation probably applies to *Huperzia* and *Dryopteris* tp spores as noted above.

Discussion

Terrestrial palaeoecology and palaeolimnology

Because no plant macrofossils were found in member A and very little pollen, no firm conclusions about the vegetation in the Kap København area during its deposition are possible. However, I suggest that the area

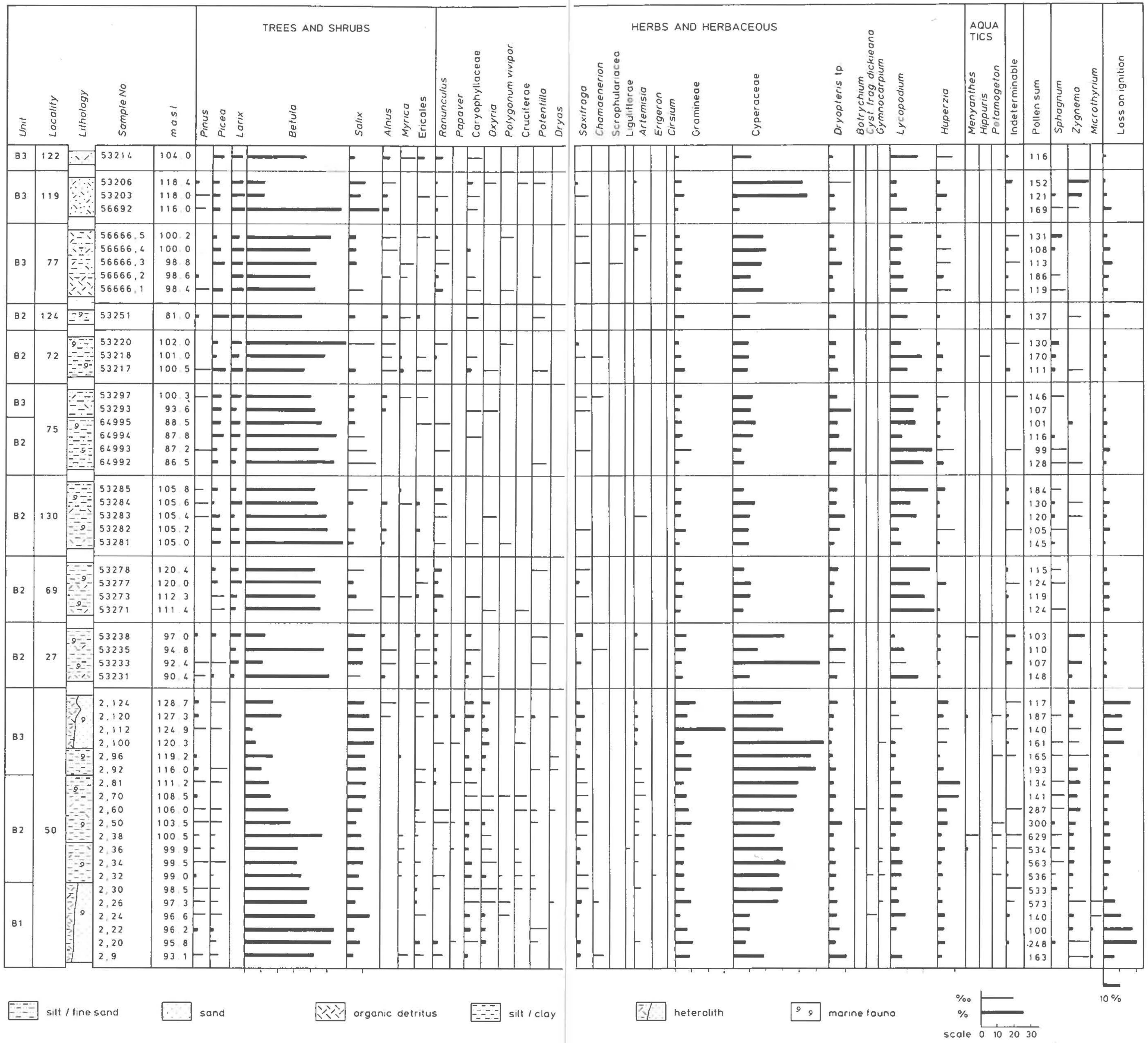


Fig. 71. Pollen diagrams and pollen spectra from the Kap København Formation. Note that the vertical distance between the samples is highly variable.

was sparsely vegetated, in accordance with the sediments (dropstones, diamicton) and the marine fauna which is interpreted as reflecting a high arctic environment.

In member B the assemblages of macrofossils vary greatly from sample to sample, a characteristic which is especially pronounced if unit B1 is compared with unit B3 (Table 3). I believe, however, that this variation is due to effects of hydrodynamic sorting rather than to vegetational differences. For example, the assemblages from the transition between unit B1 and B2 at locality 74 and 75 are completely dominated by *Menyanthes* seeds which are very buoyant. No changes in vegetation can be firmly demonstrated during the deposition of those parts of the formation that contain a reasonable concentration of pollen grains and spores.

The list of macrofossils and the pollen spectra from member B indicate the former presence of a rich flora of plants that presently grow in a variety of habitats, forming a range of plant communities.

Although logs and other remains of trees are a conspicuous element in parts of the Kap København Formation, the remainder of vascular plant fossils consist mostly of remains of dwarf-shrubs. Arboreal pollen only play a minor role in the pollen spectra, contrasting with the pollen rain in modern subarctic sites in North America where the regional pollen rain is dominated by arboral taxa, notably *Picea* (Ritchie 1987). Part of this discrepancy may be due to the fact that *Picea*, a prolific pollen producer, dominates the northern boreal forests of these regions today, while *Larix*, a poor pollen producer, apparently dominated in eastern North Greenland. But this difference alone can hardly account for the low arboral pollen value in the Kap København sediments. I believe that trees were indeed very rare in the area, being restricted to small favourable sites, and that closed forests were only to be found far to the south of Kap København. Heaths and thickets were the dominant plant communities on upland areas with the prevalent shrubs being *Betula nana*, *Vaccinium uliginosum* and *Empretum nigrum*. *Arctostaphylos uva-ursi*, *Salix reticulata* and other salices constituted minor components. *Dryas octopetala* probably grew mostly on exposed places, such as ridge-tops, mountain slopes and elevated sites in the adjacent low mountains of Kim Fjelde.

The trees probably grew singly or in small patches of forest (tree islands), in sheltered areas along streams and in valley bottoms (e.g. Arno 1984, Hustich 1979, Larsen 1974).

Larix, which was by far the most common tree species, probably grew on well drained sites, whereas *Picea mariana* and *Thuja occidentalis* grew in more moist soil. Warmth-demanding plants such as *Taxus*, *Alnus*, *Betula alba*, *Cornus* spp. and *Viburnum* grew in the same general areas.

Herbs on upland sites included *Oxyria digyna*, *Rumex acetosa*, *Arabis alpina*, *Hedysarum*, *Potentilla* spp., *Artemisia* (?) and Gramineae.

The landscape no doubt included an abundance of different wet land habitats. Many samples of detrital organic matter are dominated by remains of semi-aquatic or aquatic mosses, especially *Scorpidium scorpioides* and *Calliergon sarmentosum* (Mogensen 1984, Funder et al. 1984) and vascular plants which chiefly grow in mires e.g. *Selaginella selaginoides*, *Ledum palustre*, *Andromeda polifolia*, *Oxycoccus palustris*, *Rubus chamaemorus*, *Juncus*, *Carex* spp. and *Scirpus microcarpus*. Several of these, notably *Andromeda polifolia*, *Oxycoccus palustris* and *Rubus chamaemorus*, are acidophilous, as are also some of the mosses, especially *Sphagnum* sp. Today acidic substrates are rare in the Kap København area, and nearly all plants growing there are calciphilous.

The fossil insects from the Kap København Formation tend to confirm this picture (J. Böcher 1989, Bennike & Böcher in press). Several of the beetles and the carpenter ant (*Camponotus herculeanus* (L.)) depend on trees. Some interesting details are added by the insect fauna. Noteworthy is the presence of *Elaphrus*, *Notiophilus* and several others which are highly active predating beetles which live on open, sandy or gravelly shores of lakes and streams.

The moss species *Schistidium maritimum* (Turn.) B. S. G. grows on rocks and boulders near the sea shore and is the only representative for such habitats (G. S. Mogensen, pers. comm.).

In summary, both plant macrofossil, pollen and insect data indicate the former presence of forest-tundra vegetation with small, stunted trees in the Kap København area. A mosaic of drier and wetter habitats was available.

Representatives from almost every group of freshwater organisms may leave remains, and such remains constitute a major part of many Quaternary lake deposits. Many different aquatic plants and animals are also represented in the Kap København Formation, including diatoms, Characeae, Tracheophyta, Turbellaria and Oligochaeta (represented by cocoons), Notostraca (*Lepidurus* sp.), Cladocera, Coleoptera, Chironomidae, Trichoptera and Bryozoa (*Cristatella mucedo* Cuvier and *Plumatella* spp. (Fredskild & Røen 1982, J. Böcher 1989, W. Hofmann (pers. comm)., U. Røen (pers. comm.)). Together with fossils of plants such as *Menyanthes trifoliata*, *Hippuris vulgaris*, *Potamogeton* spp., *Nuphar*, *Sparganium*, *Zygnema* tp. (Geel 1979), they indicate that shallow mesotrophic neutral and alkaline waters were once present in the area, as opposed to the present situation where the lakes are ultra-oligotrophic and very sparsely vegetated. The presence of *Tolypella* indicates that alkaline waters were also present.

Palaeoclimate

Summer temperatures. – The modern arctic tree line roughly follows the mean 10°C isotherm for the warmest month, except for very dry or very wet areas, where it is situated somewhat more southerly. The former presence of forest-tundra vegetation in the Kap København area thus implies mean temperatures slightly above 10°C for the warmest month. The modern northern limit of the most warmth demanding plants found in the formation approaches the arctic tree line.

The insects found in the Kap København Formation are primarily boreal species. Only some of them enter the low arctic region, and it could be argued that the insects point to higher summer temperatures than the plants. In Britain, some Devensian interstadial deposits contain a mixture of boreal insects and arctic plants, and Coope (1977) argued that the insects (many of which are aquatic beetles) reacted quicker to climatic ameliorations than plants due to their greater dispersal potential. However, tree ring measurements from Kap København clearly show that climatic conditions were marginal for tree growth.

The presence of arctic plants, notably *Dryas octopetala* and *Oxyria digyna*, may not be very significant in this connection. Their southern limit follows approximately the forest line, but it is determined by competition rather than by climate. These heliophilous plants may thrive in more southerly areas of low competition, where shade from trees is not a problem. Aichinger (1951) reported on *Dryas octopetala* growing together with the Mediterranean trees *Fraxinus ornus* L. and *Pinus nigra* Arnold on landslide areas at the southern foot of the Alps.

It should be noted that the marine mollusc fauna also includes several extralimital southern species associated with relatively warm water masses. One of these, *Macoma balthica*, has a modern northern range limit in the western Atlantic off central west Greenland (Lubinsky 1980).

Winter temperatures. – Winter temperatures are more difficult to assess than summer temperatures, because the ranges of few plants or animals are confined by winter temperatures. However, it is well known from its natural range and from plantings in northwest Europe that *Thuja occidentalis* does not endure very cold winters. By comparing the modern natural range of *T. occidentalis* with climate maps it was found that its northern limit approximately follows the January isotherm of −17°C. *Taxus* spp. also avoid regions of very strong winter frost. They do not tolerate low temperatures during the winter and especially during the early spring (Melzack & Watts 1982). The northern limit of *Taxus* in eastern North America follows roughly that of *T. occidentalis*.

Precipitation. – *Thuja occidentalis* demands a relatively humid climate, and its range is limited by a precipitation of about 500 mm per year (Fowells 1965). On the other hand, the common presence of *Artemisia* pollen grains in the Kap København sediments may indicate more xeric conditions. Unfortunately, it is impossible to identify *Artemisia* pollen grains to species, but most species require a dry climate, or at least dry soil conditions.

It is suggested that wet land areas and upland areas formed a mosaic in the Kap København area. Regional precipitation probably exceeded 500 mm per year. Studies of the moss remains in the Kap København Formation also point to a precipitation higher than today (Mogensen 1984).

The winters were rather rich in snow, but the snow cover was patchy. *Dryas octopetala* with the wind-adapted leaf type grew on exposed sites. The trees grew in sheltered locations where the snow accumulated in snow drifts, causing the marked deformation of the branches of the trees. Some of the dwarf shrubs represented by fossils, such as *Ledum palustre*, *Vaccinium uliginosum* and *Empetrum nigrum* also prefer a constant or near constant snow cover during the winter.

Discussion. – Although there is controversy over the usefulness of aquatics as palaeoclimatic indicators (Johansen et al. 1906, Warner & Hann 1987, Walker & Mathewes 1987) many of the aquatics from the Kap København Formation are extralimital southern species and clearly confirm that the regional climate was much warmer during the deposition of the Kap København Formation than it is today. For example, the present northern limit of *Cristatella mucedo* approximately follows the arctic tree line (Lacourt 1968). This species flourished in sub-arctic southwest Greenland during the Holocene "climatic optimum", but probably does not have a permanent population in Greenland today (Fredskild et al. 1975, Røen 1977).

It is concluded that the climate during the deposition of the Kap København Formation was subarctic and oceanic. Mean July temperature was 10–11°C, corresponding to an increase of 7°-8°C as compared with today. I am less certain about mean January temperature, but it was probably between −10°C and −15°C, corresponding to an increase of 15°-20°C. Precipitation probably amounted to at least 500 mm per year, and the winters were rather rich in snow. The increase in precipitation corresponds to at least double its current value. Light was not a restricting factor to heliophilous plants.

Palaeo-phytogeography

Most of the plant species found in the Kap København Formation today have a boreal/low arctic circumpolar (Holarctic) distribution. Examples are *Arctostaphylos uva-ursi*, *Ledum palustre*, *Vaccinium uliginosum*, *Empetrum nigrum* and *Rubus chamaemorus*. To the circumpolar catagory also belong the water plants *Hippuris vulgaris*, *Menyanthes trifoliata* and *Potamogeton natans*, which are characterised by large modern ranges in temperate and arctic climates.

Some taxa, such as *Selaginella selaginoides*, *Taxus* sp., *Salix reticulata* and *Myrica* have discontinuous circumpolar ranges, and the fossils at Kap København indicate that their ranges once were continuous along the shores of the Arctic Ocean.

Another main group of Kap København plants is presently confined to the Nearctic. The most notable examples are *Picea mariana*, *Thuja occidentalis*, *Cornus stolonifera*, *C. canadensis* and *Scirpus microcarpus*. However, many plants presently confined to North America are known as fossils from the Late Cainozoic of Europe, including *Thuja occidentalis* and *Cornus stolonifera*. Hence, these plants once had a much larger area of distribution (amphi-atlantic or even circumpolar) than today.

No plants presently confined to the Palaearctic biogeographical region have been recovered from the Kap København Formation, but *Dryas octopetala*, *Betula nana* and *Rumex acetosa* do not grow in central North America and are predominantly Palaearctic. *Sedum annuum* is apparently the only representative in the assemblage of a plant with a present amphi-atlantic distribution.

Overall the Kap København fossils show that North Greenland during the Plio-Pleistocene (*c.* 2–2.5 Ma) was more closely allied phytogeographically with North America than Eurasia, a condition which also characterises the modern North Greenland flora (T. Böcher et al. 1959).

While a large fraction of the identified plant species presently can be found growing in Greenland, only two of the identified beetle species presently occur in Greenland (J. Böcher 1989). The beetle fauna also includes a small fraction of palaearctic species, and also some species which now occur far from Greenland, showing that distributional shifts among the Coleoptera involved more than simple south to north movements. Similar much more drastic shifts of Coleoptera distributions than of plants are well documented in other studies (Coope 1979). Also a few cladocerans of present-day Palaearctic range have been found (U. Røen, pers. comm.).

All *c.* 50 species of mosses so far identified from the Kap København Formation presently occur in Greenland (G. S. Mogensen, pers. comm.), although some are extralimital southern species. *Dicranum undulatum* and *Schistidium maritimum* are primarily boreal species which in Greenland are confined to the southwest. On the other hand, the species *Cinclidium arcticum* is restricted to arctic and alpine regions.

The origin of the arctic flora and vegetation has been much discussed, mostly by phytogeographers (e.g. Hadač 1960, Hultén 1937, A. Löve 1959, A. Löve & D. Löve 1967, 1974, Tolmatchev 1966a, b, Yurtsev 1964, 1972). The question of the survival of plants in refugia in the arctic regions during the glaciations has been debated in numerous papers. With regard to the Greenland flora the discussion was begun by Warming (1888, 1892) and Nathorst (1892). The last major contribution was provided by Funder (1979) based on pollen analysis of Holocene lake sediments and investigations of the Weichselian stratigraphy of East Greenland.

The Kap København flora, in combination with other high latitude Late Cainozoic floras, puts some time constraints on the question of the origin of the present arctic flora and vegetation. Such common and widespread arctic plants as *Dryas octopetala*, *Oxyria digyna*, *Cassiope tetragona* and *Papaver* sect. *Scapiflora* existed in the Late Tertiary, but lowland tundra vegetation did not exist in the northern hemisphere to any extent during the deposition of the Kap København Formation, and did not appear until late in the Neogene (Matthews 1987, Wolfe 1980, 1985). In addition, we now know that arctic plants grew in Greenland prior to the Quaternary glaciations.

Investigations of the glacial geology of East and North Greenland indicate that large areas remained unglaciated during the Weichselian (e.g. Funder 1979, 1982, Kelly & Bennike 1985), but it must be stressed that the temperature decline and the rigour during the Weichselian maximum, or the Pleniglacial (22 000–18 000 years B.P.) should not be underestimated. This was also stressed by for example Iversen (1954), who first showed that *Betula nana* and other relatively warmth demanding plants did not survive the last glaciation in West Greenland. In Britain mean summer temperatures during the Pleniglacial were lowered by about 10°C (Atkinson et al. 1987), in agreement with results from the North Atlantic which implies a similar drop in summer sea surface temperatures (Ruddimann et al. 1986). On the other hand it may be speculated that a plant like *Dryas octopetala* could have existed in Greenland from the Plio-Pleistocene transition until the present day.

The main point raised by many neo-botanists against a Holocene immigration of plants to Greenland is that the distance to Greenland is too long for any effective dispersal of diaspores (e.g. A. Löve & D. Löve 1974). The high degree of endemism in isolated oceanic islands seems to show that long-distance dispersal is an ineffective method of spread. However, there is strong circumstantial evidence for several such instances of long distance chance dispersal to Greenland. Besides *B. nana* may be mentioned *Alnus crispa* (Fredskild 1983), *Potamogeton praelongus* Wulf. and *P. perfoliatus* L. (Lægaard 1960), several plants growing at hot springs (Halliday et al. 1974) and *Spergularia canadensis* (Pers.) G. Don (J. Böcher 1978). Apparently, given sufficient time, chance dispersal may be an effective mechanism with regard to Greenland. Dispersal by geese has been discussed by Iversen (1954) and Halliday et al. (1974).

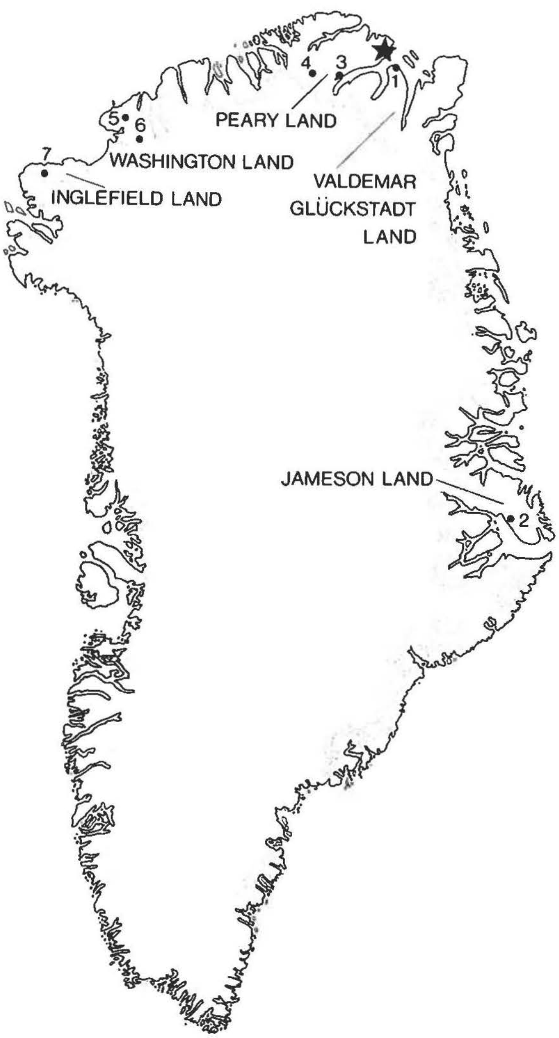


Fig. 72. Map of Greenland showing some occurrences with which the Kap København Formation may correlate. 1: Kap Rigsdagen, 2: Lodin Elv, 3: Uglegylphøj, 4: Baggården, 5: Central Washington Land, 6: Southern Washington Land, 7: Inglefield Land. The asterisk marks the position of Kap København.

Correlation and comparisons with other sites

A number of sites in the northern hemisphere have yielded fossils of plants and provide a basis for comparison with Kap København (Figs 72 and 73).

Greenland

1. Marine strata near Kap Rigsdagen in northern Valdemar Glückstadt Land, only 40 km to the south of Kap København, yielded alloisoleucine/isoleucine (aIle/Ile) amino acid ratios from mollusc shells that are identical to ratios from the Kap København Formation, and indicate that the two deposits are correlatable (Funder et al. 1984). A single sample (GGU 222324) of organic detritus contained abundant moss fragments of *Scorpidium* tp., six 3-sided and two 2-sided *Carex* achenes and two seeds of *Menyanthes trifoliata*, a southern extralimital semi-aquatic common in the Kap København flora.
2. The only other deposit in Greenland which can be reliably correlated with the Kap København Formation is the Lodin Elv Formation in central East Greenland (Feyling-Hanssen et al. 1983). This is a *c.* 40 m thick sequence of marine sand, silt and diamicton, which is also dated to the Plio-Pleistocene boundary by correlation of its foraminiferal assemblages to faunas in the North Sea area. The aIle/Ile ratios from Lodin Elv average 0.52 in the total fraction, and are thus much higher than the ratios from Kap København which average 0.156 (Funder et al. 1987). The sparse pollen flora from the Lodin Elv Formation does not indicate tree growth in the area (Feyling-Hanssen et al. 1983).

In two places in southern Peary land and in two places in Washington Land concentrations of wood have produced "infinite" radiocarbon ages.

3. From Uglegylphøjen, north of Jørgen Brønlund Fjord, 40–45 m a.s.l., wood of *Picea* sp. and unidentified wood have yielded ages of > 35 000 and > 35 600 years B.P. (K-1445, Fredskild 1969, Knuth 1984; I-9688, Weidick 1977, 1978).

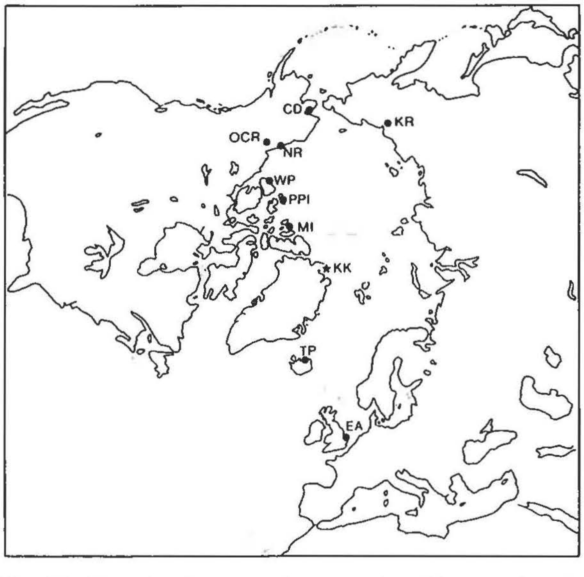


Fig. 73. Map showing some important localities mentioned. KK: Kap København, MI: Meighen Island, PPI: Prince Patrick Island, WP: Worth Point on Banks Island, NR: Niguanak River, Alaska North Slope, CD: Cape Deceit on Seeward Peninsula, KR: Kolyma River (Krestovka sequence), OCR: Old Crow River region, TP: Tjörnes Peninsula, EA: East Anglia.

4. From Baggården at the western end of Øvre Midsommersø, *c.* 95 m a.s.l. three samples of *Picea* sp. yielded ages of > 35 000 years B.P. (K-1446, K-1447, K-1448, Fredskild 1969, Knuth 1984).
5. From central Washington Land, unidentified wood samples yielded ages of > 40 000 years B.P. (Jepsen 1982).
6. From north of Humbolt Gletscher, southern Washington Land. Many wood pieces occur scattered along a gravel river bed, 245–260 m a.s.l. One sample identified as *Picea* sp. has yielded an age of > 51 000 years B.P. (GSC 2447, Blake 1987).

The wood from localities 3 and 6 was interpreted by Weidick (1978) as interglacial driftwood redeposited by fluvio-marine action and trough action by glaciers respectively, while the wood from locality 5 was interpreted by Jepsen (1982) to be of preglacial age, washed out from the Bjørnehiet Formation. It is noteworthy that all four localities are characterised by concentrations of wood rather than by single pieces. I suggest that the wood originates from local tree growth, and the possibility exists that the occurrences correlate with each other and with the Kap København Formation.

7. From central Inglefield Land a sandy clay with only 1.6 % organic matter yielded a pollen spectrum with 43 % monolete fern spores and 20 % *Huperzia selago* spores. Excluding these spores from the sum, the spectrum comprises 30 % *Betula*, 13 % *Artemisia* and 5 % *Alnus*. The radiocarbon age of 20 800 ± 2900 years B.P. indicate mixing of old and new material (I-2322, Tedrow 1970, Blake 1974). The pollen flora shows some similarity to the Kap København pollen flora, and a correlation is possible, although the evidence is very weak.

Two other Greenlandic occurrences may be mentioned.

From West Greenland two marine carbonate concretions contained between 5.5 and 20 % *Picea* pollen (Bryan 1954). The pollen flora was interpreted by Bryan as reflecting local interglacial boreal forest growth, but the *Picea* pollen was reinterpreted by Funder et al. (1984) as long distance transported pollen.

From central East Greenland a peat deposit which was described by Backlund (1931) was assigned an interglacial age by Weidick (1971). However, more recent studies in the area indicate a Holocene age (S. Funder, pers. comm.).

Canada and Alaska

The Neogene Beaufort Formation in arctic Canada has received considerable attention during the past decades (e.g. Hills & Ogilvie 1970, Kuc & Hills 1971, Roy & Hills 1972, Hills et al. 1974, Hills & Matthews 1974, Matthews 1974, 1976, 1987, 1989, Matthews & Ovenden in press, Matthews et al. 1986, Matthews et al. 1990. Other Late Tertiary occurrences in northern North America have also been studied, and although much of these data remains to be published, some authors have attempted to synthesise the available data (e.g. Repenning et al. 1987, Repenning & Brouwers in press).

The fossil flora to which the Kap København flora shows the greatest resemblance is the flora from the Beaufort Formation on Meighen Island in northernmost Canada (Matthews 1987). The insect faunas from the two deposits also show great similarity (Bennike & Böcher in press). However, the presence in the Beaufort Formation on Meighen Island of e.g. *Pinus*, *Picea banksii* Hills & Ogilvie, *Comptonia*, *Claytonia* and *Physocarpus*, which have not been recovered from the Kap København Formation, indicates that the Beaufort Formation on Meighen Island is older than the Kap København Formation (Matthews 1987). Unique to the Beaufort Formation on Meighen Island is a marine unit with sparse foraminifers and molluscs. The foraminifers are indicative of an Early Pliocene age (McNeil in press). Alle/Ile ratios from the southern, extralimital bivalve genus *Arctica* average 0.213 in the total fraction (Brigham-Grette et al. 1987). This taxon epimerises at about the same rate as *Hiatella arctica* and *Mya truncata*, which yielded an average ratio of 0.156 from the Kap København Formation (Funder et al. 1987). This difference also suggests that the Beaufort Formation on Meighen Island is somewhat older than the Kap København Formation. A recent ^{87}Sr/^{86}Sr analysis on *Arctica* shell fragments suggests a Late Miocene age (Matthews 1989).

The Beaufort Formation as currently defined (Fyles 1989) is widely distributed in northern Canada, and probably spans from late Early Miocene to Early Pliocene. The flora from Meighen Island and the Kap København flora also show similarity to floras from Prince Patrick Island (Matthews et al. 1990).

A number of Pliocene/Early Pleistocene deposits are now known in the Alaska/Yukon region. While it is beyond the scope of this discussion to review these deposits, their faunas and floras, it should be mentioned that some molluscs found at Kap København, such as *Macoma balthica*, *Cyrtodaria kurriana* and *Trichotropis bicarinata*, are characteristic elements of the lower part of the Late Pliocene Gubik Formation, Alaska North Slope (L. Marincovich, pers. comm.). Extralimital southern elements including sea otter and various molluscs are present in deposits of the Bigbendian and Fish Creekian transgressions at 2.5–3 Ma and *c.* 2.4 Ma B.P. (Carter et al. 1986, Repenning et al. 1987). Matthews & Ovenden (in press) reported on plant and insect remains from organic detritus from a deposit at Niguanak River, Alaska North Slope, which they propose is > 2.1 Ma old. The dominant conifer is *Larix*, and the overall assemblage of plants and insects point to a forest-tundra environment, although distinctly different from any modern analogue due to the presence of *Pinus*, *Abies* and others. Several southern extralimital species, including *Lonicera* sp., point to warmer climate during the deposition of this detritus than today.

The Cape Deceit Formation, western Alaska was investigated by Matthews (1974), and dated by Repenning et al. (1987) to *c.* 2.1 Ma. However, a younger age of 1.2 to 1.8 Ma has been suggested by Sher (1986). No extinct plants have been recovered from the Cape Deceit Formation. The flora in part of the formation is dominated by *Larix*, which grew in a forest-tundra environment, in a climate slightly warmer than the present. This episode of forest-tundra vegetation was preceeded and followed by periods of tundra vegetation.

The Old Crow and Bluefish Basins in Yukon contain long records of Neogene/Early Quaternary sediments. But in comparison with the Kap København Formation it is striking that no intervals of much warmer than present day climate have been identified in the Late Neogene/Early Quaternary part of the sequence. Thus open boreal forest physiognomically similar to the present local vegetation are recorded from locality 47, the Surprise Creek tephra locality on the Old Crow River, in sediments dated by small mammals to *c.* 1.7 Ma. This period of boreal forest was preceeded by a period of tundra vegetation as recorded on locality 94, the Little Timber tephra locality (Schweger 1987).

The Worth Point Formation on Banks Island, which contains evidence of forest-tundra vegetation and warmer than present climate, is assigned to the Matuyama reversed polarity chron (Vincent & Barendregt 1987). However, it is probably considerably younger than the Kap København Formation because of the lower taxonomic diversity of its flora and fauna, and because it lacks extinct plants such as *Aracites* (Matthews 1989).

Siberia

Pliocene/Early Pleistocene deposits are very widespread in north east Asia (Baranova 1978). The Krestovka section on the Kolyma River in eastern Siberia has the most detailed record of the Late Pliocene floral and faunal history in this vast area (Sher et al. 1979, Sher 1987, Repenning 1984, Repenning et al. 1987). The Kap København Formation may correlate with parts of the Olyor Suite. During the deposition of these beds the area was vegetated by forest-tundra. The only conifer represented by macroscopic remains is *Larix*. The climate was not much different from the present.

North Atlantic

The Plio-Pleistocene Tjörnes sequence in northern Iceland has already been mentioned. During the deposition of the lower part, the *Tapes* and *Mactra* zones, > 3 Ma ago, sea water temperatures were about 5°C higher than at present (Símonarson 1980). The flora included the trees *Larix* and *Betula alba* (Akhmetiev et al. 1978). About 3 Ma ago a climatic deterioration took place, and sea water temperatures during the deposition of the *Serripes* zone were only slightly above the present (Schwarzbach 1955, Símonarson 1980). The only tree species during this time was *Betula alba* (Akhmetiev et al. 1978).

In Bakkabrúnir lacustrine Late Pliocene (≥ 1.7 Ma) deposits contain leaf imprints mostly of *Alnus*, but including *Salix* spp., *Vaccinium uliginosum*, *Betula* and of particular interest *Dryas octopetala* (Akhmetiev et al. 1978, Einarsson & Eiríksson 1988). *Dryas octopetala* leaves are also recorded from another Late Pliocene deposit in Iceland, Litlisandur in Hvalfjödur (Akhmetiev et al. 1978).

The pre-glacial sequence of East Anglia in England has recently been reviewed by Gibbard & Zalasiewicz (1988). During the deposition of the Coralline Crag between 3.6 and 2.3 Ma ago sea water temperatures were considerable higher than at present (Jenkins & Houghton 1987), whereas during the deposition of the younger parts of the Crag sequence, from < 3.2 to *c.* 1.3 Ma ago, sea water temperatures resembled those of today. It is not possible to make any correlation between Kap København and East Anglia on the basis of vascular plants, but it is worth noting that the first period of open tundra-like vegetation is recorded in the Netherlands *c.* 2.3 Ma B.P. (Zagwijn 1974).

The St. Erth Beds in southwestern England were laid down during subtropical marine palaeotemperatures, between 1.9 and 2.1 Ma ago (Jenkins & Houghton 1987).

Deep sea

Finally a few notes on the deep sea record of the North Atlantic and Arctic Oceans will be given. Northern hemispherical cooling and the first major continental glaciation occurred at 2.5–2.4 Ma B.P. (Shackleton et al. 1984, Rea & Schrader 1985). This first major glaciation was antedated by progressive enrichment of δO^{18} values in benthonic foraminifers after 3.1 Ma B.P. (Ruddiman & Raymo 1988), and on Iceland glaciations already occurred at least 3 Ma ago (Einarsson & Albertson 1988). While climatic variations during the past 0.7 Ma were of a large amplitude, the variations during the Matuyama chron (0.73–2.47 Ma ago) were lower in amplitude (Jansen & Sejrup 1986, Ruddiman & Raymo 1988).

On the Vøring Plateau, a deep sea core at site 644 shows evidence of cold water at 2.5 Ma ago followed by a brief return to warmer conditions about 2.2 Ma ago (Eldholm et al. 1987).

The history of the sea ice cover of the Arctic Ocean is highly controversial, but it is noteworthy that Y. Herman reported on a major change also at about 2.5 Ma ago – before the importance of this date in the North Atlantic and North Pacific was recognised. The suggested change was from ice-free conditions to an episodically or seasonally ice covered ocean, lasting until about 0.7 Ma ago (Herman & Hopkins 1980).

In the Baffin Bay region a drastic change from open boreal forest to tundra vegetation occurred at about 1.6 Ma ago (Vernal & Mudie 1987), as recorded in deep sea sediments from Baffin Bay.

As appears from the foregoing, a higher rise of temperatures is recorded from Kap København at the Plio-Pleistocene transition than elsewhere. It is suggested that the large warming was mostly a North Atlantic phenomenon. It is unlikely that the Greenland Inland Ice existed contemporaneously with forest-tundra in North Greenland. If the Inland Ice did not exist, this would have had very pronounced consequences for the climate of Greenland. The albedo would fall, leading to a feed-back mechanism. In addition, relatively warm air masses could have penetrated northwards.

Summary

Biostratigraphic correlation using mammals, foraminifers, molluscs and ostracodes, supplemented by palaeomagnetic studies, indicate that the age of the Kap København Formation is 2–2.5 million years, i.e. Plio-Pleistocene by northwest European standard or Late Pliocene in North American terminology.

The sequence was deposited in near-shore marine environments, from inner shelf through shoreface and foreshore to backshore along a high to medium energy coast (Fig. 74). The abundance of organic detritus in parts of the sequence probably result from nearby influx of fresh water, and the large volume of sediments also points to deposition along a deltaic coast line. The lower part of the formation contains evidence for glaciation in the area.

During the deposition of the middle and upper part of the sequence the area was vegetated by forest-tundra vegetation (Fig. 74). The dominant tree was larch, which also dominated Late Neogene forests of northern North America (Matthews & Ovenden in press) and perhaps elsewhere. The forest-tundra at Kap København, although physiognomically similar to modern forest-tundra, was floristically different, notably in being taxonomically more diverse. This non-analogous condition may in part be attributed to the effect of the following Quaternary glaciations which lead to range reductions and extinctions among many species.

It may also in part be a consequence of the former combination of a northern light regime and a subarctic climate, which perhaps allowed some plants that are not presently tree line plants to grow at that boundary during the Plio-Pleistocene.

The forest-tundra vegetation implies a climate much warmer than the present. Summer temperatures were 7–8°C warmer than today. By two million years ago Kap København was situated only about 100 km farther south than today (Smith et al. 1981); this slight southern displacement cannot account for the warmer climate. The general Tertiary global cooling trend has been attributed to a fall in the atmospheric carbon dioxide concentration and changes in geography (e.g. Barron 1985). However, when compared to other Late Neo-

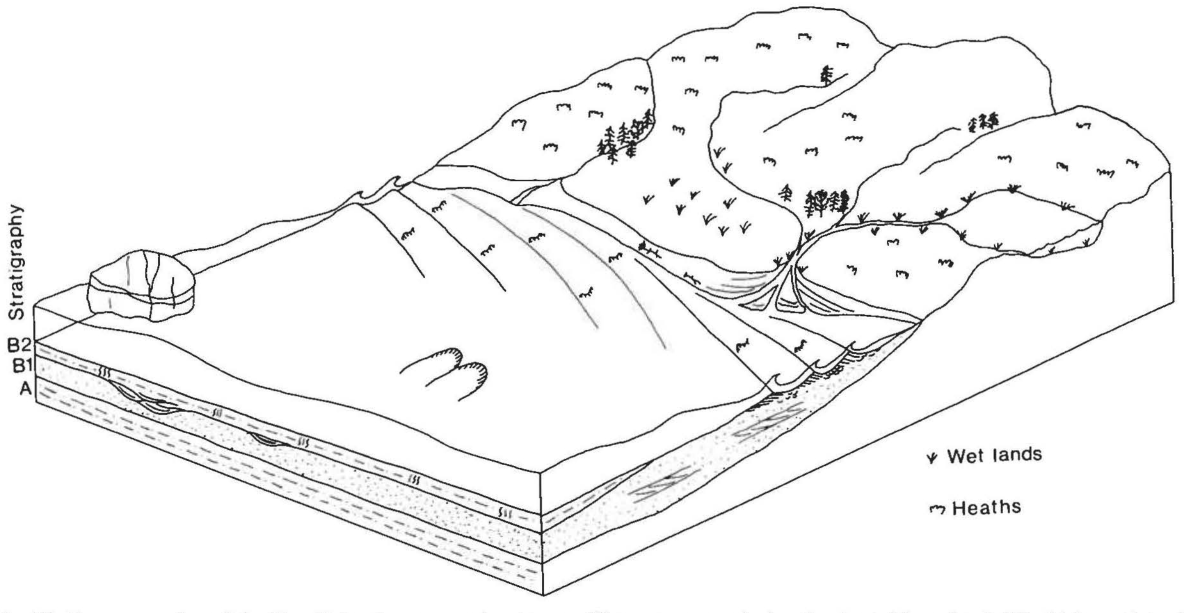


Fig. 74. Reconstruction of the Kap København area about two million years ago, during the deposition of unit B2 which consists of bioturbated mud. At the transition between unit B1 and B2 some large scour-and-fill structures are seen (in cross section and from above). Unit B1 consists of sand, partly showing large scale cross- bedding created by long shore bars migrating obliquely towards the coast. Where the river debouches into the sea a wave dominated delta is formed. The sea is ice free apart from a small iceberg. The upland area is vegetated by heaths and some small patches of trees. Wet land areas are extensive.

gene/Early Quaternary deposits on the northern hemisphere, it appears that the Kap København Formation indicates warmer temperatures as compared with today than recorded elsewhere. I suggest that this may have been primarily a North Atlantic phenomenon. The Greenland Inland Ice did not exist and the Arctic Ocean was at least seasonally ice free.

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Index to generic and lower taxa

(Numbers in bold face indicate major references)

Table 3. Plant macrofossils from the Kap København Formation.

Unit		Sample No.	Locality	m a.s.l.	Sample vol. (liter)	*Picea mariana* needles	*Larix* needles	*Larix*/*Picea* seeds	*Larix*/*Picea* cone scales	*Thuja occidentalis* twigs	*Betula alba* fruits	*B. alba* catkin scales	*Salix* sp. leaves	*S. reticulata* leaves	*Alnus* remains	*Betula nana* fruits	*B. nana* catkin scales	*B. nana* leaves	*Myrica arctogale* fruits	*Cornus stolonifera* fruits	*Arctostaphy. u.-u.* fruits	*Andromeda* seeds	*Vaccinium ulig.* leaves	*Empetrum nigrum* fruits	*Dryas* leaves	*Oxyria* fruits	*Ranunculus* spp. fruits	*Potentilla* spp. fruits	*Viola* sp. seeds	Caryophyllaceae seeds	*Carex* 2-sided fruits	*Carex* 3-sided fruits	*Menyanthes* seeds	*Hippuris* fruits	*Potamogeton natans* fruits	*P.* cf. *vaginatus* fruits	*Cennococcum* sclerotia	*Cristatella* statoblasts	*Coleoptera* fragments
B3	GCI	64980	157	125	1	–	–	3	3	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	3	2	–	–	3	4	–	–
B3	–	53262	75	106.7	–	3	–	10	–	–	–	–	–	–	+	2	–	–	1	–	–	–	1	3	6	–	–	–	1	–	2	1	2	1	–	1	20	–	2
B3	–	53261	–	104.3	–	3	–	12	1	–	1	–	–	–	–	1	–	–	2	1	1	1	–	14	10	–	1	1	3	–	–	5	5	2	–	7	85	3	7
B3	–	56680	–	90.2	–	–	11	–	–	–	–	1	1	–	–	28	–	–	–	–	–	–	5	2	4	–	–	–	–	–	–	4	2	4	–	–	120	4	20
B3	–	64991	77	100	–	–	–	4	–	1	–	–	–	–	–	–	–	–	–	2	–	–	–	3	1	–	–	–	–	–	–	7	30	4	–	3	25	2	1
B3	–	64990	–	115	–	1	–	5	3	–	–	–	–	–	+	–	–	–	1	–	–	–	–	3	–	–	–	–	–	–	1	4	10	1	–	4	15	1	3
B3	–	64989	–	110	–	–	–	8	4	–	–	–	–	–	+	–	–	–	–	–	–	–	–	1	8	–	–	–	1	–	–	2	4	–	–	–	10	1	1
B3	–	64988	–	105	–	1	1	7	3	–	–	–	–	–	+	3	–	–	–	–	3	–	–	3	4	–	–	–	1	–	1	2	6	–	1	2	20	–	3
B3	–	64987	–	102	–	–	35	–	–	–	–	–	–	–	–	11	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	2	3	1	–	1	–	–
B3	–	56666	–	100	0.5	6	483	–	–	2	–	–	–	–	–	20	1	3	5	–	–	–	5	1	1	5	–	1	–	–	18	6	14	1	–	–	50	15	7
B3	–	53214	122	104	1	10	2	14	13	–	1	1	–	–	+	3	–	–	5	2	–	–	3	5	76	–	–	1	–	–	4	10	24	3	–	4	45	3	22
B3	–	53203	119	118	–	–	15	–	–	2	15	1	–	–	–	5	–	–	3	–	–	–	4	1	7	–	–	–	–	–	1	2	9	1	–	–	30	4	11
B3	–	56688	–	118	–	–	45	–	–	–	9	2	2	–	–	42	4	2	4	–	–	–	4	1	2	3	–	1	–	–	2	3	2	3	1	–	30	9	2
B3	–	56692	–	116	10	260	20	120	110	3	–	–	–	–	+	4	–	–	3	2	3	–	1	29	330	–	–	22	10	1	22	58	85	8	1	24	400	25	+
B3	–	56691	–	115	1	–	168	–	–	–	–		11	–	–	6	5	2	4	–	–	–	4	–	5	–	–	–	–	–	5	3	–	–	–	–	7	5	3
B3	–	56690	–	105	–	2	–	–	–	–	–	–	1	–	–	3	–	–	–	–	–	–	–	4	1	–	–	–	–	–	3	1	2	2	–	1	8	1	2
B3	–	56693	–	90	–	1	63	–	–	2	1	–	–	–	–	1	1	2	–	–	–	–	–	–	6	–	–	–	–	–	3	2	–	–	–	–	4	6	2
B3	–	56698	69	103	0.5	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	6	–	–	–	–	–	–	1	3	6	2	–	1	22	47	–
B3	–	53286	130	107	–	–	–	–	–	–	3	1	–	–	–	32	11	–	23	–	–	–	4	26	1	–	–	2	–	–	24	58	63	8	–	–	–	14	5
B3	–	53267	132	155	5	–	11	6	1	34	30	2	3	–	–	23	7	2	9	5	1	–	23	14	16	–	–	1	–	–	11	15	47	27	1	4	60	7	9
B3	–	53266	–	153	1	–	19		–	7	25	2	4	–	–	15	3	5	15	2	–	–	7	3	15	–	–	2	–	–	8	9	17	7	–	2	40	5	+
B3	–	53265	–	152	–	–	36	1	1	6	30	4	14	2	+	60	2	3	15	2	–	–	94	2	17	1	–	–	–	–	7	8	18	5	–	1	75	11	22
B3	–	53264	–	117	–	3	–	12	2	–	–	–	–	–	–	–	–	–	3	–	–	1	–	5	14	–	–	–	1	–	2	6	27	–	–	3	13	29	4
B3	–	53263	–	115	–	43	146	7	–	6	3	3	19	–	–	6	–	7	2	–	–	–	46	4	33	–	–	2	4	–	8	5	16	1	–	–	14	–	–
B3	–	53290	131	155	–	–	–	3	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	4	–	–	–	–	–	2	1	2	–	–	–	4	–	–
B3	–	53288	–	150	–	6	24	1	–	–	4	–	–	–	–	2	–	–	1	–	–	–	1	1	6	1	–	–	–	–	7	1	1	–	–	–	14	2	–
B3	–	64972	152	165	–	–	52	7	–	18	28	3	5	–	–	15	1	1	3	3	2	–	6	5	8	–	–	2	–	–	4	3	7	2	–	–	45	3	9
B3	–	64965	146	160	–	21	3	28	7	7	–	–	1	–	–	6	–	–	4	5	–	–	–	7	1	–	–	1	1	–	9	16	52	8	1	10	18	1	–
B3	–	64956	141	100	–	–	57	1	–	7	25	13	7	1	–	30	11	8	3	–	–	–	6	1	26	1	–	–	–	–	2	3	4	1	–	–	12	5	6
B3	–	56618	17	86	–	–	–	–	–	–	–	–	1	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	26	44	1	–	–	–	14	–	4
B3	–	56611	–	68.4	–	–	3	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	7	–	–	6	–	–	1	1	6	–	–	–	280	–	–
B2	–	56678	74	82.9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	51	–	–	2	125	1	–
B2	–	56674	75	84.6	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	1	–	–	–	–	–	–	–	11	–	–	–	65	10	–
B2	–	56673	–	84.2	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	2	–	–	–	–	–	–	3	–	27	–	–	–	25	1	–
B2	–	56625	27	87.4	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	6	–	116	1	–	1	–	–	–	1	–	–	–	–	8	–	–
?	–	56608	16		–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	71	6	1	10	–	–	1	1	8	–	–	–	45	1	1
?	–	56606	15	165	–	–	–	–	–	–	–	–	78	66	–	22	1	490	–	–	–	–	930	–	1462	5	–	4	–	–	13	17	–	–	–	–	60	–	–
?	–	56605	–	160	–	–	–	–	–	–	–	–	4	7	–	6	1	56	–	–	–	–	37	–	387	1	–	2	–	–	6	8	1	–	–	–	120	–	1
B3	GGU	197163	50b	129.7	1	–	–	–	–	–	–	–	1	–	–	3	–	–	–	–	–	–	–	–	1	4	–	4	–	–	3	–	–	–	–	–	230	1	1
B3	–	197162	–	129.0	–	–	–	–	–	–	–	–	–	–	–	7	–	–	–	–	–	–	–	–	1	2	–	–	–	–	–	–	–	–	–	–	120	–	2
B3	–	197161	–	127.8	–	–	–	–	–	–	–	–	–	–	–	8	–	–	–	–	–	–	6	–	4	14	2	13	–	–	–	–	–	–	–	–	340	1	10
B3	–	197160	–	127.5	–	–	–	–	–	–	–	–	–	–	–	14	–	2	–	–	–	–	6	–	11	9	1	10	–	2	2	1	1	–	–	–	520	1	13
B3	–	197159	–	127.1	–	–	–	–	–	–	–	–	–	–	–	4	–	1	–	–	–	–	1	–	–	1	1	7	–	1	1	–	1	–	–	–	190	2	7
B3	–	197158	–	126.2	–	–	–	–	–	–	–	–	–	–	–	24	–	8	–	–	–	–	2	2	5	13	1	7	–	–	4	1	–	–	–	–	340	2	5
B3	–	197157	–	124.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	10	–	–	–	1	5	–	–	–	560	1	–
B3	–	197156	–	123.4	–	–	–	–	–	–	–	–	–	–	–	4	–	1	–	–	–	–	–	–	3	3	–	2	–	–	–	–	–	–	–	–	290	–	2
B3	–	197154	–	121.9	–	–	–	–	–	–	–	–	–	–	–	49	–	10	–	–	–	–	9	–	7	5	–	12	–	–	1	1	–	–	–	–	350	2	8
B3	–	197153	–	121.3	–	–	–	–	–	–	–	–	–	–	–	16	–	3	–	–	–	–	3	–	7	6	1	2	–	–	–	–	3	–	–	–	270	1	4
B3	–	197152	–	120.0	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	320	–	–
B3	–	197151	–	118.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	50	–	1
B3	–	197150	–	117.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	40	–	–
B2	–	197149	–	116.1	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	3	–	–	–	–	3	–	–	–	–	–	–	–	–	10	2	2
B2	–	197130	–	98.5	–	–	–	–	–	–	–	–	–	–	–	48	–	1	1	–	–	–	5	–	10	–	–	–	–	–	2	2	–	–	1	–	160	–	–
B2	–	197120	50a	91.8	–	–	–	–	–	–	–	–	–	–	–	1	–	2	–	–	–	–	–	–	1	–	–	–	–	–	7	–	–	–	–	–	4	–	–
B2	–	197119	–	90.7	–	–	–	–	–	–	–	–	34	–	–	95	1	155	–	–	–	–	170	1	120	1	2	–	–	–	3	1	1	1	–	1	240	2	19
B2	–	197118	–	89.5	–	–	–	–	–	–	–	–	–	–	–	4	–	2	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	3	13	150	–	–
B2	–	197182	50	98	0.2	–	–	–	–	–	–	–	1	–	–	157	16	77	5	–	–	–	146	3	18	21	1	3	–	–	5	2	2	–	–	–	100	6	–
B1	–	197129	50b	89.0	1	–	–	–	–	–	–	–	2	–	–	193	11	3	–	–	–	1	6	1	–	7	–	1	–	–	5	–	–	–	–	1	200	4	14
B2	–	197128	50	96.7	–	–	–	–	–	–	–	–	2	–	–	86	4	15	–	–	–	1	27	–	90	16	–	–	–	–	2	–	–	–	–	–	50	16	13
B1	–	197127	–	95.9	–	–	–	–	–	–	–	–	–	–	–	165	4	12	1	–	–	1	29	3	16	4	–	–	–	–	4	2	1	–	1	1	650	3	43
B1	–	197126	–	95.0	–	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–	2	–	–	1	–	–	–	–	–	–	1	–	–	–	30	–	–
B1	–	197125	–	94.4	–	–	–	–	–	–	–	–	–	–	–	55	1	2	–	–	–	–	4	–	–	2	–	3	–	–	1	–	–	–	–	–	91	–	7
B1	–	197124	–	95.8	–	–	–	–	–	–	–	–	3	–	–	218	9	13	1	–	–	1	31	3	41	4	–	5	–	–	1	2	3	–	–	–	760	3	31
B1	–	197123	–	94.6	–	–	–	–	–	–	–	–	1	–	–	16	–	2	–	–	–	–	9	–	6	3	–	–	–	–	1	1	–	–	–	–	190	1	15
B1	–	197117	50a	86.2	–	–	–	–	–	–	–	–	1	–	–	1	–	18	1	–	–	–	6	4	59	3	–	2	–	–	1	5	5	–	–	–	60	–	2
B1	–	197114	–	73.9	–	–	–	–	–	–	–	–	1	–	–	26	–	29	–	–	–	–	51	1	103	2	–	16	–	1	1	2	1	–	2	–	115	3	1

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