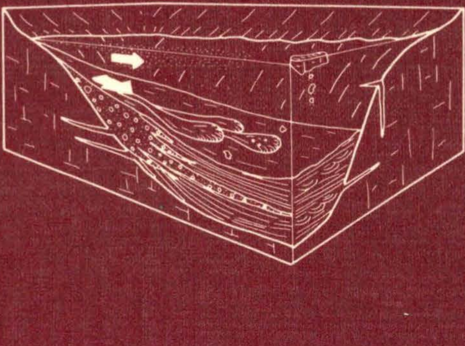
Danmarks Geologiske Undersøgelse
Geological Survey of Denmark . Yearbook 1981

Årbog 1981



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A Middle Weichselian moss assemblage from Hirtshals, Denmark, and some remarks on the environment 47,000 BP.

Bent Vad Odgaard

Odgaard, B. V.: A Middle Weichselian moss assemblage from Hirtshals, Denmark, and some remarks on the environment 47,000 BP. *Danm. geol. Unders., Årbog 1981:* 5–45, København, 1. oktober 1982.

Macrofossil analysis of an organic deposit from Hirtshals, northern Jutland, previously radiocarbon-dated to 47,300 BP (Moershoofd Interstadial complex) yielded a subarctic/low-arctic flora of 41 moss and two phanerogamous taxa. Next to the mosses in the nearby Skærumhede deposit, identified by A. Hesselbo early in this century, this is the richest fossil moss flora recorded in Denmark. Among the mosses in the Hirtshals deposit were *Aongstroemia longipes, Aulacomnium turgidum, Barbula acuta, Conostomum tetragonum, Cynodontium tenellum* and *Entodon concinnus.* The macrofossil- and pollen-assemblages reflect a treeless landscape with a vegetation dominated by herbs, dwarf shrubs and mosses. Based on the present distribution and ecology in Fennoscandia of the recovered taxa, the following conclusions on the environment are drawn: the climate was non-oceanic with mean July temperatures between 8 and 10°C; the topography was varied, dry exposed microsites were important in the landscape, and acid stones were present; surface erosion was strong and calcareous raw soil dominated. The Hirtshals macrofossil flora shows many similarities to the flora found by A. Hesselbo and N. Hartz in synchronous layers of the Skærumhede deposit.

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Lykke-Andersen (1971) in a description of the Older Yoldia Clay of the Hirtshals coast cliff, northern Jutland (Fig. 1), mentioned an organic layer intercalated between marine deposits. Two radiocarbon datings of this layer gave ages of > 35,000 BP (K-1321) and $47{,}300\ ^{+1500}_{-1200}$ BP (GrN-9707), both thought to be reliable (Lykke-Andersen 1981). Thus for the first time a deposit contemporary with the Moershoofd Interstadial complex of the Netherlands (van der Hammen et al. 1967, van der Hammen 1971, Zagwijn 1974, Kolstrup and Wijmstra 1977) was shown to exist in Denmark. The organic layer was noted to contain many moss remains, and a sample was submitted to the present author for botanical investigation.

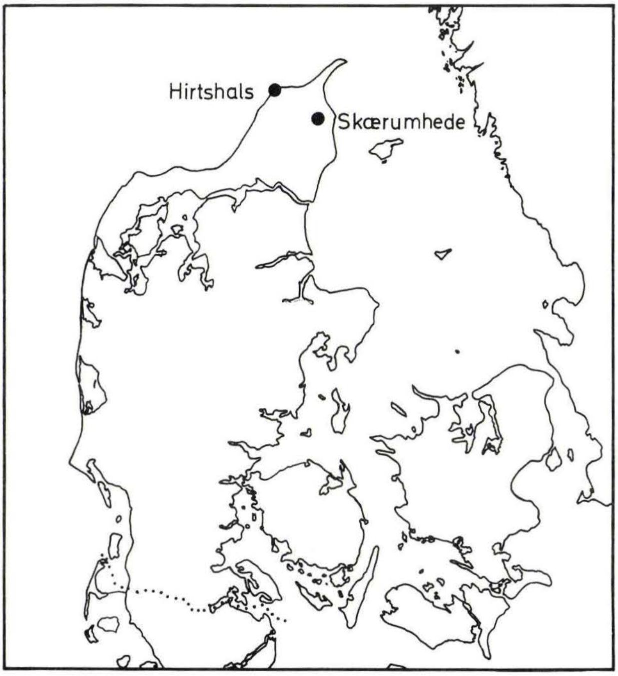

Fig. 1. Location of sites discussed.

Site

The Hirtshals coast cliff consists for the most part of marine deposits, Older Yoldia Clay, the stratigraphy of which is very complex due to folding and faulting caused by ice-pressure (Lykke-Andersen 1971). Based on studies of foraminifera, molluscs and lithology, Lykke-Andersen (1971) succeeded in establishing a stratigraphy of the cliff. She divided the deposits into 6 foraminiferal assemblage zones: F-A, zone F being the oldest. The environmental conclusions drawn from these studies may be summarized as follows (cf. Lykke-Andersen 1971: Fig. 41, Lykke-Andersen 1981: Fig. 2):

Zone F: Rather shallow and slightly brackish water. Subarctic conditions.
Zone E: Very shallow water, lowered salinity and boreo-arctic conditions. A sand layer Eo, lacking foraminifera and molluscs, is intercalated in the middle of zone E, while the organic layer, investigated by the present author, is found in the upper part of zone E, at some places tens of centimeters in thickness.

Zone D: Deeper water, increasing salinity and lower temperatures. Ice-rafted stones in the deposits suggests an advancing ice-margin.
Zone C: Mainly shallow water, arctic conditions. Ice- margin perhaps very near.
Zone B: Unfavourable conditions for foraminifera, assumed to be caused by melt water from a retreating ice-margin.
Zone A: Deeper water and increasing temperatures.

Material

The sample, Lykke-Andersen E 28 C, is part of a bulk sample collected by Anne-Lise Lykke-Andersen in 1977 at about 152 m in her local reference system (indicated by the right-hand cross in Lykke-Andersen 1981: Fig. 1). The finite radiocarbon date (Lykke-Andersen 1981) was achieved by measurements on another part of the same bulk sample (Lykke-Andersen, personal communication). The sample is distinctly stratified and consists mainly of fragments of herbaceous plants and mosses, and sand; it is slightly calcareous.

A description in terms of components (Troels-Smith 1955) is given below.

Turfa bryophytica 1, Turfa herbacea 1, Detritus granosus 1, Grana arenosa 1, Detritus lignosus +, Detritus herbosus +, Limus detrituosus +, Grana saburralia +.

Methods

Analyses of pollen and macrofossils were performed on dried material.

The confidence of the identifications is indicated according to the system proposed by Birks and Birks (1980: 24).

Pollen analysis. A subsample was boiled in KOH and HF, acetolyzed and mounted in silicone oil. Pollen was counted using an immersion oil objective at a magnification of ca. 720, and the size of *Betula* grains was measured (Lt +, Iversen and Troels-Smith 1950). The size class was 0.43µm.

Macrofossil analysis. The plant material was too fragile to allow sieving. The sample was, instead, soaked in water for a few days and then dissected under the stereomicroscope at a magnification of 7–40. Totally, about 15 cm^3 were analyzed. All isolated fossils were mounted in glycerol jelly, and the slides are stored at the Geological Survey of Denmark. Identification manuals consulted during the investigation cover northern Europe. Mosses: A. G. Andersen et al. (1976), Brotherus (1923), Gams (1950), Jensen (1923), Limpricht (1895), Nyholm (1954–69), Smith (1978). Seed plants: Beijerinck (1947), Katz et al. (1965).

All species and genus identifications have been checked by comparison with recent material from Scandinavia, mostly collected and identified by the present author.

Results

Pollen analysis

The pollen spectrum is shown in Table 1. Tree and shrub pollen constitutes about 30%, mainly composed of *Betula* pollen, but pollen of *Salix* is fairly common as well.

Table 1. Pollen spectrum from Hirtshals. The pollen sum is 333.

Included in pollen sum:		Excluded from pollen sum:	
Betula	22.2	*Alnus*	1.8
Juniperus	0.3	*Corylus*	0.9
Pinus	5.4	*Ilex*	0.3
Salix	3.6	*Picea*	0.6
		Quercus	0.3
		Tilia	+
Bruckenthalia	0.3		
Calluna	0.6	Pre-Quaternary types	2.6
Empetrum	0.3		
		Hystricosphaeridae	1.7
Artemisia	0.3		
Cyperaceae	35.4	*Sphagnum*	6.6
Dryopteris	1.4		
Fabaceae	0.3	*Botryococcus*	0.3
Filipendula	0.3	*Pediastrum boryanum*	1.4
Poaceae	25.2	*Pediastrum* cf. *P. kawraiskyi*	15.9
Rosaceae undiff.	1.2		
Rumex	1.2	*Tetraëdron*	+
Saxifraga	0.3		
Sedum	0.3		
Selaginella	0.3		
Thalictrum	0.3		
Urtica	0.3		

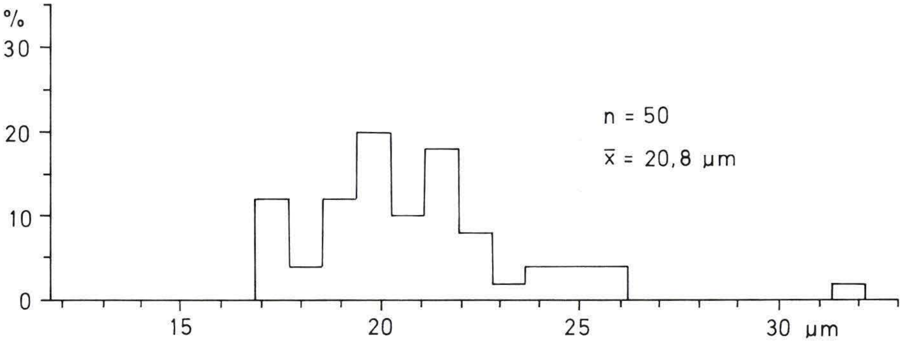

Fig. 2. The size-frequency distribution of *Betula* pollen grains in the Hirtshals organic deposit.

The herb pollen is dominated by Cyperaceae and Poaceae.

Only small amounts of typically interglacial and pre-Quaternary types, 6.5% in all, were found.

Lumps of pollen grains were noted in the case of *Betula,* Cyperaceae and Poaceae.

Sphagnum spores amount to 6.6%.

Freshwater algae are represented mainly by numerous *Pediastrum* colonies (2 species) but *Botryococcus* and *Tetraëdron* were also found.

The size-freqency distribution of *Betula* pollen grains is shown in Fig. 2. The distribution appears almost symmetrical with a mode at 20µm. Sample mean and standard deviation are 20.8±2.71µm. The hypothesis that the size

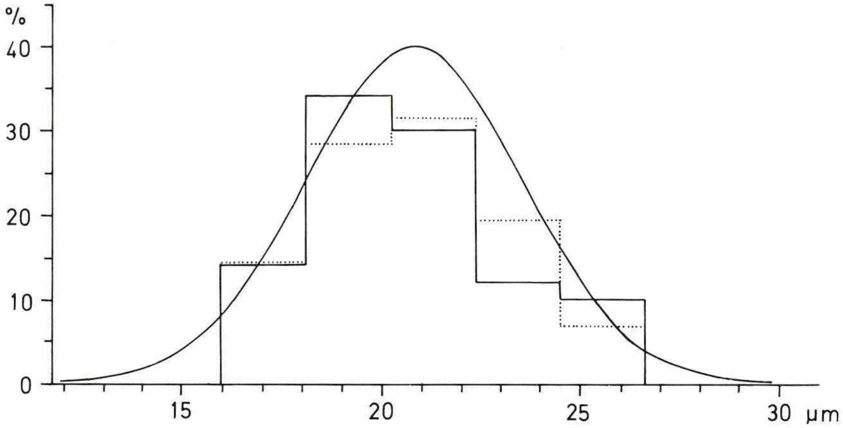

Fig. 3. Normal distribution N(µ;σ = 20.8; 2.71) and histograms showing size-frequency distribution of *Betula* pollen grains in the Hirtshals deposit (— observed, . . . expected).

of the parent population of *Betula* pollen grains is normally distributed $N(\mu;\sigma = 20.8; 2.71)$ was tested by the χ^2 method. To meet the requirements of the test of at least 5 observations in each group, it was necessary to rearrange the material into 5 histogram columns; the single measurement at 31.5 μm was included in the column 24.5–26.6 μm (Fig. 3). The result P (χ^2) = 0.41 (4 degrees of freedom) is not significant and the hypothesis not rejected. From the small mean size of pollen grains and the presence of macrofossils of *B. nana* (see below), it can thus be concluded that *B. nana* was the only Birch species present.

Macrofossil analysis

All taxa found are listed in Table 2. 41 mosses, 2 seed plants and 2 animal taxa were identified. Next to the Skærumhede flora (Hesselbo in Jessen et al. 1910) this is the richest fossil moss flora recorded in Denmark. A full description of the material is given below, including for each taxon: the number of fossils, the length of longest shoot fragment, the preservation, notes on identification, and references to previous fossil finds.

Plants

Bryophyta

The preservation is indicated according to the system of Dickson (1973: 52–53).

Where possible, nomenclature and taxonomy is according to A. G. Andersen et al. (1976). For mosses which do not appear in Andersen et al., Nyholm (1954–69) is followed.

Only some of the present reports were included in the previously published list of Danish Quaternary bryophytes (Odgaard 1981).

Abbreviations: b: bad, g: good, l: leaf, s: shoot, t: shoot tip, v: very.

Table 2. Macrofossils identified in the Hirtshals deposit. For the mosses, an estimate of abundance in the deposit is given.
Key: ++ = Taxon abundant, + = Taxon scanty.

Abietinella abietina (Hedw.) Fleish.	+
Aongstroemia longipes (Sommerf.) B.S.G.	+
Aulacommium palustre (Hedw.) Schwaegr.	++
A. turgidum (Wahlenb.) Schwaegr.	++
Barbula acuta (Brid.) Brid.	+

Bryum	+
Calliergon giganteum (Schimp.) Kindb.	+
C. stramineum (Brid.) Kindb.	+
Campylium protensum (Brid.) Kindb./*C. stellatum* (Hedw.) C. Jens.	+
Conostomum tetragonum (Hedw.) Lindb.	+
Cynodontium tenellum (B.S.G.) Limpr.	+
Dicranum fuscescens Turn./*D. muehlenbeckii* B.S.G.	+
Dicranum sect. Scoparia	+
Dicranaceae undiff.	+
Distichium	++
Ditrichum flexicaule (Schwaegr.) Hamp.	++
Drepanocladus exannulatus (B.S.G.) Warnst. sensu Nyholm (1954–69)	+
D. uncinatus (Hedw.) Warnst.	+
Drepanocladus undiff.	++
Entodon concinnus (De Not.) Par.	+
Fissidens cf. *F. osmundoides* Hedw.	+
Hylocomium splendens (Hedw.) B.S.G.	++
Oxyrrhynchium swartzii (Turn.) Warnst.	+
Paludella squarrosa (Hedw.) Brid.	+
Philonotis fontana (Hedw.) Brid. / *P. tomentella* Mol.	+
Philonotis undiff.	+
Pohlia	+
Polytrichum alpinum Hedw.	+
P. affine Funck/ *P. juniperinum* Hedw.	+
Polytrichum sect. Juniperina undiff.	++
Racomitrium cf. *R. canescens* (Hedw.) Brid. s. str.	+
Racomitrium undiff.	+
Scorpidium scorpioides (Hedw.) Limpr.	++
Sharpiella seligeri (Brid.) Iwats.	+
Sphagnum sect. Cuspidata	+
Thuidium	+
Timmia norvegica Zett.	+
Tomenthypnum nitens (Hedw.) Loesk.	++
Tortella fragilis (Hook. et Wils.) Limpr.	+
Tortella cf. *T. tortuosa* (Hedw.) Limpr.	++
Tortula ruralis (Hedw.) Gaertn., Meyer et Scherb.	+

Betula nana L.
Carex sect. Distigmata

Cladocera
Cristatella mucedo Cuvier

Abietinella abietina (Hedw.) Fleisch.

2 s, 2mm, b; a few l, g – b.

Abietinella is distinguished from *Lescuraea patents* by the branched paraphyllia. In *Thuidium* spp., the leaf- and paraphyllia-cells are distinctly mamillose and all leaves, except the stem leaves near margins, are smooth on the ventral side. In *Abietinella,* the cells are papillose rather than mamillose and are not smooth on the ventral side.

Previously, fossil finds have been reported from Denmark (Saalian), England, Poland, the USSR, and North America (Odgaard 1981, Dickson 1973, Szafran 1952, Savicz-Ljubitzkaja 1954, Partyka 1976, Miller 1980a).

Aongstroemia longipes (Sommerf.) B.S.G. Plate 1: 1–4.

1 s, 3mm, g; 1 l, g.

Easily identifiable by the small, imbricate, obtuse and concave leaves. The cells are rectangular, narrower at the margins than in the middle of the leaf.

Apparently not previously reported as fossil.

Aulacomnium palustre (Hedw.) Schwaegr.

2 s, 3mm, b; numerous l, b.

Leaf fragments may be difficult to distinguish from *A. turgidum,* but the papillae of that species are lower and the cell walls more strongly incrassate.

A. palustre is among the most frequently recorded fossil mosses in the Northern Hemisphere. Thus there are numerous Danish reports from the Saalian onwards (Odgaard 1981).

A. turgidum (Wahlenb.) Schwaegr.

A few s, 5mm, b; numerous l, b. The most abundant macrofossil in the deposit.

For identification, see *A. palustre.*

A. turgidum has previously been reported twice from Middle Weichselian and once (tentatively) from Late Wechselian Danish deposits (Odgaard 1981). There are glacial reports from Norway, Britain, Germany, Poland, the USSR, and North America (Övstedal and Aarseth 1975, Vorren 1978, Dickson 1973, Jovet-Ast 1967, Szafran 1952, Savicz-Ljubitzkaja 1954, Partyka 1976, Miller 1980a).

Barbula acuta (Brid.) Brid. Plate 1: 5–6.

1 s, 3mm, g.

Margin entire, recurved at base; nerve excurrent; cells apparently smooth, quadrate, even above the nerve on the ventral side of the leaf. *B. acuta* is very closely related to *B. icmadophila,* a boreal, stream-bank species which is distinguished from *B. acuta* by a different leaf shape and by a more longly excurrent nerve (Crundwell and Nyholm 1965, Smith 1978). Mr. A. C. Crundwell has kindly identified the present fossil to species level.

The author is not aware of any previous fossil reports of *B. acuta,* but *B. icmadophila* has been reported from a Late Devensian site in the Inner Hebrides (Birks 1973: 314).

Bryum

3 s, 2mm, b; a few l, b.

The material is too scanty and badly preserved to allow identification to lower taxonomic levels in this large and difficult genus.

There are numerous Quaternary reports of *Bryum,* especially *B. pseudotriquetrum,* from the Northern Hemisphere.

Calliergon giganteum (Schimp.) Kindb.

1 s (branch), 3mm, b; 1 (stem-) l, g.

For the difference between branch leaves of this species and of *C. cordifolium,* see Boje (1959).

There are numerous Danish reports of this species from the Saalian and onwards (Odgaard 1981), as well as many from other parts of the Northern Hemisphere.

C. stramineum (Brid.) Kindb.

2 l, g.

Margin narrowly recurved at base; angular cells forming a triangular group of rectangular (upwards quadrate) cells; a few rhizoid-initials present in the leaf apex.

There are many Danish fossil reports of *C. stramineum* from the Saalian and onwards (Odgaard 1981), as well as numerous reports from outside Denmark.

Campylium protensum (Brid.) Kindb./*C. stellatum* (Hedw.) C. Jens.

1 s (branch), 2mm, b.

The scanty material does not permit an identification to species level.

There are several Danish fossil reports of *C. stellatum* from the Saalian onwards, and two Weichselian reports of *C. protensum* (Odgaard 1981). *C. stellatum* is among the most commonly found mosses in Quaternary deposits of Europe, the USSR, and North America.

Conostonum tetragonum (Hedw.) Lindb. Plate 2: 1–4.

1 t, 1mm, g.

Recognized by its ovate-lanceolate leaves, serrate in the upper part, the strong nerve, denticulate at back towards apex, and the incrassate, mamillose cells. The typical five-ranked leaf arrangement could not be seen on this tiny fragment.

The author is aware of only one previous fossil report of this species: the Weichselian site at Ludwinow in Poland (Szafran 1952, Srodon 1960).

Cynodontium tenellum (B.S.G.) Limpr. Plate 3: 4.

2 l, b. A few very badly preserved leaf fragments possibly belong here also.

Leaves lanceolate; margin entire and recurved at base while flat, bistratose and distantly denticulate in the upper part; nerve smooth at back in the upper part; cells apparently smooth, quadrate in the upper part, 8–10 µm wide, somewhat incrassate.

The author is not aware of any other fossil reports.

Dicranum fuscescens Turn./*D. muehlenbeckii* B.S.G.

1 l, b.

Leaf channeled in the upper part; margin incurved in basal part, flat in the upper part, denticulate; nerve strong, mamillose at back towards apex; cells shortly rectangular at base, quadrate elsewhere, mamillose on dorsal side.

There are two Danish reports of *D. fuscescens* var. *congestum* (Saalian and Middle Weichselian) as well as a few European, Russian, and North American records of this species and *D. muehlenbeckiii* (Odgaard 1981, Jovet-Ast 1967, Savicz-Ljubitzkaja 1954, Partyka 1976, Miller 1980a).

Dicranum sect. Scoparia

A few l, b.

The prosenchymatic, strongly porose and rather wide cells make the section identification easy, but the material is too small to allow species identification.

Within this section there are Danish fossil reports of *D. scoparium* (Saalian, Eemian, Flandrian) and *D. bonjeanii* (Eemian, Odgaard 1981). Outside Denmark, there are scattered reports of all the present North European species of this section, especially *D. scoparium.*

Dicranaceae undiff.

A few l, b.

Dicranum or *Kiaeria* spp. are probably represented but the material is too small for precise identification.

Distichium

Several s, 5mm, g; some l, g.

Species identification is not possible on the present material.

Distichium capillaceum has been reported from many glacial deposits in the Northern Hemisphere, the cloosely related *D. inclinatum* only from Britain and Poland (Dickson 1973, Szafran 1952), while *D. hagenii* has so far no fossil record.

Ditrichum flexicaule (Schwaegr.) Hamp.

Several s, 3mm, g; some l, g-b.

The Quaternary record of this species is almost the same as that of *Distichium capillaceum,* the two taxa frequently being found together in the deposits.

Drepanocladus exannulatus (B.S.G.) Warnst. sensu Nyholm (1954–69)

A few s, g; a few l, g.

The denticulate leaf margin and the strong, percurrent nerve characterize this species.

D. exannulatus is among the most commonly found mosses in Quaternary deposits of the Northern Hemisphere.

D. uncinatus (Hedw.) Warnst.

1 t, 2mm, g.

D. uncinatus has previously been reported from Saalian, Eemian and Weichselian deposits in Denmark (Odgaard 1981), and from mainly glacial deposits from Britain, Siberia and North America (Dickson 1973, Partyka 1976, Miller 1980a).

Drepanocladus undiff.

Some s, 3mm, b-vb; numerous l, b.

Entodon concinnus (De Not.) Par.

3 l, b.

Leaves lingulate; margin entire, recurved at base, flat elsewhere; nerve very short and indistinct; cells in the middle of the leaf ca. 6 × 50–70 μm, somewhat flexuose, much shorter at apex, porose at base; angular cells quadrate – shortly rectangular, ca. 10 μm wide.

Pleurozium schreberi differs i.a. in the rectangular ca. 20 μm wide angular cells.

The species has not previously been reported from Danish Quaternary deposits, but there is an interglacial report from Britain (Dickson 1973), as well as several Polish and Russian glacial reports (Szafran 1952, Jovet-Ast 1967, Partyka 1976).

Fissidens cf. *F. osmundoides* Hedw. Plate 2: 5–6.

1 l, g.

Margin crenulate all round, not bordered; nerve ending well below apex; lamina cells varying in size, 10–20 μm wide.

Although the leaf is small and evidently originates from the lower part of a stem, it seems quite typical.

There is one previous fossil (Weichselian) report from Denmark (Odgaard 1981) and a few mainly late-glacial ones from Europe and North America (Jovet-Ast 1967, Dickson 1973, Miller 1980a).

Hylocomium splendens (Hedw.) B.S.G.

A few s, 4mm, g-vb; many (branch-) l, g-b.

The paraphyllia are clearly seen on the shoots. This species is distinguished from other *Hylocomium* spp. i.a. by the scattered papillae in the upper part on the dorsal side of the leaves. The branch leaves are almost obtuse as in the arctic-alpine var. *alpinum* Schlieph. (*Hylocomium alaskanum* Lesq. et Jam.), which is perhaps only a habitat modification (cf. Steere 1978).

There are many glacial, interglacial, and Flandrian reports of this species from the Northern Hemisphere.

Oxyrrhynchium swartzii (Turn.) Warnst. Plate 3: 1–3.

1 s, 5mm, g.

Leaves ovate, flat, shortly decurrent, apex slightly twisted; margin flat, denticulate almost throughout; nerve thin, ending in a spine at back in the upper part; cells thin-walled, 6 × 40–50(-60) µm in the middle of the leaf, shorter in the apex; angular cells few, rectangular, ca. 10 µm wide, badly delimited.

O. swartzii is reported once from a Danish late Eemian deposit and a few times from British, Polish and Russian interglacial and Flandrian layers (Odgaard 1981, Dickson 1973, Szafran 1952, Partyka 1976).

Paludella squarrosa (Hedw.) Brid.

1 l, g.

The previous Danish reports are early Eemian, Early and Late Weichselian and Early Flandrian (Odgaard 1981). The British reports are mainly Early Flandrian (Dickson 1973). Also reported from Quaternary deposits in Norway, Sweden, Germany, Poland, the USSR, and North America (Vorren 1978, Lundquist 1978, Jovet-Ast 1967, Szafran 1952, Savicz-Ljubitzkaja 1954, Partyka 1976, Miller 1980a).

Philonotis fontana (Hedw.) Brid./*P. tomentella* Mol.

1 l, b.

Leaf ovate-cordate; margin recurved almost from base to apex, with double teeth in the upper part; nerve strong, widened at base; no cells exceed 40 µm in length, papillae of basal cells proximal.

P. fontana and *P. tomentella* are closely related and differently delimited by various authors. According to Mårtensson (1956), the two species cannot be clearly separated in the mountains of Scandinavia.

There are many, mostly glacial, fossil reports from the Northern Hemisphere, especially of *P. fontana*.

Philonotis undiff.

1 l, g.

Leaf ovate-lanceolate; margin flat; nerve weak; cells in the upper part of the leaf with both proximal and distal papillae.

The leaf does not seem fully developed and is therefore not identifiable to species level.

Pohlia

2 s, 3mm, g.

Leaves ovate-lanceolate, somewhat concave; margin recurved in the lower part, flat in the upper part, denticulate at apex; nerve strong, ending in apex; cells in the middle of the leaf prosenchymatic, 8–10 × 30–50 μm, incrassate, in the basal fifth quadrate – shortly rectangular, marginal border of long narrow cells lacking.

Pohlia cruda, drummondii, nutans and *obtusifolia* have previously been reported from Danish Quaternary deposits and *P. nutans, P. cruda,* and *P.* sp. from British, Russian, and North American ones (Odgaard 1981, Dickson 1973, Partyka 1976, Miller 1980a).

Polytrichum alpinum Hedw.

6 l, g.

This species is easily recognized by the combination of papillose top cells of the leaf lamellae and uneven thickening of these cells. When seen in side-view, the top wall is much more incrassate than the side and bottom walls, while in *Pogonatum urnigerum* – with which the species might be confused – the top-cell walls are equally thick all round. Leaves can also be safely identified by the shape of the top-cell papillae, without dissecting the lamellae from the leaves. In *Pogonatum urnigerum,* the papillae are regular, isodiametric, and ca. 2 μm in diameter, while those of *Polytrichum alpinum* are irregular, often elongate and up to 7 μm long.

Previously *Polytrichum alpinum* has been reported twice from Danish Late Weichselian deposits (Odgaard 1980, 1981). The numerous British reports are mostly late-glacial as well (Dickson 1973). Furthermore there are glacial reports from Norway, Germany, Poland and the USSR (Vorren 1978, Jovet-Ast 1967, Szafran 1952, Savicz-Ljubitzkaja 1954, Partyka 1976) and Flandrian ones from Greenland (Miller 1980a).

P. affine Funck/*P. juniperinum* Hedw.

4 l, b.

The inflexed, entire margins and the teeth at back in the upper part are characteristic features of these two mosses, but species identification based on detached leaves is problematic.

P. juniperina and *P. affine* have been reported numerous times from glacial, interglacial, and Flandrian deposits from the Northern Hemisphere.

Polytrichum sect. Juniperina undiff.

Numerous l, b.

The bad preservation does not permit further differentiation, but a few leaves with the basal part of a strongly denticulate point preserved may perhaps belong to *P. piliferum/P. hyperboreum*. None of the leaves have the typical cuculate apex of *P. norvegicum*.

Racomitricum cf. *R. canescens* (Hedw.) Brid. s. str.

1 l, b.

Of the present North European *Racomitricum* species, only *R. aquaticum, R. canescens,* and *R. ericoides* have papillose lamina cells. In the present leaf, the weak nerve and the high papillae exclude *R. aquaticum*. On well-preserved parts of the middle of the leaf, the majority of papillae seem to be higher than their width, as in *R. canescens* s. str. (cf. Heinonen 1971).

The closely related *R. canescens* and *R. ericoides* are usually reported together as *R. canescens* s. lat. There are mainly glacial reports of this taxon from Denmark, Norway, England, and North America (Odgaard 1981, Övstedal and Aarseth 1975, Dickson 1973, Miller 1980a).

Racomitrium undiff.

8 l, b.

The cells are smooth but the lack of leaf apices forbids species identification.

Scorpidium scorpioides (Hedw.) Limpr.

1 t, 2 mm, g; some l, b.

S. scorpioides is distinguished from *S. turgescens* i.a. by its wide midleaf cells and much narrower marginal cells.

S. scorpioides is one of the most commonly found mosses in Quaternary deposits of the Northern Hemisphere.

Sharpiella seligeri (Brid.) Iwats.

1 s, 4 mm, g.

Leaves longly acuminate, very shortly or not at all decurrent; margin flat, sharply serrate throughout; nerve absent or short and double; cells in midleaf ca. 8 µm wide, angular cells few.

The author is not aware of any previous fossil reports of this species.

Sphagnum sect. Cuspidata

1 (branch-) l, g.

The chlorophyl cells have the broadest exposure on the dorsal side of the leaf. Large dorsal pores in the hyaline cells, as characteristic of sect. Squarrosa, are absent.

Remains of *Sphagnum* are mostly common in interglacial and Flandrian deposits, but rare in glacial ones.

Thuidium

1 s, 2 mm, vb.

For identification, see *Abietinella.*

Thuidium spp. has been reported from glacial as well as interglacial deposits of the Northern Hemisphere.

Timmia norvegica Zett. Plate 3: 5–6.

3 l, b.

Nerve papillose at back towards apex; lamina cells in the upper part of the leaf 10–12 µm, highly mamillose on ventral side; cells in the sheathing part strongly papillose on dorsal side, except at the very margin of the leaf.

T. norvegica has been reported a few times previously from glacial depostis in Denmark, Britain, Germany, Poland, and the USSR (Odgaard 1981, Dickson 1973, Jovet-Ast 1967, Szafran 1952, Savicz-Ljubitzkaja 1954, Partyka 1976).

Tomenthypnum nitens (Hedw.) Loesk.

1 s, 8 mm, vb; a few t, g; some l, b.

Known from the closely related *Camptothecium lutescens* and *Homalothecium sericeum* by the hardly differentiated angular cells and by the margins being entire at base.

Tomenthypnum nitens is commonly found in Quaternary deposits of the Northern Hemisphere.

Tortella fragilis (Hook. et Wils.) Limpr.

1 l, b.

The leaf fragment is readily recognized by the strong nerve, by the two-layered lamina in the upper part, by the small cells, and by the marginal row of elongate cells extending far up on the leaf.

There are a few previous glacial reports of this species from Denmark, Britain, Poland, Germany, the USSR, and North America (Odgaard 1981, Dickson 1973, Szafran 1952, Jovet-Ast 1967, Partyka 1976, Miller 1980a).

Tortella cf. *T. tortuosa* (Hedw.) Limpr.

Some l, b.

Margin undulating in some fragments; nerve rather weak, well defined also in the upper part; lamina single-layered throughout; cells slightly larger than in modern *T. fragilis.*

T. tortuosa has been reported a number of times from glacial deposits in the Northern Hemisphere, including Denmark.

Tortula ruralis (Hedw.) Gaertn., Meyer et Scherb.

3 l, b.

This species is readily recognized by the leaf margins which are recurved almost to the apex. The cells are 12–16 μm wide in the upper part.

T. ruralis is known from a number of glacial deposits in Northern Europe, including Denmark, the USSR, and North America.

Tracheophyta

Betula nana L.

1 female catkin scale; 2 fruits with damaged wings.

The identification is based on the deep incisions and the parallel lobe-margins of the catkin-scale, and the almost circular shape of the nuts.

Carex sect. Distigmata

2 nuts.

Animals

Crustacea, Cladocera

1 ephippium.

Bryozoa

Cristatella mucedo Cuvier

1 half of a statoblast.

Discussion

The deposit

Although the Hirtshals coast cliff has been disturbed by ice-pressure, the original stratigraphy can still be reconstructed (Lykke-Andersen 1971) and the entire deposit – which in several places contains undamaged mollusc shells (Lykke-Andersen 1971) – cannot have moved horizontally to any great extent.

The absence of marine fossils and the presence of numerous freshwater algae shows that the organic layer is a freshwater deposit. This is in accordance with a lowering of the sea water level in the early part of zone E, and a deepening after zone E, as indicated by the fauna assemblages (Lykke-Andersen 1971).

The organic deposit is mainly allochtonous, and the basin where the sedimentation took place must have received large amounts of surface runoff water. The fragmentation of the macrofossils points to a violent transportation, perhaps over great distances; still, since the organic material is transported by fresh water, it can be assumed that the plants must once have grown within a distance of a few kilometers from the deposit.

Only small amounts of typically interglacial and pre-Quaternary pollen types are present, and the entire fossil plant assemblage can thus be expected mainly to reflect the flora and vegetation at the time of deposition. Furthermore, the macrofossil flora gives the impression of an entity, consisting of open-ground heliophytes with two exceptions: *Oxyrrhynchium swartzii* and *Sharpiella seligeri.* Today, both species are found mainly in shady forest habitats, although *O. swartzii* includes some open-ground forms as well (var. *distans* and var. *rigidum*). Both have a southern distribution in Scandinavia today, and the fossils are probably rebedded from interglacial deposits. It is notable that *O. swartzii* is known from late Eemian deposits at Ejstrup, Jutland (Odgaard 1981). The vast majority of the plant fossils points at arctic conditions (see below) and, since *Sphagnum* sporophytes are rare in the Arctic today (Holmen and Scotter 1971: 38–39), the *Sphagnum* spores are probably rebedded too. The fact that the amount of *Sphagnum* spores is of the same order of magnitude as the amount of typically interglacial pollen, suggests that the rebedded material is peat and not gyttja. It is possible that the scanty macrofossils of *Calliergon giganteum, C. stramineum, Campylium protensum/C. stellatum, D. exannullatus* and *Sphagnum* may also be secondary, since these mosses today are among the common peat-forming plants in temperate areas. The rest of the macrofossils must, however, be considered primary.

Flora and vegetation

The nature of the organic deposit: the occurrence of fragments of wet-ground taxa immediately beside fragments of dry-ground species (see below) shows that the plant macrofossils originate from a larger area, and that they are well-mixed in the deposit. Thus the abundance of the following taxa in the deposit probably reflects a high frequency of these plants in the past vegetation, which covered some larger area around the deposit: *Aulacomnium palustre, A. turgidum, Distichium, Ditrichum flexicaule, Drepanocladus* undiff., *Hylocomium splendens, Polytrichum* sect. Juniperina, *Scorpidium scorpioides, Tomentypnum nitens* and *Tortella* cf. *T. tortuosa.*

Of the 43 plant taxa recognized, the 31 mosses and one seed plant identified to species level – or very nearly so – form the main basis of the palaeoecological interpretations below. From this flora, however, *Oxyrrhynchium* and *Sharpiella* have been excluded, since the fossils of these are probably rebedded (see above), but the possibly rebedded taxa (*Calliergon gigantum, C. stramineum, Campylium protensum/C. stellatum, Drepanocladus exannulatus,* see above) have been retained. The resulting 30 taxa are listed in Table 3.

Today several of these plants are absent, or very rare, in Western Norway, the Faroe Islands and Western Scotland: *Abietinella abietina, Cynodontium*

Table 3. Synopsis of the present-day distribution and frequency in the vegetation regions of non-oceanic Fennoscandia (sensu Sjörs 1956) of the plants identified to low taxonomic levels in the Hirtshals deposit (excluding *Oxyrrhynchium* and *Sharpiella*). This synopsis is based on information in Albertson (1946), Arnell und Jensen (1910), Brotherus (1923), Hagen (1909a, b, 1910, 1915, 1929), Hedberg et al. (1952), Heinonen (1971), Junnilainen (1977), Krusenstjerna (1945), Kujala et al. (1979), Möller (1913, 1923a, b, 1936), Mårtensson (1956), Nyholm (1954–69), Persson (1943), Persson och Waldheim (1940), Tuomikoski (1939), Ulvinen et al. (1976) and Zachrisson (1978). The frequencies are based on the assumption that suitable habitats are present. Key: 0 = absent, 1 = rare, 2 = occasional, 3 = common; I = southern deciduous forest, II = southern coniferous forest, III = northern coniferous forest, IV = subalpine birch forest, V = low-alpine, VI = middle-alpine, VII = high-alpine.

	I	II	III	IV	V	VI	VII
Abietienella abietina	3	3	3	2	2	1	1
Aongstroemia longipes	0	1	1	1	1	0	0
Aulacomnium palustre	3	3	3	3	3	2	1
A. turgidum	0	0	0	1	3	3	3
Barbula acuta	1	1	1	0	0	0	0
Calliergon giganteum	3	3	3	3	2	0	0
C. stramineum	3	3	3	3	2	1	0
Campylium stellatum/C. protensum	3	3	3	3	3	1	0
Conostomum tetragonum	0	0	1	2	3	3	3
Cynodontium tenellum	0	2	3	3	3	1	1
Dicranum fuscescens/D. muehlenbeckii	2	2	3	3	3	3	3
Distichium	1	2	2	3	3	3	1
Ditrichum flexicaule	1	2	2	3	3	2	1
Drepanocladus exannulatus	3	3	3	3	3	2	1
D. uncinatus	2	3	3	3	3	3	3
Entodon concinnus	1	1	1	1	1	0	0
Fissidens osmundoides	1	2	3	3	3	1	0
Hylocomium splendens	3	3	3	3	3	3	1
Paludella squarrosa	1	2	2	3	3	1	0
Philonotis fontana/P. tomentella	3	3	3	3	3	2	1
Polytrichum alpinum	0	1	3	3	3	3	3
P. affine/P. juniperinum	3	3	3	3	3	1	0
Racomitrium canescens	1	2	3	3	3	3	2
Scorpidium scorpioides	2	2	3	3	3	1	0
Timmia norvegica	0	0	1	3	3	2	1
Tomenthypnum nitens	1	2	3	3	3	2	1
Tortella fragilis	1	2	2	3	3	1	1
T. tortuosa	1	2	3	3	3	2	1
Tortula ruralis	3	3	2	1	1	1	1
Betula nana	0	1	3	3	3	0	0

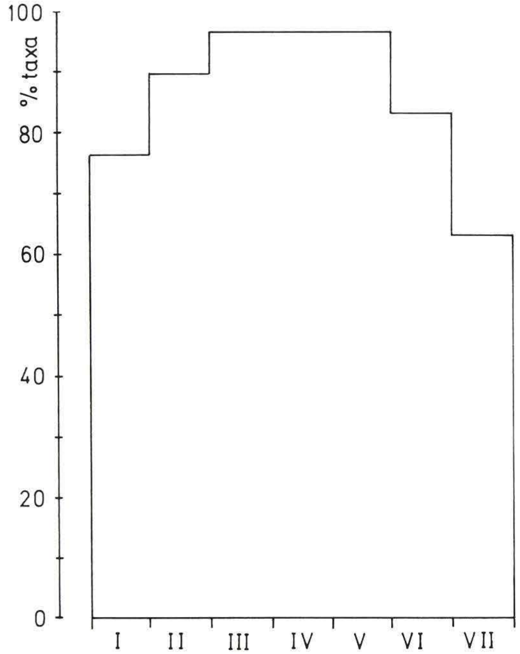

Fig. 4. Percentage of taxa of the Hirtshals flora (Table 3) present in the vegetation regions of non-oceanic Fennoscandia. (100% = 30 taxa). I - VII, see legend for Table 3.

tenellum, Entodon concinnus, Paludella squarrosa, Racomitrium canescens s.str., *Timmia norvegica, Tomenthypnum nitens* and *Tortella fragilis* (Hagen 1909a, b, 1915, 1929, Havaas 1962, Heinonen 1971, Kaalaas 1911, Krusenstjerna 1945, Boesen et al. 1975, Jensen 1901, Birks and Birks 1974, Corley and Hill 1981). Thus, the conclusion may be drawn that conditions were not oceanic, and the Hirtshals flora can be compared to the present floras of the vegetational regions of non-oceanic parts of Fennoscandia. Table 3 shows a synopsis of the present distribution and frequency of the Hirtshals plants in these regions.

Since many mosses have wide distributions, the Hirtshals flora cannot be very precisely characterized when only presence/absence in the vegetational regions is considered (Fig.4). Greater precision is achieved when the present frequencies of the taxa are taken into account (Fig. 5), and still greater when concentrating only on the present frequencies of the taxa which are relatively abundant in the deposit (Fig. 6). Provided the number of taxa is not too small, the latter method yields the most reliable information since the taxa

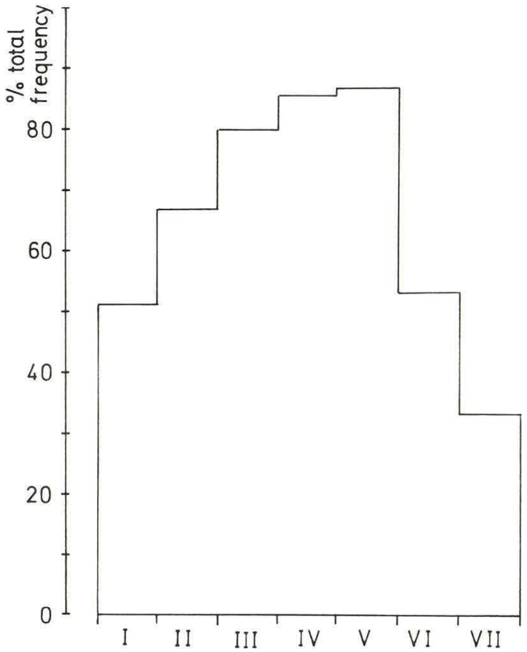

Fig. 5. Frequency of the Hirtshals plants in the Fennoscandian vegetation regions (frequencies of Table 3 in percentage of total frequency; 100% = 90). I - VII, see legend for Table 3.

which were common in the past naturally were those whose environmental demands were fulfilled to a high degree, while less common species may have been near the limits of their ecological, including climatic, amplitude. Another advantage of this method is that it excludes the possibly rebedded taxa, since all of these are scanty in the deposit.

Figures 5 and 6 indicate that the Hirtshals macrofossil flora may be termed subarctic/low-arctic (subalpine/low-alpine).

As shown above the only *Betula* species present was *B. nana.* Thus the pollen spectrum reflects a landscape devoid of trees but dominated by an open herb vegetation with many dwarf shrubs like *Betula nana* and *Salix* spp. Mosses, of course, have played a considerable role in this vegetation.

The environment

Climate. The absence of trees reflected in the pollen assemblage might be explained by the hypothesis that the period of climatic amelioration indicated by the foraminifera assemblages was too brief for trees to have immigrated

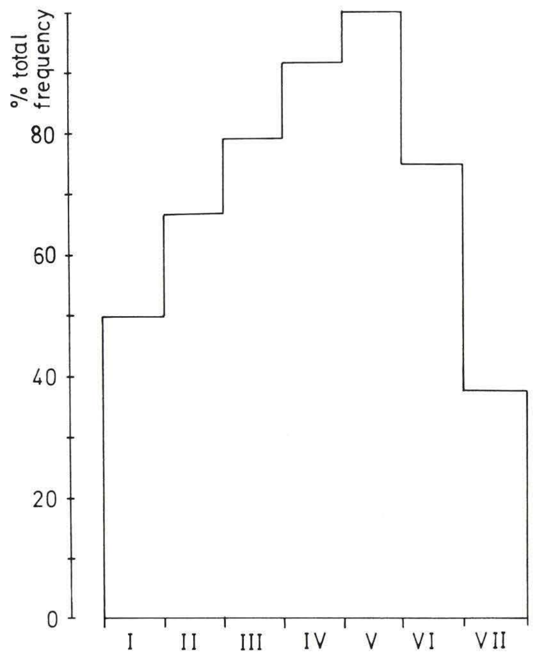

Fig. 6. As Fig. 5, but limited to plants of which macrofossils are abundant in the deposit: *Aulacomnium palustre, A. turgidum, Distichium, Ditrichum flexicaule, Hylocomium splendens, Scorpidium scorpioides, Tomenthypnum nitens, Tortella tortuosa* (100% = 24). I - VII, see legend for Table 3.

from their distant refugia – even if the climate were favourable for tree growth. The importance in the past vegetation of *Aulacomnium turgidum* is, however, notable in this connection. This species is common in the alpine regions of Scandinavia, but rare in the subalpine region (Table 3), and there are but very few scattered occurrences in the northern part of the northern coniferous forest region – at least some of which can be considered glacial relic stands (cf. Junnilainen 1977). The scarcity of *A. turgidum* in the subalpine region today can hardly be due to shading by trees, since the birch forests here are very open and many boreo-alpine heliophilous mosses are still common. High summer temperatures are more likely to be the most serious limiting factor below the tree line for this truly arctic-alpine moss. Vorren (1978: 30) mentions that fossils of *A. turgidum* are characteristic of a Middle Weichselian fresh-water sediment in northern Norway, but he did not find it in the overlying Late Weichselian layers which were deposited during climatically more favourable conditions.

Thus, from the abundance of *A. turgidum* fossils in the Hirtshals deposit, we must assume a mean July temperature below 10°C. On the other hand, the fact that *Betula nana* was common, and the general subarctic/low-arctic (subalpine/low alpine) character of the moss flora (Figs. 5 and 6), indicate a mean July temperature not below 8°C – indeed probably slightly higher.

Another species of interest in a discussion of the palaeoclimate is *Barbula acuta.* Today this species has a submediterranean- subatlantic distribution in Europe, and has not been found above the northern coniferous forest region in Scandinavia. The presence of *B. acuta* in the Hirtshals deposit might thus be taken as evidence for boreal-temperate conditions. *B. acuta,* however, belongs to the group of heliohilous calcicolous pioneer plants which, as pointed out by Iversen (1954), are poor indicators of macroclimate. They are opportunists and are more dependent upon low competition and open calcareous soil than on the climate itself. Thus in Denmark today, *B. acuta* grows on pure chalk in an abandoned pit (Brandt-Pedersen 1978). The occurrence of *B. acuta* in the Moershoofd Interstadial in Denmark is, therefore, a Middle Weichselian cryptogamic parallel to the group of southern heliophilous seed plants that flourished in Denmark during the Late Weichselian (Iversen 1954).

Edaphic interpretation. Based on their modern edaphic preferences, the mosses identified to low taxonomic levels (excluding *Oxyrrhynchium* and *Sharpiella*) can be divided into the following ecological groups (Table 4):

1. Taxa preferring dry calcareous soil, though many thrive on moist calcareous soil and calcareous rock as well.
2. Taxa preferring dry/moist non-calcareous soil.
3. Dry/moist ground taxa with wide pH-ranges.
4. Taxa preferring rich fens. Some also thrive on moist calcareous soil.
5. Taxa preferring poor fens.
6. Wet-ground taxa with wide pH-ranges.
7. Epilithic taxa.
8. Taxa not referable to any of the above groups due to wide ecological amplitudes or imprecise identifications.

It can be seen from Table 4 that five of the eight mosses which are abundant in the deposit (*Distichium, Ditrichum flexicaule, Scorpidium scorpioides, Tomenthypnum nitens, Tortella tortuosa*) prefer calcareous substrates, and that the remaining three are more or less indifferent to the acidity of the substrate. Of the 21 scanty taxa, the corresponding figures are nine and seven. Only five of these mosses prefer non-calcareous substrates: *Calliergon stramineum,*

Table 4. Survey of the modern edaphic preferences of the Hirtshals mosses in non-oceanic Fennoscandia, with special consideration given the subalpine and low-alpine regions, based on personal experience and the references mentioned in the legend for Table 3. The upland taxa are classified according to the growth-form scheme of Gimingham and Birse (1957); however, the Te and t forms are delimited according to the modification of La Roi and Stringer (1976). The estimated abundances of the fossils in the deposit are also given.
Key: ×× = edaphic conditions optimal for taxon, × = substrate type not characteristic for taxon; – = taxon absent from, or only exceptionally present on, substrate type, ++ = taxon abundant in the deposit, + = taxon scanty in the deposit. For explanation of growth-form abbreviations, see legend for Table 5.

	calcareous soil		non-calcareous soil		fens		rock		
	Dry	Moist	Dry	Moist	Rich	Poor	Calcareous	Non-calcareous	Abundance in deposit
Group 1									
Abietinella abietina W	××	×	–	–	–	–	××	–	+
Barbula acuta t	××	××	–	–	–	–	–	–	+
Distichium t	××	××	–	–	–	–	××	–	++
Ditrichum flexicaule Te	××	××	–	–	–	–	××	–	++
Entodon concinnus W	××	–	–	–	–	–	××	–	+
Timmia norvegica Te	××	××	–	–	–	–	–	–	+
Tortella fragilis t	××	××	–	–	–	–	××	–	+
Tortella tortuosa t	××	××	–	–	–	–	××	–	++
Tortula ruralis t	××	–	–	–	–	–	××	–	+
Group 2									
Conostomum tetragonum cu	–	–	–	××	–	–	–	–	+
Racomitrium canescens Td	–	–	××	××	–	–	–	×	+
Group 3									
Aongstroemia longipes t	–	××	×	××	–	–	–	–	+
Aulacomnium turgidum Te	×	××	–	××	–	–	×	×	++
Dicranum fucescens/D. muehlenbeckii Te	××	××	××	–	–	–	××	××	+
Fissidens osmundoides t	–	××	–	××	×	×	–	–	+
Polytrichum alpinum Te	–	×	××	××	–	–	–	–	+
Group 4									
Calliergon giganteum	–	–	–	–	××	–	–	–	+
Campylium protensum/C. stellatum	–	××	–	–	××	–	–	–	+
Paludella squarrosa	–	–	–	–	××	×	–	–	+
Scorpidium scorpioides	–	–	–	–	××	–	–	–	++
Tomenthypnum nitens	–	××	–	–	××	–	–	–	++

	calcareous soil		non-calcareous soil		fens		rock		
	Dry	Moist	Dry	Moist	Rich	Poor	Calcareous	Non-calcareous	Abundance in deposit
Group 5									
Calliergon stramineum	–	–	–	–	–	××	–	–	+
Drepanocladus exannulatus	–	–	–	–	×	××	–	–	+
Group 6									
Aulacomnium palustre	–	×	–	×	××	××	–	–	++
Philonotis fontana/P. tomentella	–	××	–	×	××	××	–	–	+
Group 7									
Cynodontium tenellum t	–	–	–	–	–	–	×	××	+
Group 8									
Drepanocladus uncinatus Mr	–	××	××	××	×	××	×	××	+
Polytrichum affine/P. juniperinum t	–	–	××	×	–	××	–	–	+
Hylocomium splendens W	×	×	××	××	×	××	×	×	++

Conostomum tetragonum, Drepanocladus exannulatus, Polytrichum affine/P. juniperinum, and *Cynodontium tenellum,* of which the latter is obligate epilithic and shows the presence of acid boulders. Thus, calcareous substrates were strongly dominant.

The moss flora (Table 4) reflects a moisture gradient from dry to wet habitats. The fact that, in more arid macroclimates than the Fennoscandian today, some of the mosses (*Aulacomnium turgidum, Distichium, Ditrichum flexicaule, Timmia norvegica, Tortella fragilis, T. tortuosa,* and *Tortula ruralis*) prefer moister/wetter substrates than those indicated in Table 4, somewhat complicates the question of substrate moisture. (Cf. the present habitats of these mosses in the polar deserts of Peary Land and Arctic Alaska: Holmen 1960, Steere 1976). If, however, the ecological amplitudes indicated in Table 4 are accepted, the taxa are distributed along the moisture gradient as follows (rock ommited):

	Dry	Moist	Wet
abundant taxa	4	7	4
scanty taxa	12	13	9

The distribution of abundant taxa does not differ from that of scanty taxa. The slight dominance of the moist-ground group can be explained by the fact that some species preferring dry ground, as well as some preferring wet ground, may also occur on moist substrate.

The distribution indicates that dry and moist ground together probably covered a larger part of the area that contributed plant material to the deposit than did wet ground.

It is notable that among the upland taxa, almost all prefer mineral substrate. Only *Fissidens osmundoides,* represented by a single leaf in the deposit, has a preference for substrates with high humus content. Thus raw soil probably was the dominant upland soil type.

Miller (1980b) used the growth-form spectra of North American late glacial moss assemblages as a palaeoecological indicator. From the dominance of short turf species in the upland flora of three late glacial assemblages (two woodland and one tundra), he concluded that dry exposed microsites were important in the landscape. Through a comparison with present growth-form spectra from boreal forests in North America, he also pointed out that the dominance of the short turf type suggested a continental climate.

In Table 4, the upland mosses of the Hirtshals flora are classified according to the growth-form system of Gimingham and Birse (1957) and the growth-form spectrum is shown in Table 5.

Like the North American late glacial examples (Miller 1980b), the short turf form is dominant, and the tall turf type with erect branches is of some importance, while other growth forms are only represented by small values, or are absent entirely.

Again, the predominance of short turf taxa in the Hirtshals spectrum indicates the importance of dry exposed habitats in the Danish Moershoofdian landscape (Gimingham and Birse 1957, Birse 1958). However, if climatic conclusions were to be drawn from the growth-form spectrum, it should be compared to present artic-alpine spectra from areas with a habitat range

Table 5. The growth from spectrum (%) of upland taxa of the floras of Hirtshals and Skærumhede.
Key: cu = small cushions; Mr = rough mats; Ms = smooth mats; t= short turfs; Td = tall turfs, branches divergent; Te = tall turfs, branches erect; W = wefts.

	cu	Mr	Ms	t	Td	Te	W	n
Hirtshals	5	5	0	45	5	25	15	20
Skærumhede	0	13	8	46	4	25	4	24

thought to be very like that of the Danish Moershoofdian landscape, but with varying macroclimates. Unfortunately, information about such spectra seems to be virtually absent from literature, and further research in this area is needed.

Two species are ecologically very interesting: *Aongstroemia longipes* and *Conostomum tetragonum.* Although *Aongstroemia* has been reported as growing together with relatively strong competitors like *Distichium spp.* and *Meesia uliginosa* (Hesselbo 1918, Mårtensson 1956), it is certainly best characterized as a pioneer species. Thus it has been found on the sandy banks of streams and lakes and along roadsides in southern Finland and in the mountains of Norway (Koponen in Kujala et al. 1979: 29, Hagen 1915: 44), in large quantities on moist loamy soil exposed during dam construction in Scotland (Crundwell 1965), and as the very first pioneer moss in depressions in sandy-silty out-wash plains at the glacier Austerdalsisen, Central Norway (Theakstone and Knighton 1979). The occurrence of *Aongstroemia longipes* in the Hirtshals deposit thus indicates strong erosion, an unsurprising finding, which is in accordance with the nature of the deposit: the strongly fragmented macrofossils of both wet- and dry-ground taxa and the abundant mineral material.

The dominating role of *Conostomum tetragonum* in the vegetation of certain base-poor types of extreme snow beds is well known. According to Gjaerevoll (1956: 223), this species prefers areas where the surface is uneven due to frost-action and solifluction. However, *C. tetragonum* is also frequent on lake- and stream-banks (Mårtensson 1956) and thus cannot be used to indicate the presence of snow beds. One of the best plant indicators of snow beds, *Polytrichum norvegicum,* is still unknown from Danish Quaternary deposits, whereas it has been reported from glacial layers in Britain (Dickson 1973), Norway (Övstedal and Aarseth 1975), Poland (Szafran 1952), and the USSR (Savicz-Ljubitzkaja 1954, Partyka 1976). Frost action and erosion were probably strong in Denmark during the entire Middle Weichselian, and calcareous raw soil must have been the dominating soil type. This was certainly the case during the Moershoofd Interstadial (see above) and most of the Late Weichselian (Iversen 1954). Snow beds are a function of temperature and precipitation, and they are present almost everywhere in the Arctic today. Thus it seems obvious that snow beds were also present in Denmark during at least the greater part of the Middle and Late Weichselian, periods generally characterized by arctic climates. However, the base-rich type of snow bed must have been strongly dominant, and *P. norvegicum,* being an acidophilous species, was probably at most a rare plant. Fossils of this species can thus hardly be expected in the most frequent Danish plant-bearing glacial deposits, viz. the Late and Middle Weichselian ones.

From the discussion above, the following environmental conclusions can be drawn. The topography of the area has been varied; dry exposed microhabitats were probably important but badly-drained areas were also present. Calcareous raw soil was prevalent and soil erosion was strong; however there is evidence of smaller areas of leached acid soils, and boulders of acid rock were probably present as well.

Conclusion

The Hirtshals Moershoofdian plant assemblages reflect a treeless landscape dominated by herbs, dwarf shrubs like *Betula nana* and *Salix* spp., and mosses. The climate was non-oceanic and mean July temperatures were probably between 8 and 10°C. Surface erosion was strong and calcareous raw soil predominated in a landscape of varied topography with some acid boulders.

Few other North European plant assemblages of established Moershoofdian age have been recovered. The only Danish plant-bearing deposit that can be considered partly synchronous with the Hirtshals assemblage is that discovered at Skærumhede, ca. 30 km east of Hirtshals (Jessen et al. 1910, Fig. 1). The stratigraphic position of the thick Skærumhede marine deposits has been the subject of much debate, and a recent coring (Skærumhede II) has been carried out in order to elucidate this point (Bahnson et al. 1974). As pointed out by Lykke-Andersen (1981), the new radiocarbon date of the Hirtshals Zone E, and the probable foraminifera-based correlation between the Hirtshals and the Skærumhede series, strongly indicate a Moershoofdian age for the foraminiferal Zone IV in the Skærumhede II coring (Bahnson et al. 1974). In section 73.1–86.0 m of the Skærumhede I coring, corresponding to Zone IV of the Skærumhede II coring, many plant remains were found (Hesselbo and Hartz in Jessen et al. 1910).

The deposit of this section of Skærumhede I is clay with intercalated layers of sand and stones (Jessen et al. 1910). The plant fossils of the pure clay are almost exclusively mosses, mostly represented by detached, well-preserved leaves (Hesselbo in Jessen et al. 1910: 103), and this flora gives the same general impression of subarctic/low arctic conditions as the Hirtshals flora. In the clay mixed with coarse sediments, a temperate phanerogamous element, *Ranunculus repens,* is also present, but the moss flora does not differ from that of the pure clay. The coarse sediments and the temperate flora element are assumed to have been eroded from older deposits and transported to Skærumhede by ice floes (Jessen in Jessen et al. 1910: 78–79, Bahnson in Bahnson et al. 1974: 37), but the part of the flora bound to the clay – i.e., mosses and boreo-arctic phanerogams – can certainly be considered almost synchronous (penecontemporaneous) with the deposit (cf. Jessen in Jessen et al. 1910: 79).

Of the 56 moss-taxa found by Hesselbo (in Jessen et al. 1910: 106–109) in the assumed Moershoofdian zone, about 21 are also found in the Hirtshals assemblage, and the persistant occurrence of *Aulacomnium turgidum* in all samples is especially noteworthy. The majority of the Skærumhede taxa are calciphilous or indifferent to substrate acidity, but an acidophilous element is present as well (*Calliergon stramineum, Racomitrium ericoides*). The growth-form spectrum of upland taxa closely resembles that of the Hirtshals flora (Table 5). Among the seed plants, *Betula nana* – but no tree-birches – was found (Hartz in Jessen et al. 1910). Thus the Skærumhede assemblage gives rise to the same general environmental conclusions as the Hirtshals fossils.

A number of organic deposits in the Netherlands have finite radiocarbon dates around the interval 51,000–44,000 BP, called the Moershoofd Interstadial complex (van der Hammen et al. 1967, Zagwijn 1974, Kolstrup and Wijmstra 1977). Pollen analyses of these deposits always reflect treeless landscapes but are otherwize not very informative.

The unambigous local presence of plant taxa is more difficult to demonstrate by pollen data than by macrofossil data. Furthermore, macrofossils can generally be identified to lower taxonomic levels than can pollen grains, and the flora and vegetation – which form a very important part of the basis of the environmental conclusions – can, hence, be more precisely reconstructed when both pollen and macrofossil data are available.

Kolstrup and Wijmstra (1977) assume mean July temperatures of about 13°C for the oldest part of the Moershoofd Interstadial complex in the Netherlands, and a drop to below 10°C a few thousand years later. These estimates are, however, based on weak pollen data and need confirmation by independent methods, e.g. by macrofossil analysis, before comparison with the present results.

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Dansk sammendrag

En organisk ferskvandsaflejring fra Hirtshals kystklint, tidligere C-14 dateret til 47.300 før nu (Moershoofd Interstadial), er undersøgt for pollen og plantemakrofossiler. Aflejringen ligger i klinten indskudt mellem marine lag, Ældre Yoldia Ler, og er afsat i et ferskvandsbassin i en periode hvor havet har trukket sig tilbage fra Hirtshals-området. Aflejringen består hovedsageligt af sammenskyllet materiale og både pollen og makrofossiler kan antages at afspejle flora og vegetation i et større område. Ialt er bestemt makrofossiler af 41 mosser, 2 frøplanter og 2 dyr. Denne rige mosflora overgås kvantitativt i Danmark kun af floraen i den nærliggende Skærumhede aflejring.

Størrelsesmålinger af Birke-pollenkorn i aflejringen viser at disse stammer fra Dværg-Birk, og pollen- og makrofossilanalyserne afspejler tilsammen en træfri vegetation domineret af dværgbuske, urter og mosser.

Mosfloraen viser at klimaet ikke har være oceanisk og ved sammenligning med de fundne planters nuværende udbredelser og hyppigheder i Fennoskandinavien kan makrofossil-floraen karakteriseres som subarktisk/lavarktisk. Sammen med de rigelige forekomster i aflejringen af rester af mosset *Aulacomnium turgidum* (makrofossiler) og Dværg-Birk (pollen og makrofossiler) tyder dette på at gennemsnitstemperaturen for juli måned har ligget mellem 8 og 10°C.

Ud fra de fundne mossers økologi idag kan der desuden drages følgende konklusioner: Topografien var varieret med både veldrænede og dårligt drænede voksesteder, men tørre og eksponerede mikro-habitater synes dog at have været særligt vigtige i landskabet. Jorderosionen var kraftig og kalkholdig råjord var den dominerende jordbundstype. Forekomsten af en altid stenboende mosart viser at der har ligget større sten af sure bjergarter på jordoverfladen.

Makrofossilfloraen fra Hirtshals sammenlignes med en samtidig flora fra en del af Skærumhede aflejringen og der påvises mange ligheder.

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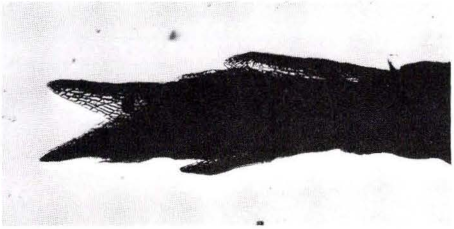
Plate 1.

Figs. 1–4. *Aongstroemia longipes* (Sommerf.) B.S.G.
1. Broken shoot, fossil, Hirtshals. ×64.
2. Fossil leaf, Hirtshals. ×64.
3. Detail of fossil leaf, Hirtshals. ×162.
4. Recent leaf from specimen collected by C. Jensen, 22 July 1913, Jämtland, Sweden. Herb C. ×64.

Figs. 5–6. *Barbula acuta* (Brid.) Brid.
5. Fossil leaf, Hirtshals. ×64.
6. Detail of fossil leaf, Hirtshals, showing quadrate cells on the ventral side of the nerve in the middle of the leaf. ×292.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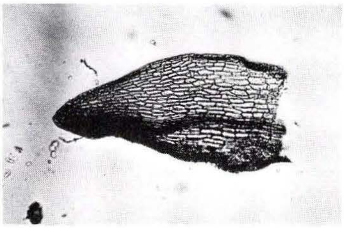
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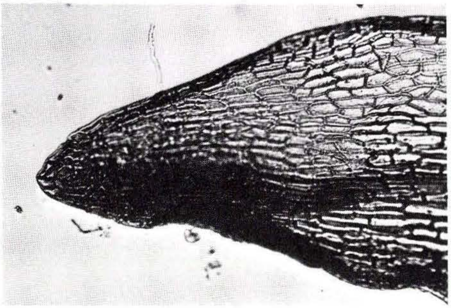
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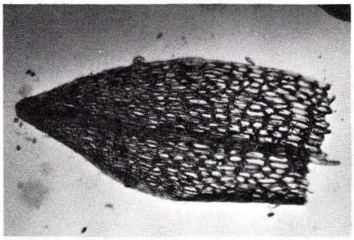
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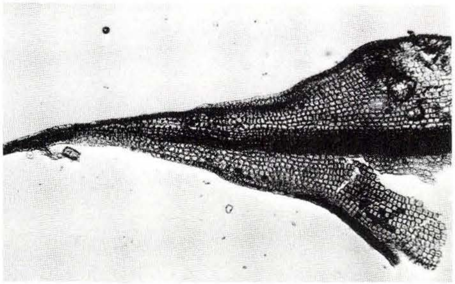
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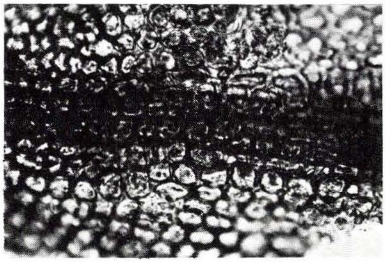
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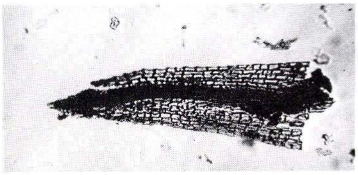
Plate 2.

Figs. 1–4. *Conostomum tetragonum* (Hedw.) Lindb.
1. Fossil leaf, Hirtshals. ×61.
2. Fossil leaf, Hirtshals, lying above a leaf fragment. ×61.
3. Detail of fossil leaf, Hirtshals. ×154.
4. Recent leaf from specimen collected by B. Odgaard, 12 July 1978, Vassijaure, Torne Lappmark, Sweden. Herb. B. Odgaard. ×61.

Fig. 5. *Fissidens* cf. *F. osmundoides* Hedw. Fossil leaf, Hirtshals. ×61.

Fig. 6. *Fissidens osmundoides* Hedw. Recent leaf from the lower part of a stem. Specimen collected by B. Odgaard 12 August 1976, Liikasenvaara, Kuusamo, Finland. Herb. B. Odgaard. ×61.



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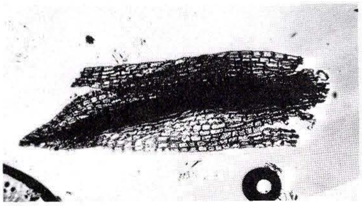

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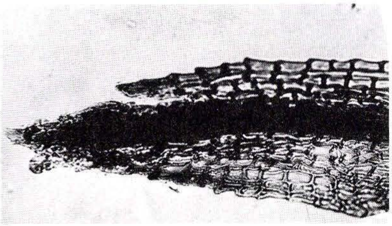

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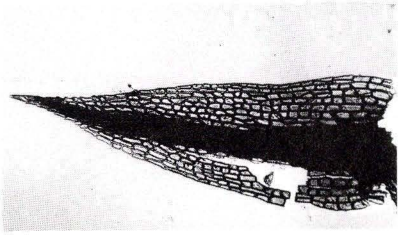

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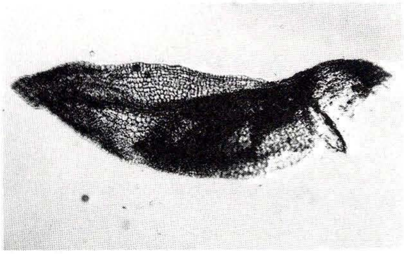

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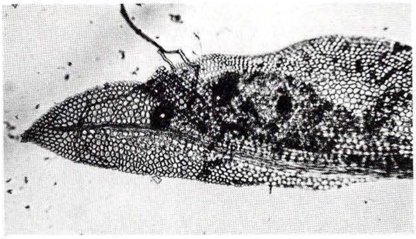

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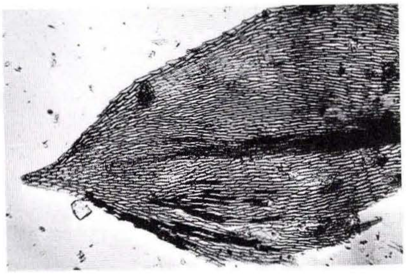
Plate 3.

Figs. 1–3.	*Oxyrrhynchium swartzii* (Turn.) Warnst.
1.	Fossil leaf, Hirtshals. ×59.
2.	Fossil leaf, Hirtshals. ×59.
3.	Detail of fossil leaf, Hirtshals, showing nerve ending in spine at back above. ×268.
Fig. 4.	*Cynodontium tenellum* (B.S.G.) Limpr. Upper part of fossil leaf, Hirtshals. ×59.
Figs. 5–6.	*Timmia norvegica* Zett.
5.	Apex of fossil leaf, Hirtshals. ×59.
6.	Base of fossil leaf, Hirtshals. ×59.



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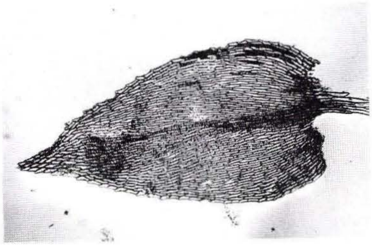

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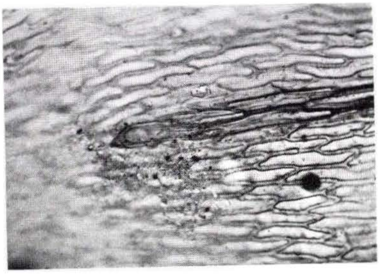

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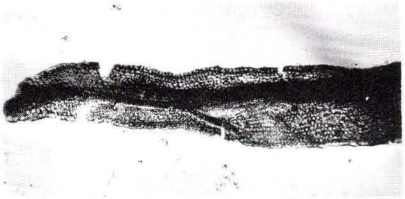

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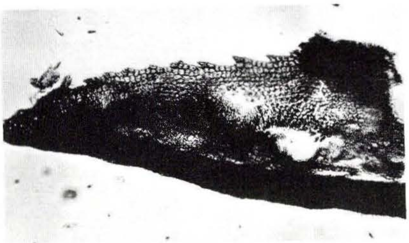

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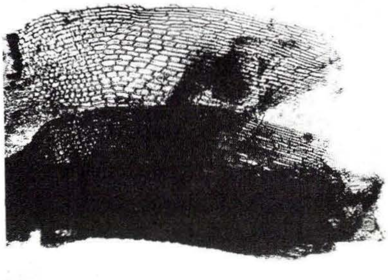

6

Turbidites and associated resedimented deposits from a tilted glacio – deltaic sequence, Denmark

Niels Balslev Jørgensen

Jørgensen, N. B.: Turbidites and associated resedimented deposits from a tilted glaciodeltaic sequence, Denmark. *Danm. geol. Unders., Årbog 1981:* 47–72, pls. 1–3, København, 1. oktober 1982.

Sedimentological facies analysis reveals that a so-called hatshaped hill in NW Zealand consists of several coarsening- upward steep slope deltaic associations, alternating with monotonous deltaic-lacustrine associations. About 58% of the beds probably were deposited from turbidity currents as underflows, inflows and overflows, and about 15–20% from buoyancy dominated debris flows and density modified grain flows.
Deposition is suggested to have taken place in a stagnant ice-marginal lake environment. Penetration of the icesheet by thermo-karst, and the actual morphology of the stagnant icemasses probably influenzed the development of large holes, which were the sites of deposition. Fluctuation in position of the active ice margin is thought to be reflected in the vertical record as repeated changes in sub-environment from steep slope deltaic to deltaic-lacustrine. The tilting was caused by ice push and gravitational overturning.

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Only a few studies of the sedimentology and interpretation of sedimentary environment of Quaternary stratified drift-deposits in Denmark have been made (se Clemmensen & Houmark-Nielsen, 1981). In the last few years, however, a systematic registration of vertical sedimentological profiles in pits all over the country has started, as a consequence of the Raw Material Act of june 1977 (see Herslund et. al., 1979). In connection with this registration several students chose their graduate work in this field. The present work is part of a cand. scient. thesis supervised by Dr. scient. Finn Surlyk. The field work was carried out during summer 1979 and 1980.

Much attention has been drawn to the origin of the hatshaped hills in NW Zealand, because of the obvious correlation between morphological appearance and internal composition, the strata being tilted to almost vertical. The origin and sedimentary environment of the deposits in these hills has been lively debated. Rørdam & Milthers (1900) suggested an ice-marginal lake environment. Andersen (1966) postulated a nearshore beach environment of

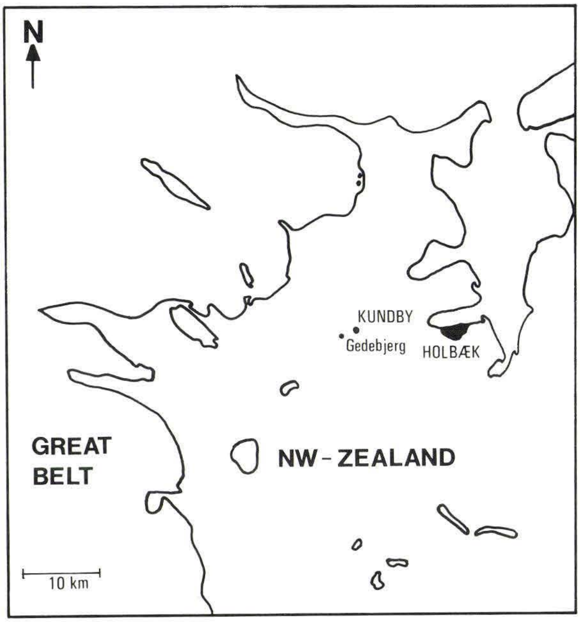

Fig. 1. Location of the gravel pit Gedebjerg.

the interglacial Skærumhede sea. Løvbakke (1974) suggested a distal braided river environment, on the basis of petrographic and granulometric studies. Surlyk (1980), in a review of the geology of Denmark, suggested a steep slope deltaic environment, originated in a glacial lake.

In the present work the sedimentary sequences was logged in detail, in order to determine the palaeoenvironment more precisely.

Setting

The observations were made in an abandoned gravel pit at Gedebjerg, near Kundby in NW Zealand (fig. 1). The surrounding area is characterized by the appearance of several hatshaped hills on a relatively flat plain.

Berthelsen (1971) believes that the tilted sequence constitute the more or less overturned limb of an overtilted anticlinal foldstructure continuing downwards. According to Binzer (1979, fig. 14) the plain is covered by a thick till bed, strongly suggesting that the stratified drift deposits of the hill are placed upon the till bed, and therefore younger.

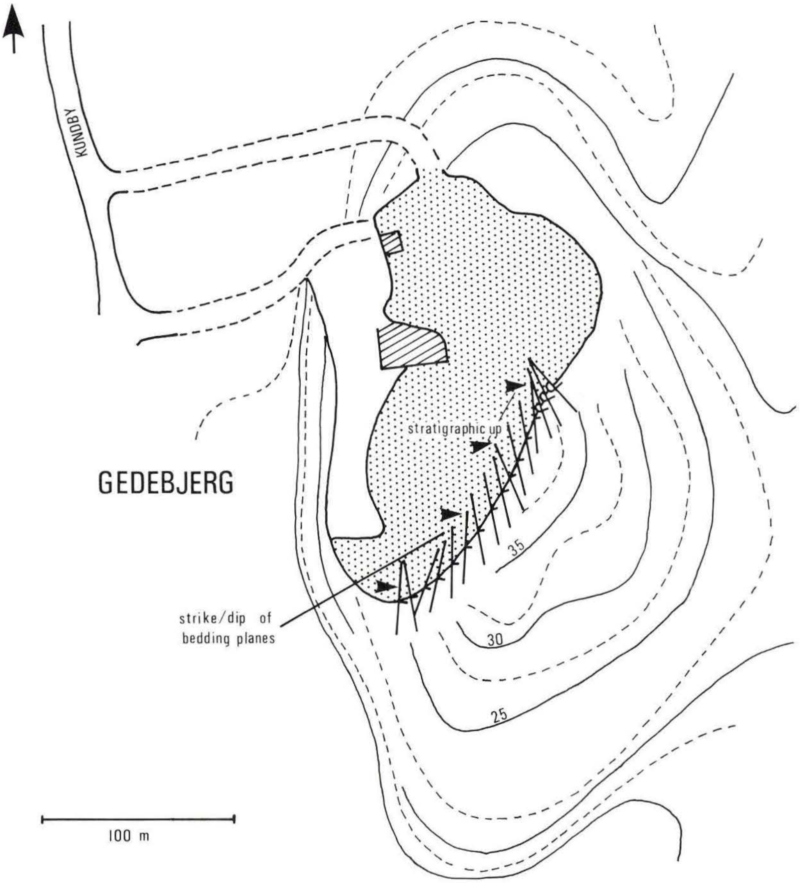

Fig. 2. Topographic map of Gedebjerg. The log was measured along th SE wall.

The wall in the gravel pit strikes SE–NW and runs for 110 meters (fig. 2). The beds strike approximately N–S and the dip is almost vertical (see also Rørdam & Milthers, 1900). Continuous recording of the strike/dip along the pit wall, around 3–10 meters over the pit bottom, shows changes in values from around 180/70–80 E in the interval from o to 40 meters, 170/70–80 E in the interval from 40 to 80 meters, and around 150/70–80 W in the interval from 80 to 102 meters (fig. 2). However, some variation in strike/dip from the bottom to the top of the pit wall, is also seen. The whole section is thus apparantly made up of at least three units, divided at about 40 and 80 meters. The uppermost unit is overtilted.

Fig. 3. The NE part of the open profile in Gedebjerg (1980). Up is to the left. Note fault planes dipping towards E-NE.

The section is strongly faulted. Normal faults dominate (fig. 3) and a few are thought to be synsedimentary (se also Rasmussen, 1967). Small reverse faults occur in the upper west corner of the pit, and the fault planes dip in a northwesterly direction. For the whole pit, dip-slip never exeeds 1 meter. As Rørdam & Milthers (1900) pointed out, there is no evidence to show that this thick sequence should be a relict of foldstructures of a sequence of much lesser vertical extend. Hence, stratigraphic up is to the NE throughout the entire section (see plates 1, 2 and 3; legend in fig. 14).

Sedimentology

A vertical section of 102 meters has been measured (plates 1, 2 and 3). In general terms the sequence is composed of beds of fine sand, silt and clay interbedded with beds containing boulder size clasts. Bed thicknesses range from millimeters to meters, and the beds extend laterally from a few decimeters to several meters. The lithology includes quartz grains, fragments of igneous and metamorphic rocks, chert, palaeozoic limestone and fragments

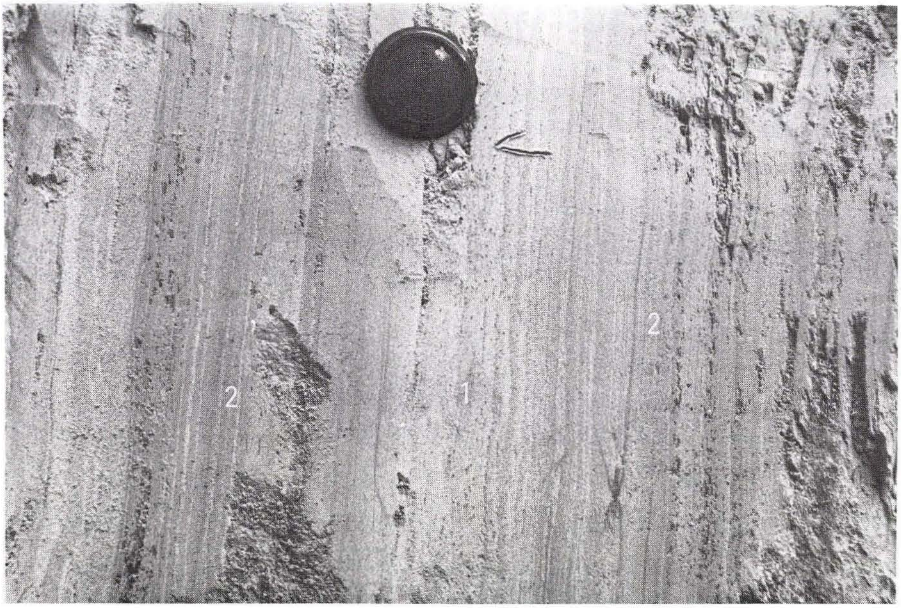

Fig. 4. Laminated sand streaked silt (1). 1) normal graded beds, up is to the left. 2) micro lamination in the clayey sequences.

of Danian bryozoans and echinoids (see also Løvbakke, 1974). Certain amounts of porphyres, *Orthoceras* limestone and *Skolithos* sandstone are also seen.

Seven sedimentary facies can be destinguished on the basis of their primary characteristics.

Description. Laminated sand streaked silt (1)

This facies is comprised of thinly interlaminated clayey silt and sandy silt. Thicknesses of individual laminae ranges from o.l. millimeters to a few centimeters, and the laminae generally have a wide lateral extend. Lamination are often cyclic, with small units dominated by clayey silt alternating with units dominated by sandy silt. In each clayey silt unit irregular coarse grained streaks, only a few thenth of a millimeter thick and not more than a few millimeters apart, are seen (fig. 4).

Individual sand layers some times are internally cross laminated, and display both normal distribution and coarse-tail grading. Reverse grading occur only sporadicly. Micro scours ranging in depth from millimeters to decimeters, and in width from around 2 to 20–30 cm occur in this facies (fig. 5). Granule size clay clasts are often seen, and out-size clasts are abundant.

Fig. 5. Micro channels or scours in facies 1. Stratigraphic up is at the bottom a) micro ripples b) debris band.

Interpretation

The overall grain size and only occasional signs of current produced structures, show that deposition took place in a low energy environment with only weak and sporadic currents. The wide lateral extend of the individual laminae shows that deposition was not confined to scours or channels. The main part of this facies, therefore, presumably was deposited from suspension.

The micro cross lamination in individual sand layers is interpreted as a result of migration of current ripples. Ripple index around 3.5 shows that velocities of about 10–20 cm/s has not been exeeded (Southard, 1975).

The ripples occur in otherwise normal graded layers in accordance with the T_{cde} unit of the Bouma-sequence (Bouma, 1962). Accordingly these layers are interpreted as a result of deposition from a turbidity flow. Turbidity flow has long been accepted as a cause of graded bedding (künen & Migliorini, 1950; Middleton, 1967). The turbidity flows probably eroded the scours.

The micro lamination shows that different orders of pulsation occured. Smith (1978) interpreted micro lamination, in deposits from a glacial lake, as a result of diurnal, subseasonal, seasonal, annual and exceptional inflow events. Exept for the diurnal variations, each of the other events produced recognizable lamination.

Description. Interlayered silt and sand. (2)

This facies is made up of beds of fine to coarse silt and sand. Individual beds range in thickness from a few to 10–15 centimeters, and are lenticular. Characteristic successions of primary sedimentary structures in each bed are from the bottom to top: horizontal lamination in coarse to fine sand, followed by small scale cross-lamination, followed by irregular faint horizontal lamination and finally structureless at the top where grain size range from clay to fine silt (fig. 6C). The succession is continuous without erosive boundaries inbetween. A large number of varities of the described succession occurs in the vertical record, ranging from structureless graded beds (fig. 6A) to beds showing the whole succession (fig. 6B and C). Most of the beds are normal distribution graded, but inverse grading also occur. The successions strongly resemble the T_{bcde} and T_{cde} of the Bouma-sequence (Bouma, 1962).

Beds starting with a distinct lower horizontal laminated unit are often seen filling erosional scours or channels eroded into the same facies.

Current ripples are asymmetric straight crested to linguoid, and occur as formsets or cosets.

Granule size clay and silt clasts, as well as out-size clasts are often seen.

Interpretation

Normal distribution grading, ripple cross-lamination and horizontal lamination in successions in accordance with the Bouma-sequence, shows that this facies probably was deposited from bottom hugging turbidity currents. This view is supported by the fact that the beds are mainly confined to scours, that presumably acted as transport paths for the current, and were formed by the erosion of a more powerfull flow. Furthermore, the deposition from succesive turbidity currents resulted in an irregular surface confining the subsequent currents to certain routes. Erosion by the currents resulted in the erosion of the uppermost part of the underlying bed. Dominance of distribution grading shows that the currents were of low density (Middleton, 1967).

The occurence of inverse grading is believed to be a result of dispersive pressure (Bagnold, 1954). The generation of dispersive pressure requires flow along an inclined plane in order to generate the shear stress necessary to keep clasts in suspension. Structureless beds result from deposition from flows flowing along a less inclined plane, but are also influenzed by the grain

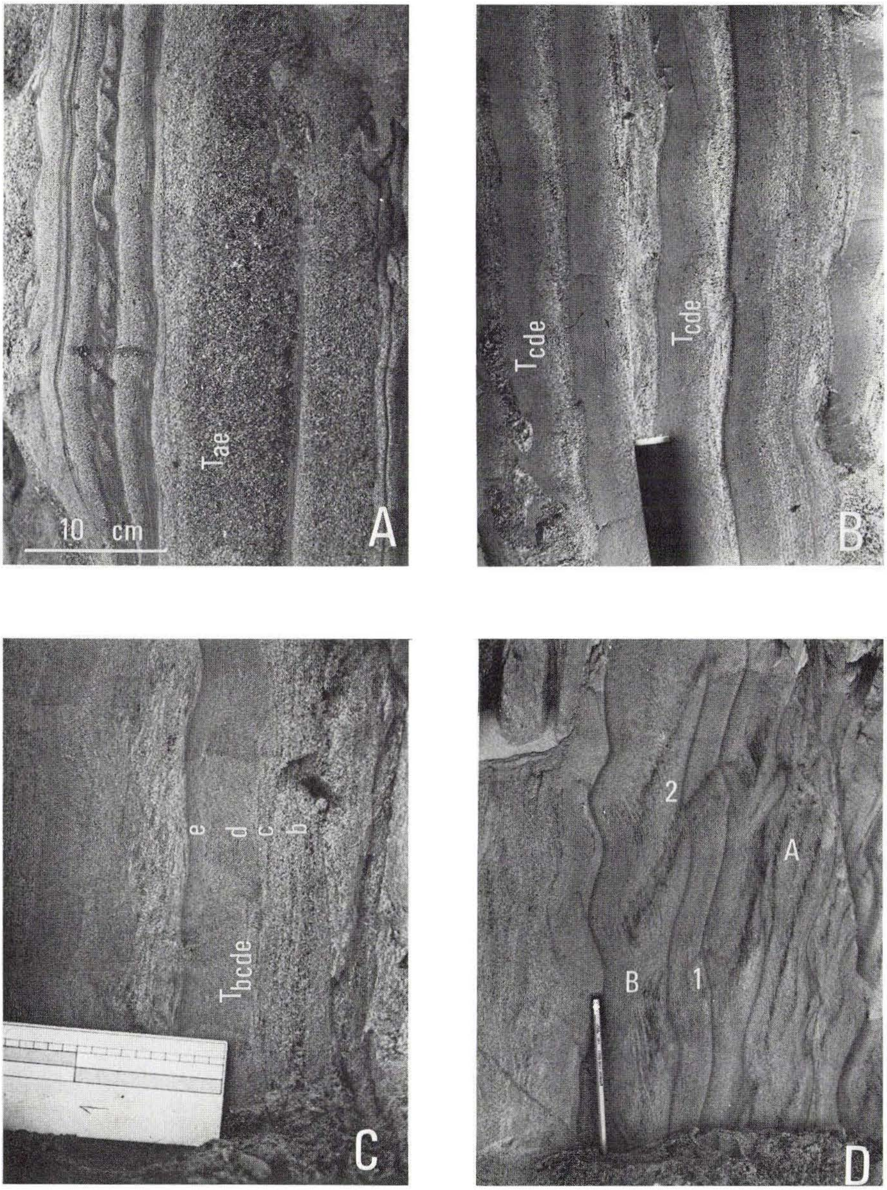

Fig. 6. A-C, Interlayered silt and sand (2). A) T_{ae} subsequence of the Bouma-sequence. Direction of flow shown by upturned ends of loadstructures. Up is to the left. B) T_{cde} subsequences of the Bouma-sequence. C) almost complete Bouma-sequence, T_{bcde}. Fig. 6D, climbing ripples type A and B (shown). 1) increasing climbing angle. 2) continuation of climbing angle across draped bed.

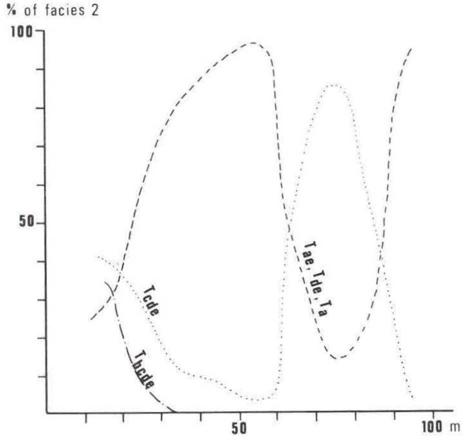

Fig. 7. Subdivision of interlayered silt and sand (2). Note four characteristic zones: 0–20 m and 65–90 m are dominated by T_{bcde} and T_{cde}, while 20–65 m and 90–102 m are dominated by $T_{de, ae, a}$.

size distribution of the flow. However, water escape processes, very likely to occur in newly deposited turbidites, can totally obliterate primary structures.

The primary sedimentary structures show that sediment transport was mainly as bed load, with velocities around 15–80 cm/s (Southard, 1975). The ripples were generated at approximately 15–25 cm/s, and the horizontal lamination, of the b-division of the Bouma-sequence, at upper flow regime conditions.

The occurence of partial Bouma-sequences with base absent could reflect deposition of different parts of the flow in different places, and/or by a limitation of time aviable for the generation of primary structures (Walker, 1965).

The supply of sediment must have been fluctuating in order to generate several decimeters of beds, each of which has been deposited by a flow of continuously decreasing velocity. Separation of different kinds of sub-units of the Bouma-sequence in the vertical record is shown in fig. 7. The most complete sequences occur in the 0–20 m interval and the 65–90 m interval, while the more incomplete sequences occur in the 20–65 m interval and the 90–102 m interval.

Description. Cross laminated sand (3)

This facies comprises beds of fine to medium sand draped by clayey silt. The sandy parts range from 5–15 centimeters in thickness, while the drapes range from millimeters to a few centimeters in thickness. Each bed shows climbing ripples of type A and/or B after Jopling & Walker (1968), the B type sometimes approaching sinusoidal lamination. An unchanged climbing angle is often seen continuing through the clay drapes (fig. 6 D). Pronounced distribution grading occur in the draped lamination.

Direction of flow was often opposite in successive beds, giving a bimodal – bipolar palaeocurrent pattern (see current rose fig. 11).

Interpretation

The occurence of climbing ripples shows that flow was unstedy and/or non uniform, corresponding to a diurnal or seasonal varying stream expanding above a submerged delta (Allen, 1970). The combination of the graded beds with climbing ripples shows that each bed was deposited under continuously decreasing flow conditions. Velocities capable of generating climbing ripples were however obtained relatively quickly after deposition of the drapes, as shown by the unaltered climbing angle (fig. 6D). This data suggests that the sediment load was supplied in pulses, each of which deposited a climbing ripple sequence draped by normal graded silty clay.

This facies resemble the glaciolacustrine proximal varves described by Gustavson (1975, fig. 13 B) and the glaciodeltaic sequences described by Gustavson et. al (1975, fig. 6), where each sequence was deposited within a few hours.

The facies is interpreted as being deposited from diurnal or seasonal sediment plumes, or density flows, flowing into a low energy environment.

Description. Stratified pebbly sand (4)

Lenticular beds of fine to coarse sand with pebbles and cobbles. The lenses have a width of about 1–5 meters and are 0.3 to 1.5 meters thick (fig. 8A). The beds show horizontal lamination accentuated by the separation of different grain sizes into different layers. Scour-and-fill structures are often seen at the lower contact (see plate 2, at 70 m). In certain cases the lower part of the beds is structureless. B-axis clast imbrication has been observed in certain beds. Intricate interfingering with fine grained facies are often seen.

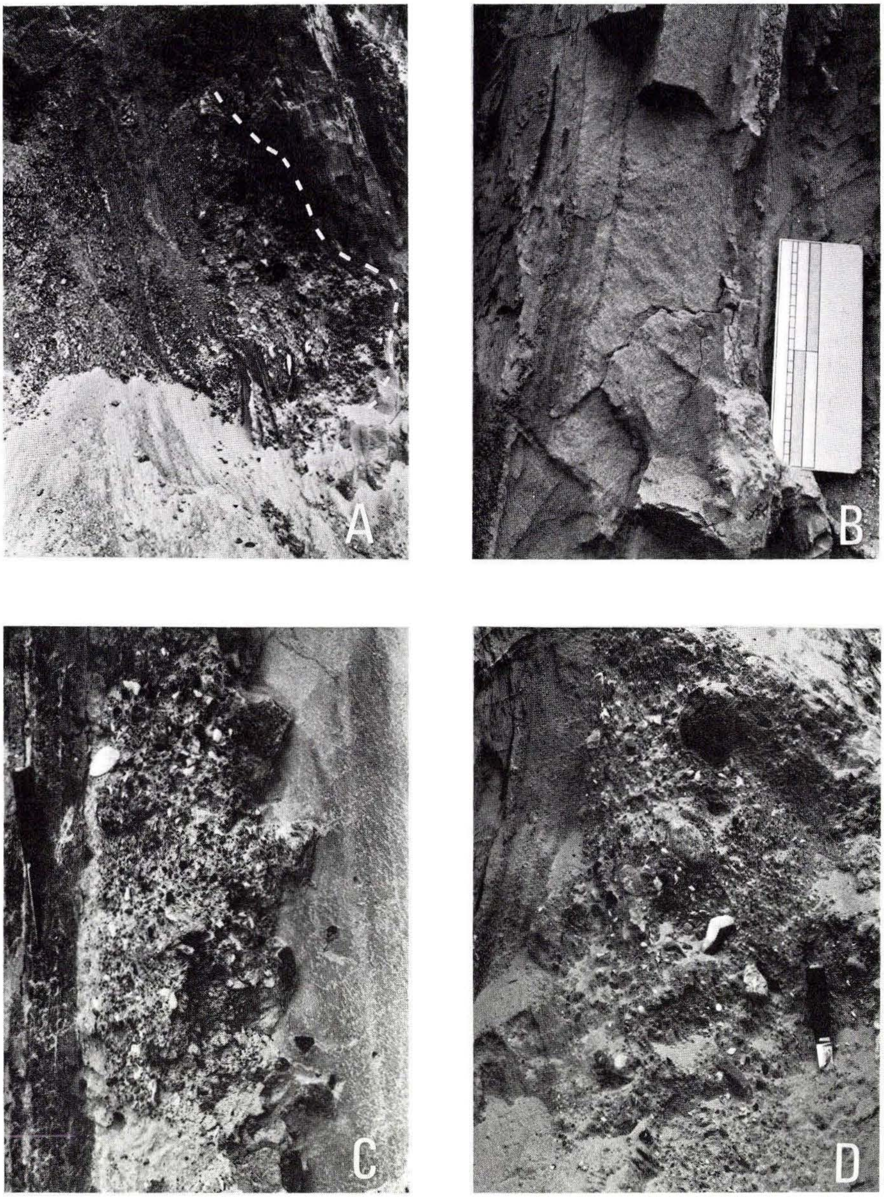

Fig. 8. A) Pebbly sand (4). Distinct erosional lower surface. Up is to the left. B) Massive sand (5). Faint horizontal lamination at the top of the bed (left). C) Matrix supported diamicton (6). Competence of flow was not able to keep the largest clasts in suspension, consequently they appear at the bottom of the bed. The underlying bed is massive due to disturbance by the debris flow. D) Clast supported diamicton (7). Inverse-to-normal grading followed by stratification. Flow was away from observer.

Interpretation

Horizontal lamination of large lenticular beds with erosional lower contact, suggests a channel- or scour-fill origin.

The interbedding with more fine grained facies (see plate 2 at approx. 70 m suggests abrupt changes in environmental conditions. Walker (1975) shows that a pulsating flow is able to deposit heterolitic sequences with separation of grain sizes in descrete layers.

The beds are therefore probably deposited by pulsating but generally decreasing flows of originally high energy into a low energy environment (see also Rust & Romanelli, 1975).

Description. Structureless sand (5)

This facies is comprised of poor sorted lenticular beds of silty medium sand with granules. The bed thickness range from 10 to 40 centimeters (fig. 8B). No primary sedimentary structures are seen apart from a faint horizontal lamination at the upper boundary of some beds. The upper part of the beds are often normal graded. Rip-up clasts are sometimes seen.

Interpretation

The occurrence of structureless normal graded beds with faint horizontal lamination, rip-up clasts, lenticularity and close association with facies 1 and 2 (see plates), suggests deposition from flows transitional between liquefied and turbidity flow (see Lowe, 1976b.). The granules were probably held in suspension by escaping pore fluids, or dispersive pressure during deposition. However, the poor sorting suggests that other forces, such as cohesion, have also acted as transport mechanism.

Transmission of shear stress from the upper surface of the flow to the above water resulted in mixing of flow material with the surrounding water, thereby forming a turbulent cloud. However, this cloud could also have been formed by dilution of the flow resulting from dilatation. Deposition from the turbulent cloud resulted in the formation of horizontal almination and normal grading as seen in the top of the beds.

Description. Matrix supported diamicton (6)

Granules, pebbles and cobbles in a matrix of clay-slit, fine or medium sand are seen (fig. 8C and fig. 9). The clasts are floating in the matrix, the clast

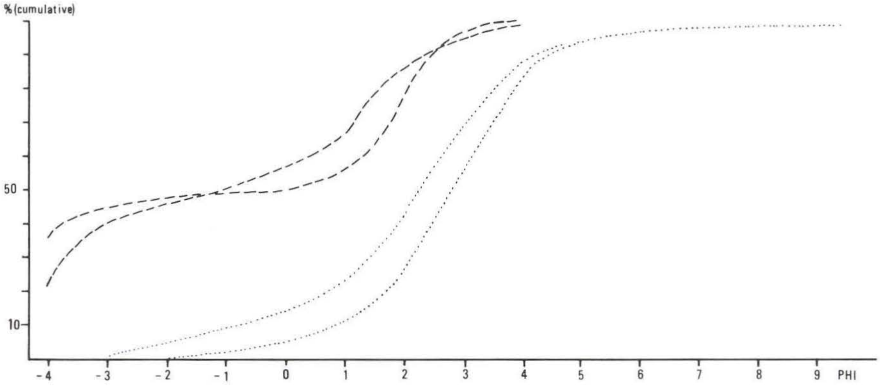

Fig. 9. Cumulative curves of matrix supported diamicton (6).

percentage varying between 10 and 60. Bed thicknesses range from 5 to 50 centimeters with varying lateral extend, and irregular upper and lower boundary. Discoid clast often show subhorizontal parallel arrangement in the lower part of the beds. Otherwise the clast orientation is chaotic. Inverse and coarse-tail normal grading are sometimes seen.

Interpretation

The chaotic arrangement of clasts floating in a fine grained matrix, and parallel arrangement of clasts at the lower boundary, shows that the matrix probably damped the clast movement suggesting a debris flow origin (Hampton, 1972). In the clay-silt and fine sand matrix (fig. 9) cohesion and friction prevailed, while in the sandy matrix (fig. 9) only friction occured (see Lowe, 1979). Hampton (1979) futhermore showed that the increase in competence with concentration of coarse grains supported by the matrix, can be explained in terms of exess pore pressures that increase bouyancy forces.

The variation im competence of the matrix and extension of the non-sheared part of the flow are factors that controlled the occasional grading; hence, inverse grading shows that transmitted shear stress and matrix competence was able to keep clasts mobil, thus suggesting a relatively steep slope. Shear stresses probably also accounts for the occasional parallel arrangement of clasts.

Description. Clast supported diamicton (7)

Granules, pebbles and cobbles in a mainly medium to coarse sand matrix. The clasts are supporting each other. Bed thicknesses range from a few decimeters to about 80 centimeters, with varying lateral extent.

Inverse and inverse – to – normal grading is seen, but non graded beds also occur. In some cases clast percentage decrease perpendicular to flow direction. The beds are massive, or show faint a-axis clast imbrication. In some beds horizontal stratification is seen at the top (fig. 8D)

Interpretation

The imbrication of long axes parallel with presumed transport direction, as inferred from the orientation of channel or scour axes, suggest a density flow origin, the flow being supported by dispersive pressure enabling the clasts to move freely (see Walker, 1975). Poor sorting and inverse – to – normal grading suggests a grain flow origin (Lowe, 1976a). The stratification in the top of certain beds is thought to be a result of a bed load transport becoming increasingly important upwards. However, penecontemporaneous reworking is also a possibility. Davies & Walker (1974) showed that stratification can develope in a fluctuating flow by maintaining different grain sizes in suspension at different times. Bed thickness and overall appearance show that the beds probably are of modified grain flow origin (Lowe, 1976a). According to Sallenger (1979) inverse grading points towards an inertial kind of flow (see also Lowe, 1976a). As some thin beds probably represent true grain flows, it can be assumed that the depositional slope varied between 8°–27° (Lowe, 1976a).

Penecontemporaneous structures

Penecontemporaneous structures are found throughout the sequence. They include load structures, convolute bedding, dish-and-pillar structures and different kinds of fluidized deformation. The occurence of these structures indicate that packing was metastable, but offers no information about the mechanism by which the sediment was brought into the environment. The structures are mainly associated with fine grained facies (see plates).

In a few cases the turned-up ends of load structures are orientated in accordance with the inferred current direction.

Between the 60 and 80 meter point in the sequence two roll-up structures are seen. The structures resemble the one described by Gustavson (1975) from a glacial lake. The largest structure is located at the 66 meter point in

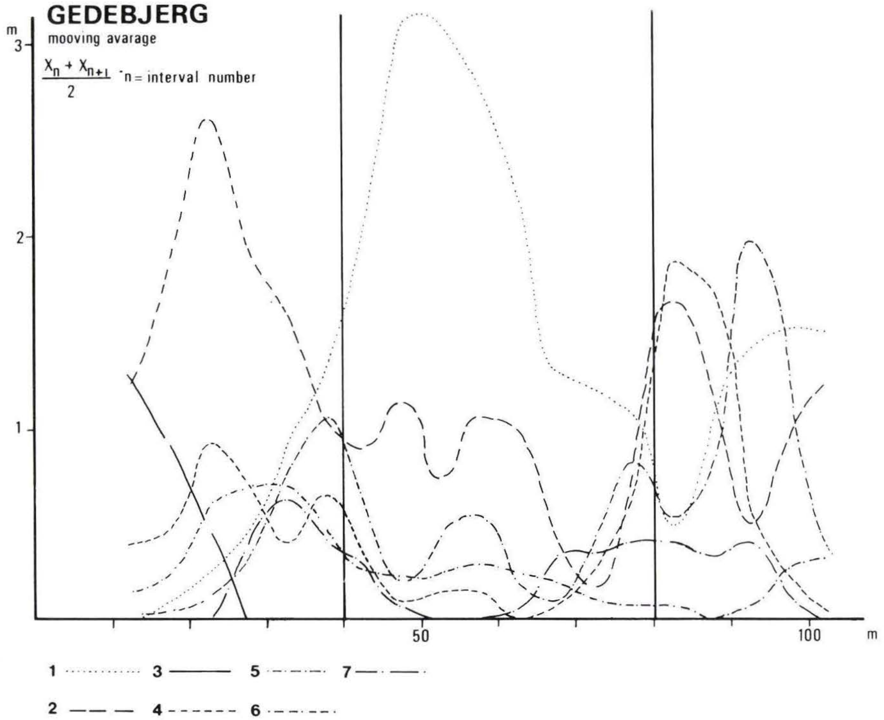

Fig. 10. Moving average of facies. Calculated by dividing the log into 5 m intervals, and measuring the vertical extent of each facies in each interval. Note four characteristic zones: 0–40 m, 40–70 m, 70–90 m and 90–102 m. The vertical lines refer to divisions based on tectonic measurements.

the sequence (see plate 2), and is probably caused by the flow of the overlying clast supported diamicton bed in a partly filled scour. High shear stress and pore pressure flucluations encouraged deformation (compare Hendry & Stauffer, 1975).

Facies associations

Moving average

The distribution of selected facies is illustrated by the computation of a moving average of the total thickness of each facies in each interval, the whole sequence beeing subdivided into 5 m intervals (fig. 10). It is seen from fig. 10, that the whole sequence can be subdivided into four subsequences. A lower subsequence (0–40 m) dominated by climbing ripples (facies 3) and interlayered silt and sand (facies 2), is followed by a sequence (40–70 m) dominated by laminated sand streaked silt (facies 1) and interlayered silt and sand (facies 2). At the top two smaller subsequences are seen. The lower (70–90 m) dominated by pebbly sand (facies 4) and interlayered silt and sand (facies 2), the upper (90–102 m) dominated by matrix supported diamicton (facies 6) and laminated sand streaked silt (facies 1). In the sequences from 0–40 m and 70–90 m clast supported diamicton (facies 7) occurs, dominating at the top of the sequences.

This subdivision coincides approximately with the subdivision obtained by measuring strike/dip values, where the whole sequence was spilt up into three units (fig. 10). Hence, changes in strike/dip and changes in facies association are simultaneous, suggesting that the distribution of facies to a certain extent is controlled by primary strike/dip of the depositional surface.

Examination of the whole sequence shows that it is possible to make a subdivision into first-, second – and third order cycles. The first order cycles is defined as major changes in environmental conditions mainly due to external factors. The second order cycles represent changes mainly due to internal factors, such as topography of depositional slope, depending on the depositional processes in action. The second order cycles are visualized in the numerous fining- upwards and coarsening-upwards sequences. The third order cycles represent depositional processes.

The pattern of cycles, together with the distribution of facies and strike/dip measurements makes it possible to define two facies associations: an overall coarsening-up association (0–40 m) and (70–90 m), and an overall monotonous association (40–70 m) and (90–102 m).

Description. Overall coarsing-up association

This association, occurs at 0–40 m and 70–90 m (see plates), and is made up of numereous second order cycles. Facies 2 and 3 dominate in the lower part of the units, while facies 4,5 and 7 dominates in the top. Climbing ripples (3) are only present at 0–40 m, (see fig. 10, and plates).

Interpretation

This association is interpreted as representing first order cycles divided into serveral second order cycles. The change from cross laminated sand (3) to stratified pebbly sand (4), together with the increase in bed thickness, the number of channelized beds, and the increase in numbers of beds indicative

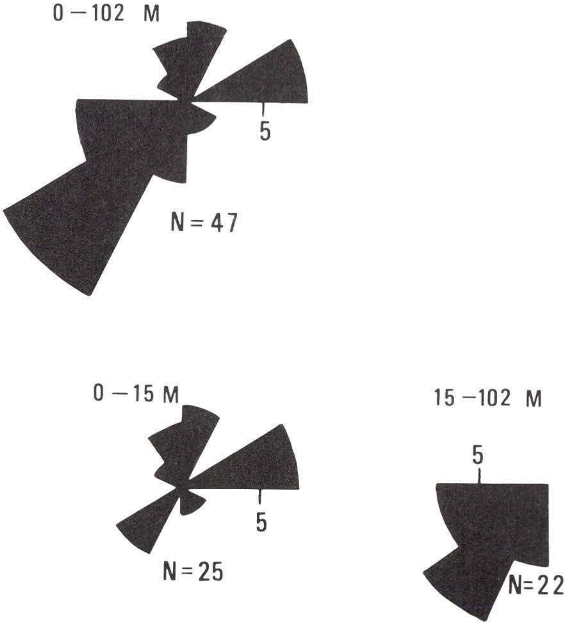

Fig. 11. Palaeocurrent rose, includes measurements of imbrication, scours and cross lamination.

of a steep slope (facies 7) is thought to represent the building of a steep delta slope into a low energy environment. The delta probably built out into a relatively deep standing water body, as suggested by the interlayering of fine grained facies into the otherwise texturally and structurally coarse part of the sequence. Occurrence of true grain flows shows that dip of delta foresets was sometimes approaching 27° (Lowe, 1976a). The palaeo-current rose (fig. 11) shows that two sources were acting in the lower part of the whole sequence, while only one source acted from approximately 15 m to the top. All values are corrected for dislocation, and reorientated to sub-horizontal, which only give approximate values because of the primary dip of the beds.

The interfingering between the fine grained facies 1 and 2 and the coarse grained facies 4, shows that while a scour was filled, the surrounding area (inter-scour-area) was exposed to deposition from suspension. From 15–18 m coarsening-upwards followed by fining-upwards is accentuated by the systematic change in type of Bouma-sequences changing from T_{de} at the bottom of the cycle, to T_{bcde} at the central part and again T_{de} at the top (see plate 1). Each sequence could be deposited within a few hours (Gustavson et. al., 1975), but the subdivision of the cycle into third order cycles shows that even each bed in the second order cycle also represents an increasing and again decreasing current suggesting a period of deposition of a day or so for each bed.

In the upper association (70–90 m) no climbing ripples occur, but here several scour-fill sequences occur eroded into facies 1 and 2 (see plates at 77–84 m) some of the cycles show scour-fill structures at the bottom (see plates at 88, 90 and 92 m).

Description. Overall monotonous association

This association represents the interval from 40–70 m and 90–102 m. Facies 1,2 and 6 dominate. Only few second order cycles are seen (see plate 2 and 3). Facies 4 and 7 have pronounced minima in these intervals (fig. 10).

Out sized clasts are particularly frequent. At approximately 55,5 m (see plate 2) facies 1 develops into varves.

Interpretation

Low energy facies clearly dominate, and the subordinate occurrence of deposits from grain flows suggests that the primary of the depositional slope was somewhat lesser than in the delta-association. However a few slump folds indicate some dip (see log at 42,7 m). Facies 1 and 2 resemble the deposits described by Gustavson (1975) from glacial lake bottoms, where the depositional processes include under-, in- and overflows, resulting from variations in the relative density of inflow (fig. 12). In the present study facies 1 is thought to be a result of mainly over- and inflow, as primary sedimentary structures indicative of bedload transport are almost absent. Facies 2, however is thought to have been deposited mainly from turbidity under-flows as primary cross-lamination and upper flow regime horizontal lamination are present.

All the data suggests that this association represents lacustrine periods in the record, deposited during periods of low sediment input.

Palaeomorphology

The estimated statigraphical thickness of the tilted sequence is 140–160 m, making allowance for the numerous normal faults. The occurence of post- and synsedimentary normal faults suggest that the sedimentary environment was supported by ice, which upon melting caused the faulting by collapse of the non supported margins of the sediment body. As no synsedimentary

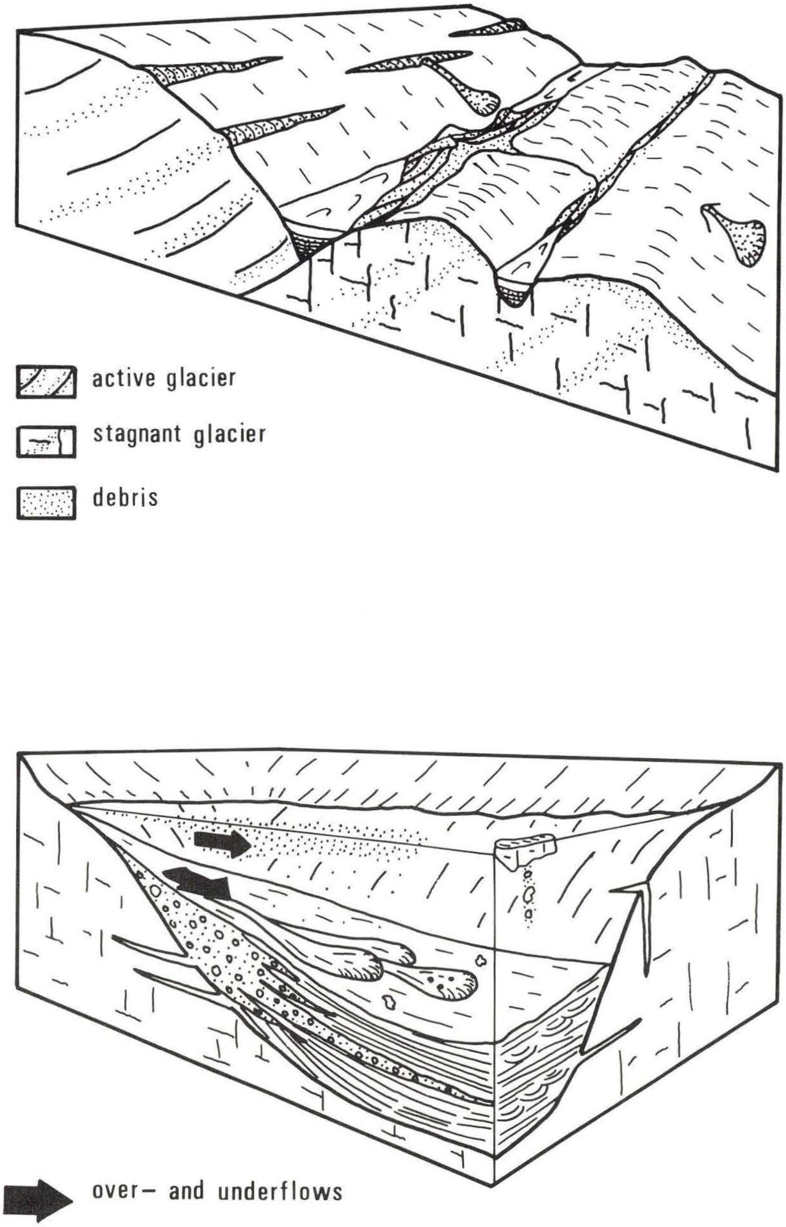

Fig. 12. Upper diagram: possible site of deposition. As a result of thermo carst and morphology of the stagnant ice, lakes develop parallel with active icemargin (compare Boulton, 1972). Lower diagram: inferred depositional processes.

tilting occurred the environment is thought to have been situated in a stagnant ice body. This, however, requires large holes in the ice body. Holes of considerable size are described by Clalyton (1964) from Martin Glacier, and these are considered a result of thermo karst in stagnant ice bodies. Russel (1897) described lakelets of a similar origin from glaciers in Alaska. In the present study it is suggested that termo karst and morphology of stagnant ice bodies (Boulton, 1972) resulted in the development of large ice marginal lakes. The coarse grain size and the fact that the whole sequence has been tilted, suggests a position somewhere between active and stagnant ice, (fig. 12) as proposed by Rasmussen (1967). The tilting was probably caused partly by icepush and partly by gravitational overturning, because of the extraordinary form of the sediment body. Direction of meltwater flow (fig. 11) was towards the south-west, parallel with the long axis of the hill. In the lower unit, flow directions were bipolar. This was not caused by backflow in the delta forset, because every bed is separated by draped lamination and no interfingering occurs. Fig. 12, gives only one of many suggestions as to the site of deposition. For instance, the collapse of an icetunnel, could cause the development of a long narrow lake. Russel (1897) described lakelets developed by the melting-back of crevasse sides.

Discussion

Andersen (1966) postulated a nearshore marine environment for the sequence described in the present paper. However, no published data points to such an environment. In the present study no indication of a marine environment was found, such as wave ripples, beach lamination, fossils and trace fossils. Futhermore one would expect a shoestring formed sand body resembling the presumed palaeobeach.

Løvbakke (1974) concluded that the sedimentary environment was the distal part of a braided river. His results suggested dominance of fluviatile material, and also material deposited by turbidity currents. The latter was rejected by Løvbakke and explained as deposits from sheet floods. Løvbakke believed that the absence of traces of subaerial exposure was caused by erosion of succesive floods. The present study, shows that deposition took place under a deep, standing water body.

Berthelsen (1971) has argued that the hill represents relicts of a larger fold structure. However, the strong correlation between the characteristic facies association revealed in this study, the topographic shape and the almost vertical tilting of the strata seems to reject this hypotesis, as proposed by Surlyk (1980).

Furthermore the downward extent of the tilted strata is limited by the underlying extensive till bed (Binzer, 1979).

From the facies analysis it is seen that the change in strike/dip values, can be explained as a result of change in primary depositional slope.

The supply of sediment of varying grain size was probably controlled by fluctuations in the position of the active ice margin. Another possibility is a fluctuation in degree of melting, however the final tilting, to some degree caused by ice push, shows that ice margin fluctuations is the most likely explanation.

Conclusion

A lower deltaic sequence (0–40 m) was deposited in a lake, situated in a depression in a stagnant ice body and enlarged by thermo karst. Sediment was supplied by two or more en- or supraglacial sources. The sediment was probably resedimented from supraglacial accumulations and shear plane accumulations in the ice. The delta was built out under influence of a progressing ice shield. The sequence is dominated by coarse grained turbidites (fig. 7) suggesting a proximal nature, probably in the delta foresets. Dip of foresets. was around 8°–27° (see also Lowe, 1976a).

An abrupt change in facies association and strike/dip (fig. 10) shows that the progression of the ice shield stopped and the deposition of a lacustrine-deltaic sequence started (40–70 m). The dip of the beds are lesser than in the underlying sequence, because deposition was mainly from suspension. However, slumped beds show that the beds were not horizontal.

A new progression of the ice shield terminated the lacustrine-deltaic phase, and a new steep slope delta sequence started (70–90 m), as seen in fig. 10. This change is shown by deep erosional scours and variation in strike/dip (fig. 13, see also plates at 70 m). However fluctuations in waterlevel (see Clayton, 1964) in the stagnant ice resulting in a lowering of erosion base, could also have caused the development of erosional scours. At the top of this sequence the progression ceased, and a new lacustrine-deltaic sequence was initiated. It is believed that during a final progression the whole sequence was tilted by icepush. Later gravitational overtuning continued the tilting, giving an almost 90° dip to the beds.

As the minor progressions did not disturbe the sediment body, the whole sequence is concidered to be built up by minor fluctuations in the position of the active ice shield.

Rasmussen (1967) believes that the hill was never overridden by an ice-

Fig. 13. Channelized unit at approx. 85 m (se plate 2 and 3). Channels filled with facies 4 are eroded into fine grained facies (right.).

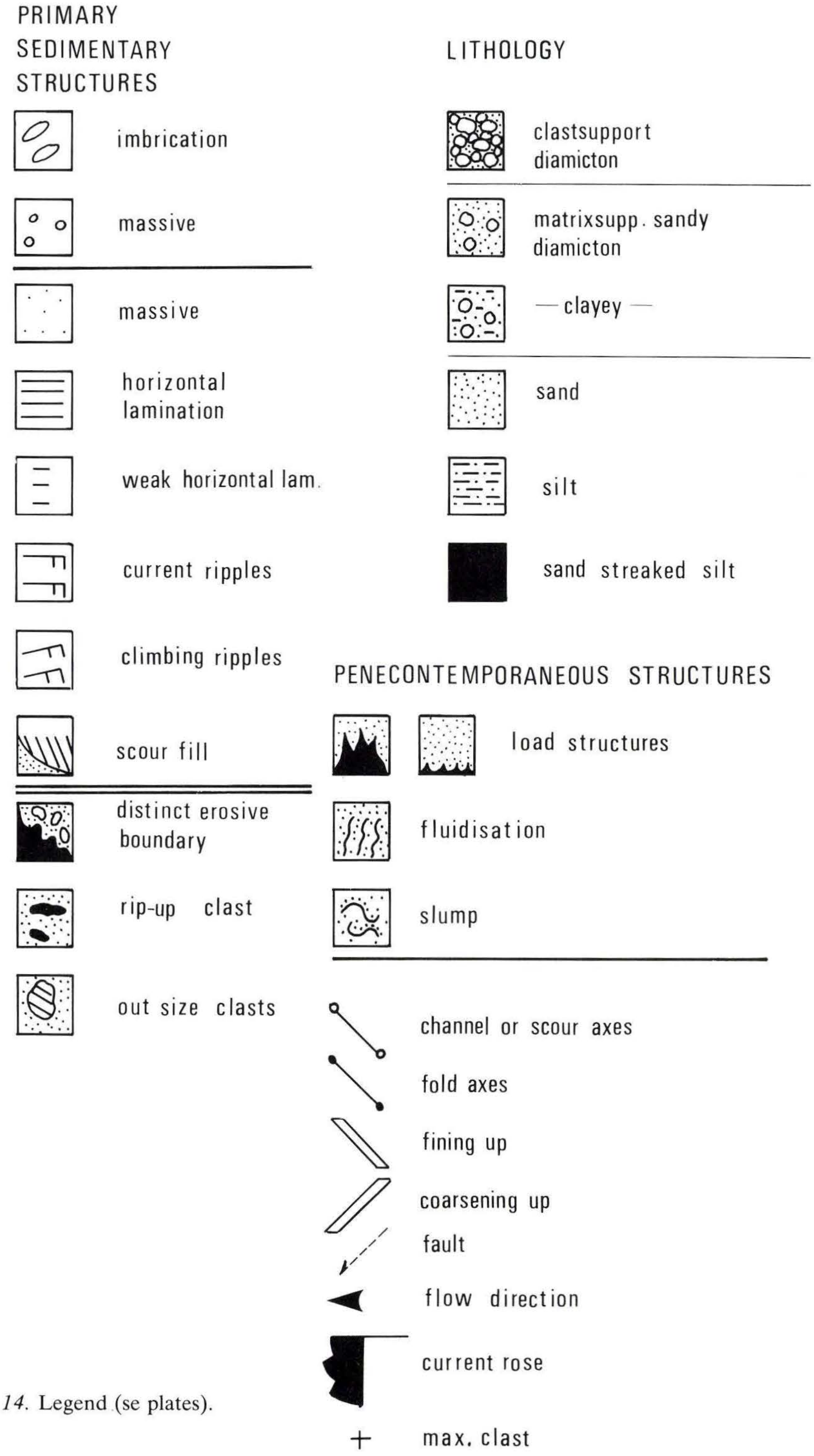

Fig. 14. Legend (se plates).

tounge. This wiew is supported in the present study. It is believed that both deposition and tilting occurred during the last glaciation on Zealand.

An interesting point is the occurence of several hills of this type, in the same area, with beds tilted to almost vertical. A connection between these hills can not be ruled out. The whole hill field might represent a wide stagnant thermo karst area.

Acknowledgement. This paper is part of a thesis carried out at the University of Copenhagen, and supervised by Dr. Finn Surlyk. I would like to thank Finn Surlyk and Lars B. Clemmensen for constructive criticism of the manuscript. Irma and Carlos Torres did the photographic work, and Andrew Stevens kindly corrected the english language, for which I extend my gratitude. Also thanks to Susan Steffensen and Karen Jensen for typing, and Danuta Kestenbaum for many helpful suggestions to the drawings.

Dansk sammendrag

1Lagserien i den hatformede bakke, Gedebjerg ved Kundby i NV-Sjælland, er opbygget af vekslende sekvenser af "steep slope" deltaisk og lakustrin oprindelse. Hver sekvens er cyklisk opbygget. Omkring 58 % sedimenterne er aflejret af turbiditstrømme, som over-, ind- og understrømme. Omkring 15–20% er aflejret fra opdrift dominerede debrisstrømme og densitetmodificerede kornstrømme.

Aflejringen fandt sted i huller i isskjoldet, på grænsen mellem aktiv og stagneret is.

Det antages at den cykliske opbygning afspejler gentagne frem- og tilbagebevægelser i isfronten, og at både aflejring af sedimenterne og dislokation fandt sted under den sidste nedisning på Sjælland.

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Lower Cretaceous sedimentation and basin extension on Bornholm, Denmark

Peter Gravesen

Gravesen, P.: Lower Cretaceous sedimentation and basin extension on Bornholm, Denmark. *Danm. geol. Unders., Årbog 1981:* 73-99, København, 1. oktober 1982.

The Tithonian?-Berriasian Rabekke and Robbedale Formations on Bornholm, Denmark rest unconformably on Lower Jurassic sand and clay and overstep Lower Palaeozoic sandstone and Precambrian basement.
The sediments were deposited in two different episodes. The Skyttegård Member (Rabekke Formation) and the Østerborg Member (Robbedale Formation) were deposited during a transgressive phase when marine low-energy intertidal beach and tidal sand flat sediments transgressed landward over fluvial, intertidal/supratidal swamp and coastal lagoon sediments.
The Langbjerg Member (Robbedale Formation) was deposited during a general shoreline progradation under high-energy conditions. The lower part of the overlying Berriasian-Valanginian Jydegård Formation was deposited in coastal lagoons migrating seawards over subtidal, intertidal and barrier sand.
The sedimentation pattern is related to eustatic sea level changes and to tectonic block-subsidence in the Fenno-Scandian Border Zone caused by the Late-Kimmerian tectonic episode.

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At the Jurassic-Cretaceous boundary, approximately 250 m of continental and shallow water marine sediments were deposited on Bornholm. The sediments are comprised of clay, clay-ironstone, silt, quartz sand and sandstone, grouped into the Rabekke, Robbedale and Jydegård Formations (Gry 1956, 1960). Gravesen, Rolle & Surlyk (1982) included these formations in a new group, the Nyker Group, and presented a formal lithostratigraphy which introduced six new members.

The present paper is based on field work in the Arnager-Sose fault block carried out in 1973-1974 (Gravesen, 1977a), and on information from borings in the well data file of the Geological Survey of Denmark. The sedimentary facies associations of the upper part of the Rabekke Formation (Skyttegård Member) and the Robbedale Formation (Østerborg and Langbjerg Members) are described, and the depositional environment interpreted. All the investigated sediments seem to be mainly of Berriasian Age (Gravesen et

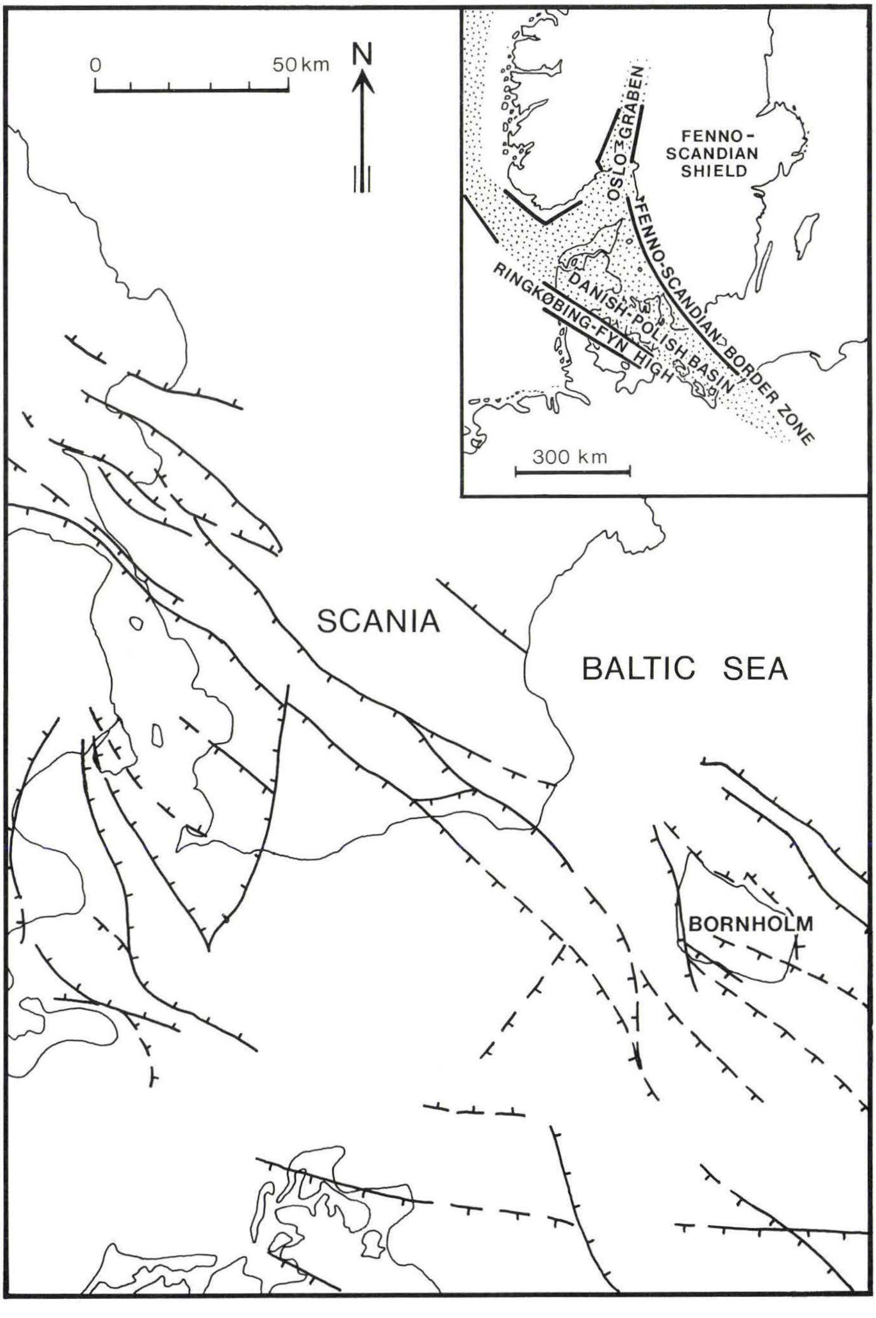

Fig. 1. Map indicating the position of Bornholm within the Fenno-Scandian Border Zone. From Gravesen et al. (1982).

al., 1982). At the end of the paper, a brief outline of the sedimentological and tectonic evolution during the ?Tithonian-Berriasian-Valanginian on Bornholm is presented.

Geological setting

Bornholm is situated in the south-eastern part of the Fenno-Scandian Border Zone (Fig. 1). Outside Bornholm, shoreline sediments of probably similar age (Berriasian) are known: in Scania, the Vitabäck Clay Member and Wealden Beds (Christensen, 1968; Norling, 1970, 1972, 1981) and, in northern Jylland, the Frederikshavn Member of the Bream Formation (Larsen, 1966; Michelsen, 1978). The Berriasian deposits on Bornholm occur on six partly fault-bounded blocks where they overlie rocks of very different ages (Fig. 2). In the Arnager-Sose block they rest on Lower Jurassic sand and clay of the Bornholm Group (Gravesen et al., 1982), in the Bøsthøj block they overstep Lower Palaeozoic sandstone (Gravesen, Bækgaard & Villumsen, 1980) and, in the Knudsker and the Nyker blocks, they overstep deeply kaolinized Precambrian basement (Gry, 1956). The blocks were down-faulted as a result of Late-Kimmerian extensional tectonic movements, and the shoreline sediments of the Robbedale Formation transgressed continental deposits of the Rabekke Formation. This synsedimentary downfaulting extended the basin in a north-eastern direction (Rolle, Koch, Frandsen & Surlyk, 1979; Gravesen et al., 1982). During the remaining part of the Cretaceous Period, a few minor tectonic episodes (*e.g.,* the Austrian phase) were also active on Bornholm (Gry, 1956; Ziegler, 1981).

In Late Cretaceous-Early Tertiary times, Bornholm was situated along an axis of inversion and was uplifted along faults (Ziegler, 1981). The present-day distribution of the sediments is a result of these Laramide inversion movements and of erosion during the Pleistocene glaciations. The blocks were tilted, and the deposits now dip a few degrees (5–10) in south-western or southern directions.

The sediments are well exposed along the south coast of Bornholm (Arnager Bugt area), in pits in the central Arnager-Sose block (Robbedale area) and in the Rabekke and Jydegård clay pits.

Facies associations

According to Collinson (1969), a facies association is understood to be a group of facies genetically related to one another and of some environmental

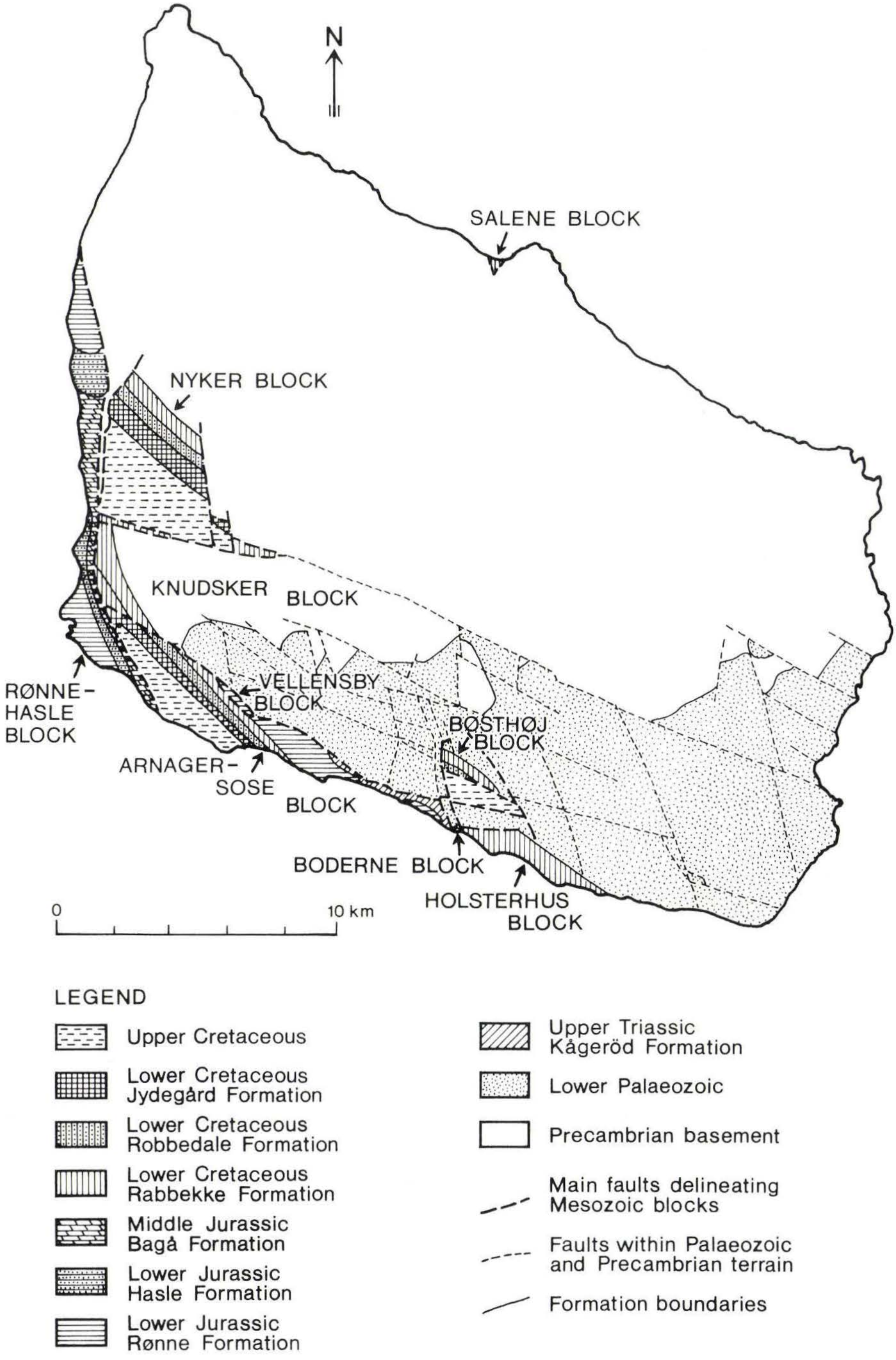

Fig. 2. Geological map of Bornholm. From Gravesen et al. (1982).

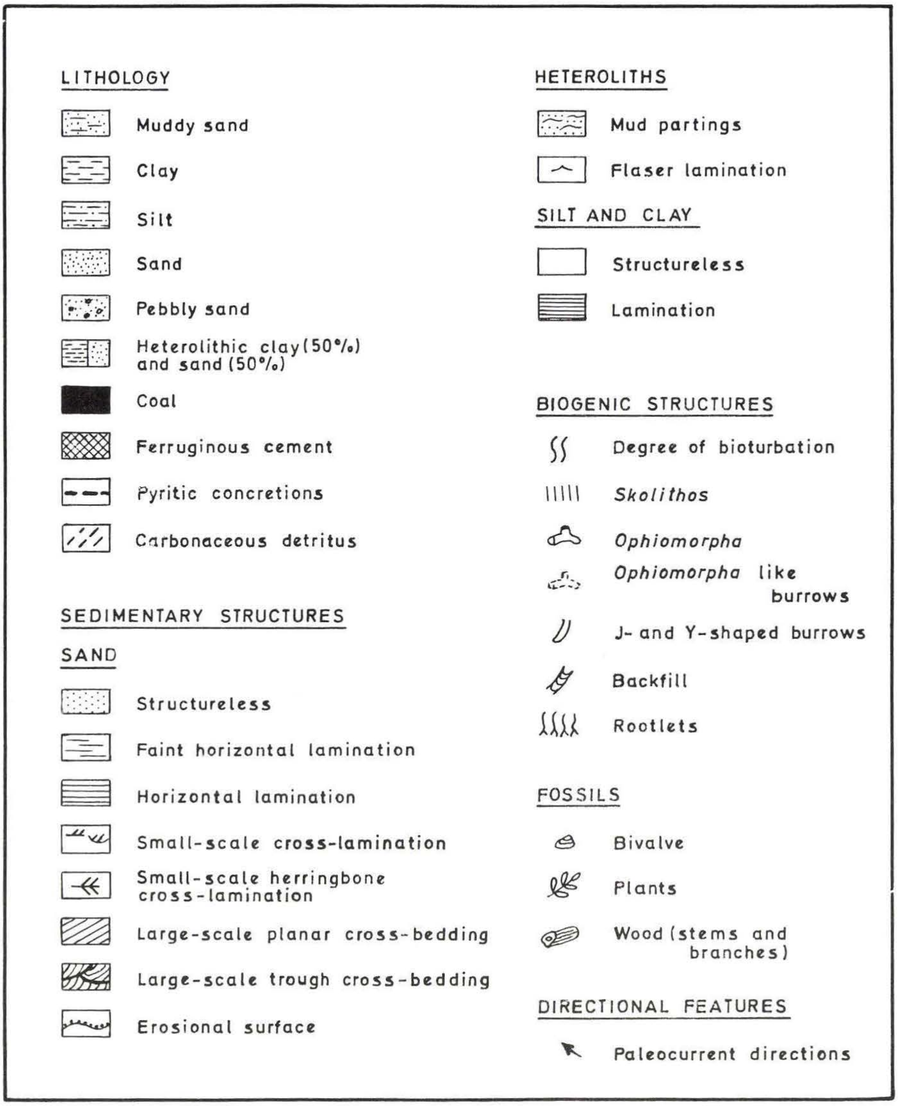

Fig. 3. Legend for the sections in fig. 4.

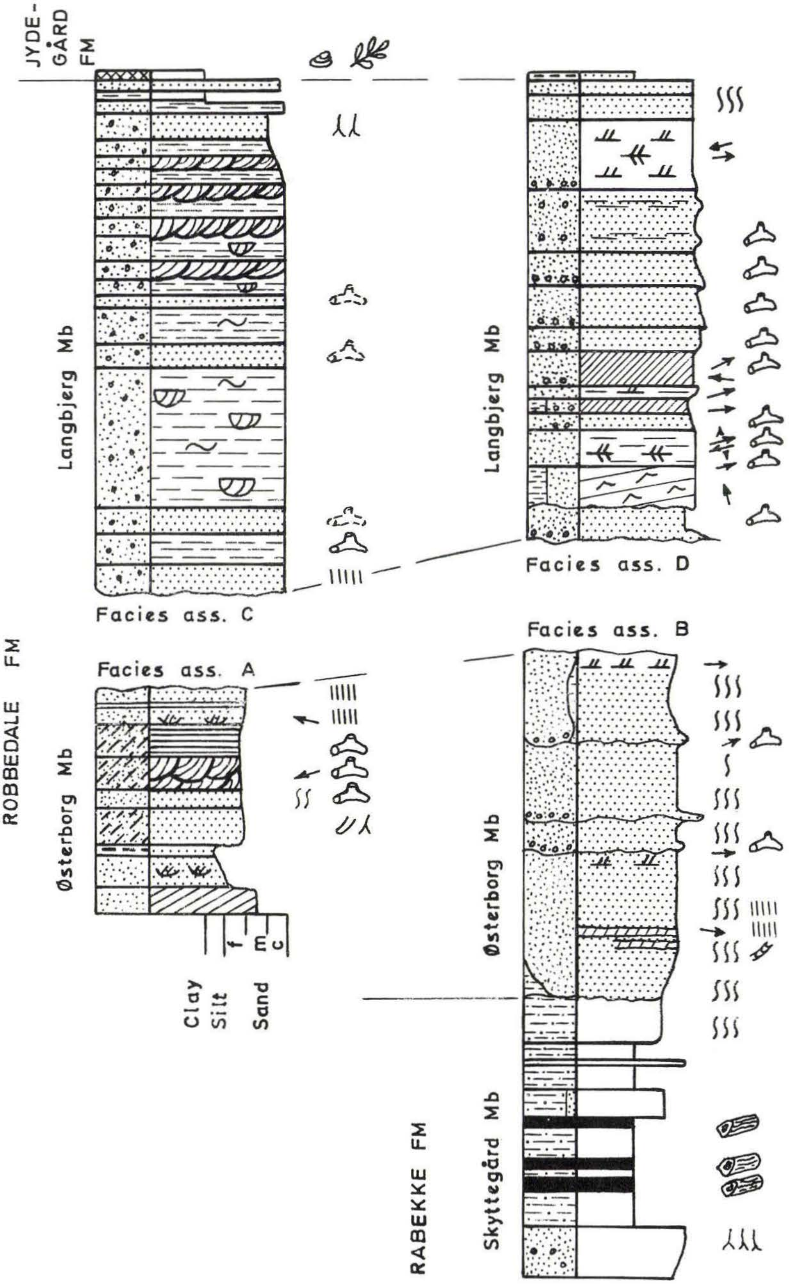

Fig. 4. Generalized vertical sections from the Arnager Bugt area (facies ass. B and D) and the Robbedale area (facies ass. A and C) showing the four facies associations of the upper part of the Skyttegård Member (Rabekke Formation), and the Østerborg and Langbjerg Members (Robbedale Formation).

significance. Four facies associations are described and interpreted below, and generalized sections of the associations from the Arnager Bugt area and the Robbedale area are shown in fig. 4.

A. Low energy coastal sand association

This facies association corresponds to parts of the Østerborg Member of the Robbedale Formation (Gravesen et al., 1982). It seems to have its main lateral distribution in the Robbedale area.

Description and interpretation of facies

Four facies, or groups of facies, are included in the association.

Fine-grained structureless sand with Ophiomorpha and Skolithos. – The most important facies consists of dominantly fine-grained, well-sorted to moderately well-sorted sand with *Ophiomorpha* and *Skolithos. Ophiomorpha* has a smooth-walled interior, knobby exterior, and a single-pellet wall construction *(Ophiomorpha nodosa)* (Jux & Strauch, 1968; Gry, 1968; Frey, Howard & Pryor, 1978). The burrows are branched in a rather irregular manner, and are concentrated in the upper part of 0.5–1.0 m thick beds, where they are sharply cut by erosion at the upper bedding surfaces (Fig. 5). Downwards, vertical or subvertical components dominate. *Skolithos* appears as vertical unbranched burrows with a length of 20 cm and a thickness of 4–5 mm, and occurs in very dense populations (Fig. 6). *Ophiomorpha* and *Skolithos* normally occur in different beds, but can be found together. The burrows are found in otherwise structureless or totally bioturbated beds, but a horizontal lamination can sometimes be recognized.

Ophiomorpha burrows have been related to the burrows of *Callianassa major* and used as an indicator for open ocean beach and shallow sublittoral sand deposits (Weimer & Hoyt, 1964), but the burrows also occur in other marine environments (Frey, 1970; Frey et al., 1978). The abundant *Skolithos* burrows suggest deposition in the littoral and shallow sublittoral zones with rapid sedimentation and erosion (Seilacher, 1967; Frey, 1971). The partly co-occurring *Ophiomorpha* and *Skolithos* in "clean" relatively well-sorted sand, with horizontal lamination produced by sheet flow of the swash-backwash movements (Clifton, 1969), suggest sedimentation in a foreshore (intertidal beach), or possibly upper shoreface environment. Totally bioturbated sand is well known from the lower shoreface (Reineck & Singh, 1973).

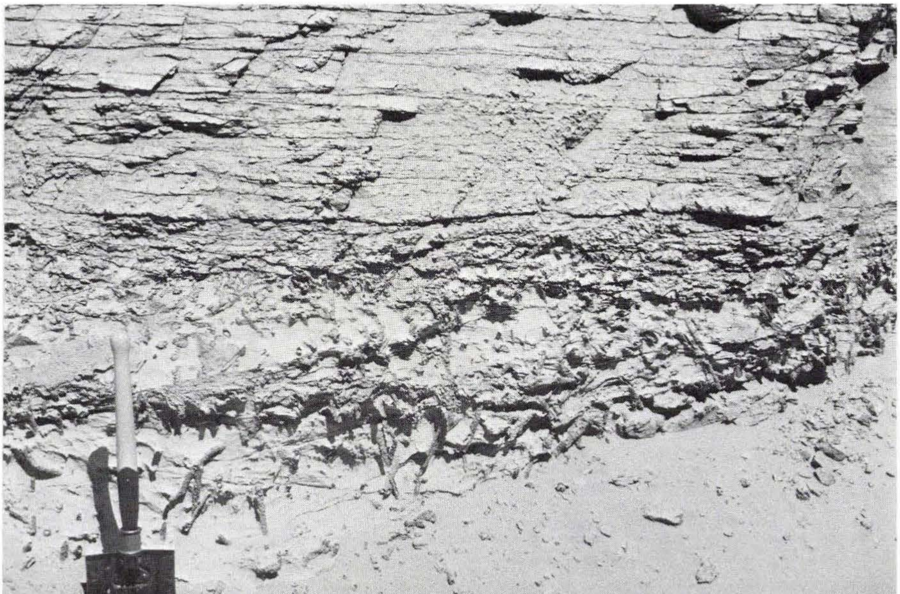

Fig. 5. Facies association A. Fine-grained, horizontally laminated sand with galleries of *Ophiomorpha*. Østerborg Member. A/S Carl Nielsen's sand pit, Robbedale area.

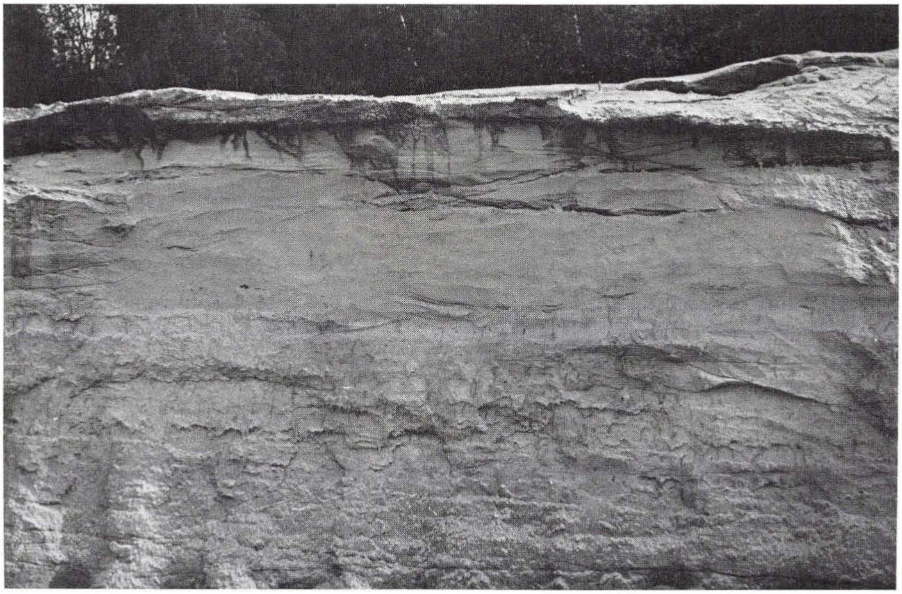

Fig. 6. Facies association A. Dense population of *Skolithos* in fine-grained sand. Østerborg Member. A/S Carl Nielsen's sand pit, Robbedale area.

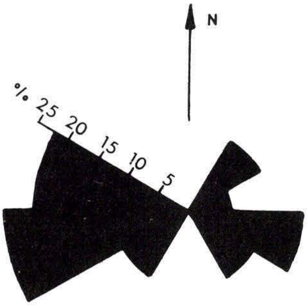

Fig. 7. Facies association A. Palaeocurrent rose of the Østerborg Member at the Robbedale area, based on 19 readings of small scale cross-laminations.

Fine-grained cross-bedded sand. – The cross-bedded facies, which also consists of fine-grained sand, is not as common as the first facies described. Small and large scale trough cross-bedding are seen, and *Ophiomorpha* occasionally cross these structures either as long escape burrows, or with resulting collapse structures (chevrons) (Asgaard & Bromley, 1974; Frey et al., 1978). Directional measurements show a bimodal E-W current pattern (Fig. 7), but no "herringbone" cross-bedding is registered. A few beds of large scale, medium to coarse-grained planar cross-bedded sand, with reactivation surfaces and current directions towards NE, are found.

The trough and planar cross-bedding was formed by migrating small ripples and mega-ripples which occur together with *Ophiomorpha* on shoals (Howard & Reineck, 1972). Reactivation surfaces, collapse structures and a bimodal palaeocurrent pattern suggest tidal influence (Klein, 1970; Asgaard & Bromley, 1974).

Fine to medium-grained sand with plant detritus. – A characteristic facies consists of 0.1–1.5 m thick, fine to medium-grained, moderately well-sorted structureless brown sand with a high content of plant detritus, mainly lignite. Vertical roots, 2–3 cm thick, with a length of 50 cm are common, but even larger roots can occur (Jux & Strauch, 1968) (Fig. 8). Burrows are recognized in a few horizons and are usually unlined or, rarely, have a thin clay lining. The burrows often show Y-bifurcations, but 30 cm long, unbranched burrows and sometimes J-shaped burrows are also seen. The burrows disappear upwards into the first sand facies with *Ophiomorpha.* Faintly horizontally laminated clayey sand, and clay with humus and lignite, occur in thin beds as part of this facies.

Plant detritus and rootlets, in combination with unlined burrows, indicate a

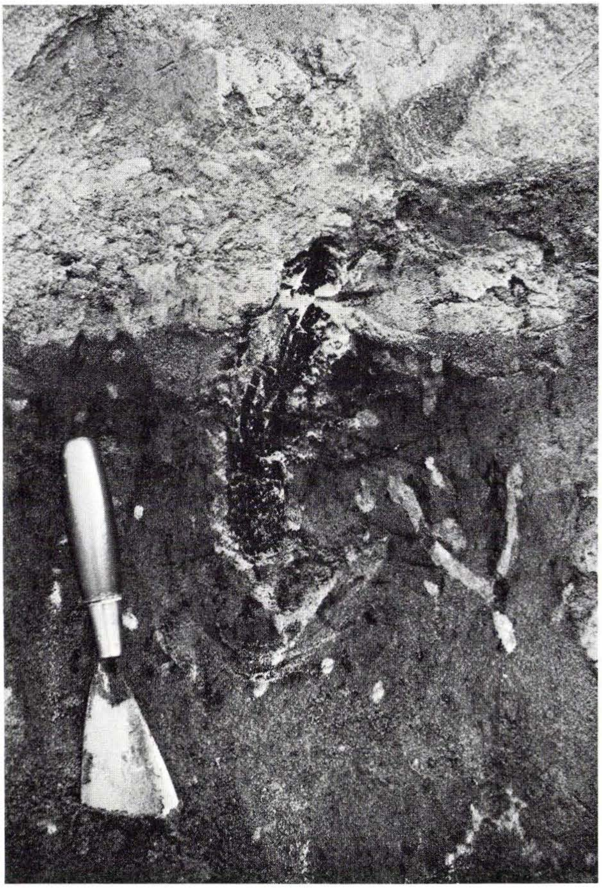

Fig. 8. Facies association A. Fine-grained sand with a very high content of plant material, thick rootlets and unlined Y-formed burrows. Østerborg Member. A/S Carl Nielsen's sand pit, Robbedale area.

very low energy environment near the coast. The burrowing animal is not easy to identify, but a decapod crab seems possible, as the burrows disappear into beds where *Ophiomorpha* is found, and branched, unlined burrows of *Callianassa major* are known from quiet, low energy subaquatic conditions (Frey & Howard, 1972). However, some of the Y and J-formed burrows also resemble burrows of the ghost crab, *Ocypode quadrata,* known from the backshore-foreshore transition and washover areas (Frey & Mayou, 1971; Hill & Hunter, 1976). The thick rootlets may indicate minor tree growth in the form of mangrove vegetation (Jennings & Coventry, 1973). A comparable facies was interpreted as a humid supratidal environment with eolian activity by Clemmensen (1976). Eolian deposits cannot be demonstrated here, but the burrows probably indicate backshore-foreshore conditions, possibly in a shallow water coastal lagoon with mangrove vegetation near the high water level.

Fining-upward sequence – Included in this facies association is a cross-bedded 1.0 m thick erosively based fining-upward sequence, commencing with coarse-grained cross-bedded sand overlain by structureless and small-scale cross-laminated fine-grained sand. On the top, sand rich in plant detritus and clay with rootlets occurs (Gry, 1968).

The sequence is interpreted as fluvial deposits by Gry (1968), and can be related to lateral accretion of a migration point bar in a meandering stream, and vertical accretion of overbank sediments outside the main channel (Walker, 1976). The fluvial sediments have been deposited very near the shore and in connection with the coastal lagoon as suggested by Gry (1968).

Facies association A interpretation

Four subenvironments seem to be represented by this association (shoreface, foreshore, lagoon, fluvial) and it is consequently interpreted as deposited in a linear shoreline environment, on the intertidal foreshore beach, and in the subtidal shoreface zone under low wave energy with dominating tide. In a shallow water coastal lagoon, deposition has occured under very low energy conditions, and the lagoon seems to have been connected with small streams.

B. Low energy supratidal swamp – intertidal sand flat association

This association comprises sediments from the Skyttegård Member of the Rabekke Formation and the Østerborg Member of the Robbedale Formation (Gravesen et al., 1982). The association is exposed at Arnager Bugt only, and the lateral distribution is not known.

Description and interpretation of facies

There are four distinct facies, the boundaries of which are gradational, and the grain-size generally displays a coarsening-upward trend.

Sandy clay with abundant plant detritus. – The first facies is dark grey, brown and variegated structureless, or rarely, horizontally laminated sandy clay, rich in fine-grained plant detritus and lignite. The lignite pieces are clearly allochthonous and deposited in 40–50 cm thick beds, but rootlets are also known (Gry, 1968). Thin sandbeds with rootlets, silt lenses and light red brown clay are subordinate.

The facies suggests near-shore supratidal/intertidal shallow water swamp deposits with tree vegetation. The trees may have been mangrove vegetation which, on mud dominated flats, can replace salt marsh in areas (coastal lagoons, estuaries and deltas) with a warm humid climate similar to that of the tropics or subtropics today (Emery, Stevenson & Hedgpeth, 1957; Oomkens, 1974).

Structureless sticky clay. – Above the first facies is a black or green, structureless sticky clay facies with a few plant remains. Thin sand and silt lenses occur very rarely. The clay facies represents a mud flat dominated by sedimentation from suspension, and occurs seawards of the swamp.

Strongly bioturbated sandy clay, silt and silty sand. – The sticky clay is immediately overlain by strongly bioturbated sandy clay and silt, which continues upwards into bioturbated silty fine-grained sand (Fig. 9). Indeterminable burrows and meniscus structures (Frey et al., 1978), together with a few *Ophiomorpha* and *Skolithos,* are seen in this facies. The sediments are generally lacking in physical sedimentary structures, but can display large scale planar cross-bedding with palaeocurrent directions towards NE and E. The strongly bioturbated sandy silt and silty sand facies may represent an intertidal sand/silt flat where all structures have been destroyed by burrowing animals.

Fine-grained structureless sand. – The silty sand is overlain by a non-silty "clean" well-sorted fine-grained sand facies which is generally structureless, but small channels, scour-and-fill cross-bedding and *Ophiomorpha* occur. Most characteristic is scour-and-fill cross-bedded, fine to coarse-grained sand which marks sharp erosion surfaces of broad, lateral extent with low relief in the "clean" sand. Collapse structures associated with vertical *Ophiomorpha* burrows are found in connection with the erosion surfaces, and they are crossed by escape traces as well. Isolated small scale cross-lamination, with palaeocurrent directions towards NE, E and SE, and thin granule and pebble beds, occur very rarely.

The facies may represent an intertidal sand flat near the open sea. The thin,

Fig. 9. Facies association B. Strongly bioturbated, silty fine-grained sand. Individual trace fossils can not be recognized. Østerborg Member. Arnager Bugt area.

coarse-grained granule and pebble beds are interpreted as storm deposits and the erosion surfaces as the result of strong bottom erosion during the storms.

Facies association B interpretation

The facies association is interpreted as having been deposited in a transgressive tide-dominated environment. The interpretation is rather difficult as there are only very few physical sedimentary structures present, but the rather fine grain-size and the intense bioturbation of the association indicate low wave and current energy and a slow sedimentation rate. The coarsening-upward grain-size is taken to reflect the shorewards-falling energy conditions.

In the described sediments, the trace fossils *Ophiomorpha* and *Skolithos* could show protected beach or sandy tidal flat environment (Frey, 1970), and the bioturbation can have destroyed most of the physical structures (Carter, 1975). The zoning of facies here is similar to those known from recent tidal flat areas (Evans, 1965; Reineck, 1972), but in a transgressive sequence. It is, suggested, therefore, that the association could represent a sandy tidal flat environment with a mangrove swamp near the coast, and that the area has been protected as a part of an embayment, estuary or coastal lagoon.

C. High energy barrier – beach association

This association comprises sediments from the Langbjerg Member of the Robbedale Formation, and is overlain by the Jydegård Formation (Gravesen, 1977a, b; Gravesen et al., 1982; Noe-Nygaard & Surlyk, in prep.). The association, or part of it, has a rather broad distribution in the Robbedale area.

Description and interpretation of facies

Three facies are important.

Coarse-grained horizontally laminated and bioturbated sand. – The first facies is a dominantly thick-bedded, coarse-grained sand facies with rare granule pockets. It consists of two alternating bed types: faintly horizontally laminated, well-sorted sand which occasionally is trough cross-bedded, and strongly bioturbated moderately well-sorted sand with a few *Ophiomorpha* and many branching "*Ophiomorpha*"-like burrows without lining. The facies thickness is about 15–18 m.

The sand was probably deposited in the shallow subtidal shoreface partly under the wave base where burrowing is abundant, and partly on shoals or bars where strong wave-activity by shoaling or breaking waves produces the horizontal lamination by sheet flow (Clifton, 1976; Davidson-Arnott & Greenwood, 1976).

Coarse-grained horizontally laminated and cross-bedded sand. – The first facies is succeeded upwards by a well-sorted coarse-grained sand facies, with granule pockets or laminae displaying faint horizontal lamination (Fig. 10) and indistinct trough cross-bedding. The physical sedimentary structures are difficult to identify, probably because of the good sorting and uniform mineralogy of the sediments. Thin discontinuous horizontal laminae can be followed only over a short distance, and current directions are impossible to measure. *Ophiomorpha* and *Skolithos* are very rare, while small isolated clay flakes are common. The facies thickness is about 8–10 m.

The sand facies was deposited in the intertidal foreshore beach area. Laminated sand is normally found on the beach, produced by sheet flow of the swash-backwash movements (Clifton, 1969), and trough cross-bedding can be produced by the migration of lunate mega-ripples and the filling of erosion troughs under strong wave and current action (Clifton, Hunter & Phillips, 1971; Clifton, 1976). The sediments correspond to the inner planar facies, and to the inner rough and outer planar facies of Clifton el al., (1971).

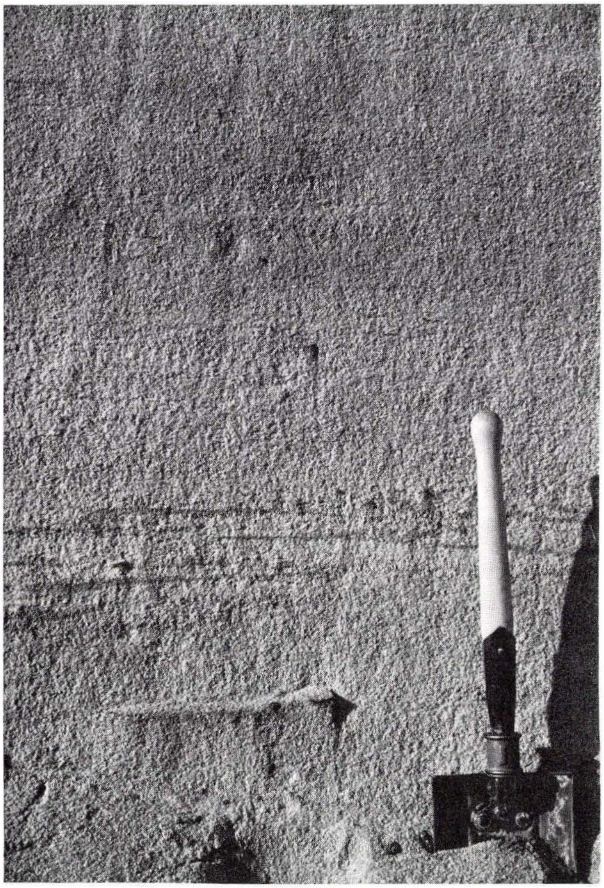

Fig. 10. Facies association C. Coarse-grained, faintly horizontally laminated sand with rare granule pockets. Langbjerg Member. A/S Carl Nielsen's sand pit, Robbedale area.

Medium-grained structureless sand. – The second facies is often overlain by a 0.5–1.0 m thick, medium-grained very well-sorted structureless white sand facies with small root-like structures.

This sand facies is difficult to interpret. A possible explanation is that it is comprised of eolian deposits with traces of roots, where all physical sedimentary structures have been destroyed by bioturbation, weathering and ground water movements as proposed by Davies, Ethridge & Berg (1971). Dickinson, Berryhill, Jr. & Holmes (1972) claim that the sediments on an eolian flat are non-laminated and mottled. The small root-like structures and

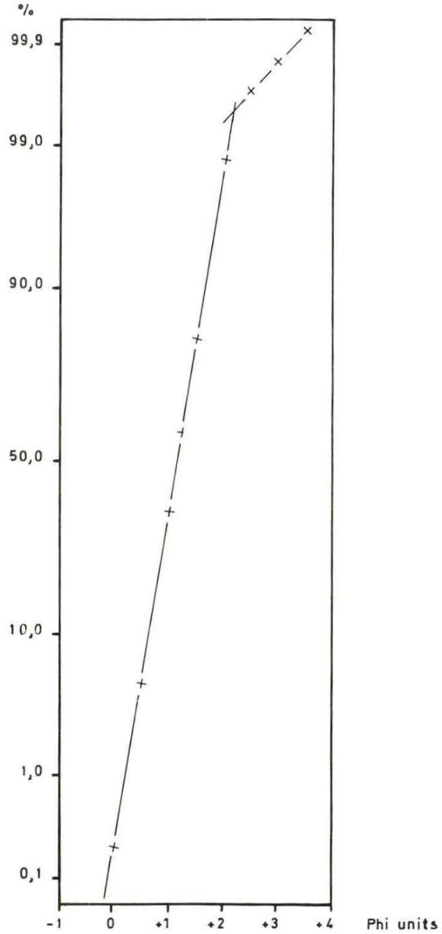

Fig. 11. Facies association C. Grain size distribution of the white structureless medium-grained sand, plotted on log-probability paper. Langbjerg Member.

the grain-size distribution here (Fig. 11) may indicate an eolian flat sediment (Visher, 1969).

In the Robbedale area the white structureless sand is overlain by the alternating beds of sand, sandstone, clay and clay-ironstone with brackish- and freshwater fossils of the Jydegård Formation, which can be partly interpreted as representing a coastal lagoon with washover sand deposits (Gravesen, 1977a, b; Noe-Nygaard & Surlyk, in prep.). At one locality the white sand is overlain by low-angle, large scale cross-bedded coarse-grained sand with graded clay-draped foresets. Reactivation surfaces and an erosive, gravelly base are characteristic of the sets. Small scale, cross-laminated sand follows and, on the top, rhythmically laminated silt and clay occur. The grain-size fines upwards, and the palaeocurrent direction is to NNE. This fining-upward sequence is interpreted as an inshore tidal channel as described by Oomkens & Terwindt (1960).

Facies association C interpretation

The association was deposited in a high energy marine environment suggested by the coarse grain-size and *Ophiomorpha* and *Skolithos.* The vertical profile of the association and the overlying sediments corresponds with a prograding barrier island complex (Davies et al., 1971; Dickinson et al., 1972) with deposits from shoreface, foreshore beach, eolian flat with sparse vegetation, in front of a coastal lagoon. Tidal channels are situated lateral to the island and lagoon. The entire sequence was deposited rapidly with a large supply of material.

D. High energy intertidal-subtidal channel and flat association

Sediments of the Langbjerg Member, Robbedale formation (Gravesen et al., 1982) are included in this association, which is known only from Arnager Bugt.

Description and interpretation of facies

The association comprises a range of different facies in random order. The following facies are the most typical.

Large scale cross-bedded heterolith. – A characteristic facies is large scale, low-angle cross-bedded heterolith with medium-grained moderately sorted sand and sandy clay, which is 1.2 m thick. The sand is bioturbated or faintly laminated with small scale cross-lamination. The clay is strongly bioturbated with distinct U-formed structures at the upper bedding surface. The heterolith base is sharp and erosive and upward, the cross-bedding clearly forms a point bar structure. The heterolith is interpreted as longitudinal cross-bedding, known from point bars in meandering channels in the intertidal or subtidal zones (Reineck, 1958). The bioturbation could have been caused by holothurian, probably like the recent *Thyone* (Frey & Howard,

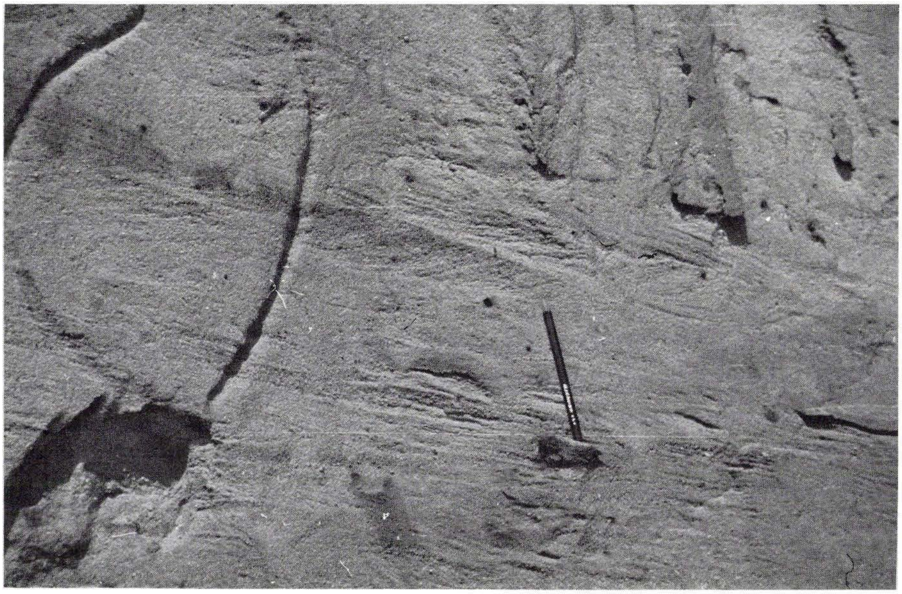

Fig. 12. Facies association D. Complex, large scale cross-bedded medium-grained sand. Large cross-sets dip to the right, and small oppositely directed foresets are seen above the pencil. Langbjerg Member. Arnager Bugt area.

1972; Radwanski, Friis & Larsen, 1975), which is known from shallow water subtidal environments and tidal channels (Howard & Frey, 1975).

Large scale complex cross-bedded sand. – Another important, 1.2 m thick, facies consists of large scale complex cross-bedded medium-grained sand, which shows an alternation of cross-sets and structureles units. Large scale planar foresets dip 18–20 degrees and, occasionally, small scale foresets, dipping 22–24 degrees, are superimposed upon the large scale sets. The palaeocurrent direction is towards NE. Oppositely-dipping small scale foresets, with palaeocurrent direction towards W, occur scattered in the otherwise structureless units (Fig. 12). Gravelly patches are common, and bottomsets are often gravelly with plant material. *Ophiomorpha* is found near the upper bedding surface which, like the lower one, is sharp.

The complex cross-bedded sand compares well with recent tidal mega-ripples or sandwaves from the intertidal or subtidal zones, where the oppositely-directed foresets are produced by alternating tidal currents (Klein, 1970; Raaf & Boersma, 1971; Boersma & Terwindt, 1981).

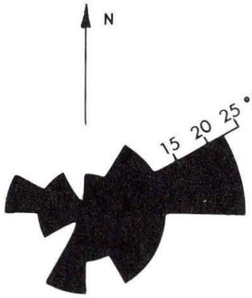

Fig. 13. Facies association D. Palaeocurrent rose of the Langbjerg Member at Arnager Bugt, based on 18 readings of small scale cross-laminations.

Small scale cross-laminated sand. – A medium-grained small scale cross-laminated sand facies is found isolated or in connection with horizontally laminated sand and, occassionally, with long unbranched *Ophiomorpha* burrows and *Skolithos.* The thickness varies from 0.6 to 2.3 m. Herringbone cross-lamination in 3–4 cosets creates a bimodal palaeocurrent pattern E-W (Fig. 13).

The cross-laminated sand is formed by migrating, small scale current ripples and the herringbone cross-lamination, which is an important indicator of tidal deposits (Raaf & Boersma, 1971), is produced by oppositely migrating current ripples. Here, the horizontally laminated sand is produced by sheet flow under strong wave action (Clifton, 1976).

Slightly graded medium-grained sand. – Another sand facies is without physical sedimentary structures, but grades sligthly upwards from gravelly, medium to coarse-grained to medium-grained sand. Vertical *Ophiomorpha* burrows, which are unbranched up to 70 cm, are sharply cut at the upper bedding surface. The lower bedding surface is also sharp and erosive. This facies occurs in 0.5–1.7 m thick beds.

Interpretation here is more difficult. A possible explanation could be a subtidal storm deposit, which is deposited under high wave activity from storm-generated currents. The sea bottom is eroded during the storm, as suggested by the sharp erosive base of the beds. When the storm wanes, the large sediment mass in suspension is rapidly deposited. During fair weather, the sediments in question are burrowed, as marked by the occurrence of *Ophiomorpha.* Recent storm deposits are described by Kumar & Sanders (1976), and fossil equivalents by Goldring & Bridges (1973), both in generally thinner beds than here, but thicker storm-generated beds are also known (Johnson, 1978).

Facies association D interpretation

The association is interpreted as representing sediments from channels and flats in the intertidal and/or subtidal zones deposited under rather high wave action and tidal current. Raaf and Boersma (1971) pointed out that it is often difficult to distinguish between various tidal subenvironments and here it is not possible. *Ophiomorpha* is found in nearly all the facies and *Skolithos* in a few, which emphasizes the intertidal or subtidal nature of the sediments.

Sedimentological and tectonic development

The ?Tithonian-Valanginian Nyker Group on Bornholm seems to show a general regressive-transgressive-regressive pattern (Gravesen et al., 1982).

The basal regressive Homandshald Member of the Rabekke Formation is deposited as coarse-grained fluviatile sediments and rests unconformably on older rocks (Gry, 1956, 1960). The fluviatile sediments terminate in lacustrine deposits of the lower part of the Skyttegård Member (Rabekke Formation), but polyhaline ostracods in the clay (Christensen, 1963, 1966) demonstrate minor episodes of marginal marine sedimentation. The upper part of the Skyttegård Member, which is included in the described facies association B, is interpreted as nearshore supratidal/intertidal swamp deposits. The upper part of the Vitabäck Clay Member (Norling, 1981) from Scania can be correlated with the Rabekke Formation (Christensen, 1968, 1974), and the dominantly clayey sediments are probably deposited under nearly the same conditions. A long, low relief-flat nearshore plain from Bornholm to Scania can be suggested in ?Tithonian-Lower Berriasian.

The stratigraphically lower associations A and B described in this paper comprise sediments of the upper part of the Skyttegård Member and the Østerborg Member (Robbedale Formation). They were deposited in low energy environments, and it is suggested that the subenvironments of association A: Fluviatile, coastal lagoon, intertidal beach/shallow subtidal open shore, pass laterally into the subenvironments of association B: Supratidal/intertidal swamp, intertidal mud-sand/silt-sand flat in a protected area (Fig. 14). The associations were deposited under general transgression with minor shoreline oscillations. The shallow marine environments migrated landwards over coastal lagoon, swamp, lacustrine and fluviatile deposits. Normally, transgressive nearshore sequences are regarded as very thin, or represented

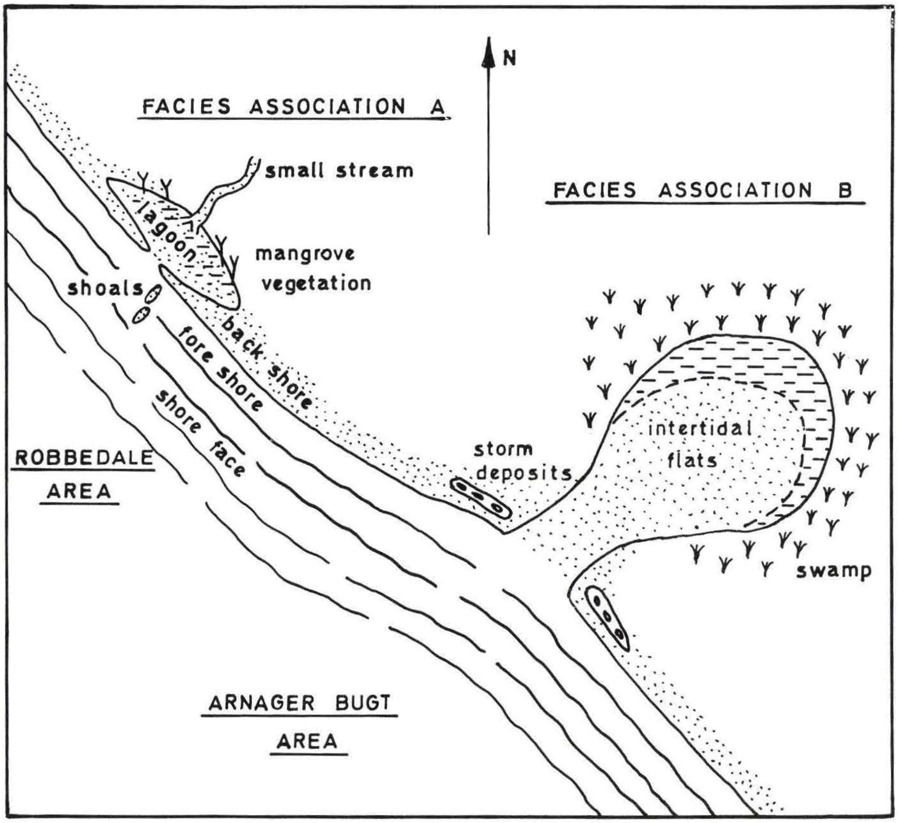

Fig. 14. Tentative reconstruction of the depositional environments of facies associations A and B, deposited under transgressive conditions.

only by an unconformity (Fischer, 1961). Here, it seems that the degree of erosion has been low, and sequences up to 18–20 m were formed. The dominating transport directions were bimodally E-W and subordinate NE.

It is suggested that the Lower-?Upper Berriasian transgression is related to both eustatic sea level rise (Vail & Todd, 1981), and to tectonic subsidence of the blocks in the Fenno-Scandian Border Zone caused by the Late-Kimmerian tectonic phase, which also activated the six blocks where the ?Tithonian-Berriasian sediments are found on Bornholm. This eustatic sea level change and tectonic episode also seem to have caused transgressions in other areas during the Early Cretaceous (Allen, 1967; Christensen, 1974; Michelsen, 1978) and, in Scania, the sandy "Wealden" Beds (Christensen, 1968; Norling, 1970; Norling & Skoglund, 1977) possibly represent sedi-

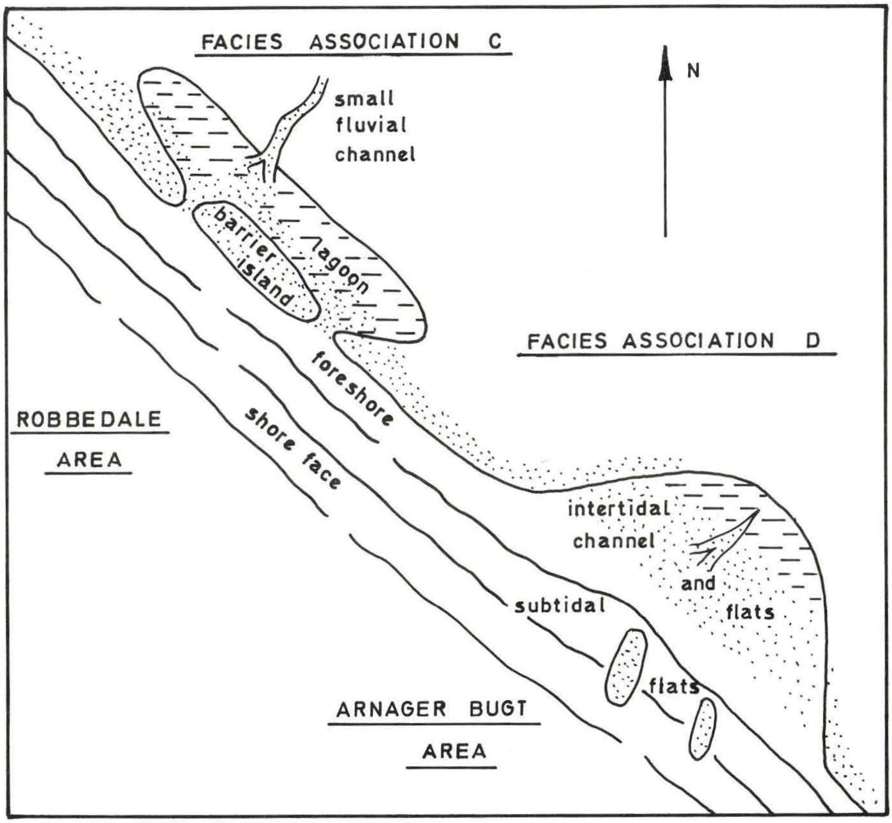

Fig. 15. Tentative reconstruction of the depositional environments of facies associations C and D, deposited under progradation of the coastline.

ments from this transgressive episode as well as from the following regressive phase of the Langbjerg Member and Jydegård Formation. The subsidence and basin extension occurred stepwise along normal-faults in a northeastern direction during the Mesozoic, as proposed by Rolle et al. (1979) and Gravesen et al. (1982).

The stratigraphically higher/younger associations C and D comprise sediments of the Langbjerg Member of the Robbedale Formation, which rests with a sharp and erosive boundary on the Østerborg Member. The associations were deposited in high energy environments under a general progradation of the shoreline with occasional oscillations. The subenvironments of association C: Barrier beach/shallow subtidal deposits, were laterally connected with subenvironments of association D: Intertidal-subtidal channel and flats (Fig. 15). The deposits of the overlying Jydegård Formation (fresh-brackish-marine) migrated seawards over the shallow marine deposits, and it is suggested that the sedimentation occurred rapidly with an abundant supply of material. This Upper Berriasian progradation is contemporaneous with a minor marine regression in the northern North Sea (Vail & Todd, 1981). The transport directions were mainly bimodally E-W, but the direction of the large structures is towards the NE.

The mineralogy of the sand is very mature, with over 99 per cent quartz, and with zirkon, rutile, tourmaline and kyanite the dominating heavy minerals. The sand seems to consist of both first-cycle detritus and recycled material (Gravesen, 1977a). Parts of the material of the four associations could have been delivered directly from the uplifted Baltic Shield and the older rocks of Bornholm, but other sources of supply are also possible.

Conclusion

The ?Tithonian-Berriasian sediments on Bornholm described in this paper were mainly deposited in two different sedimentological episodes. The Skyttegård Member of the Rabekke Formation, and the Østerborg Member of the Robbedale Formation, were deposited in fluviatile, swamp, lagoon and shallow marine subenvironments near the shoreline under a general transgression. The shallow marine intertidal and subtidal sediments were deposited under low wave energy with dominating tide.

The regressive Langbjerg Member of the Robbedale Formation and part of the overlying Jydegård Formation were deposited in lagoon, barrier beach and other shallow marine subenvironments under a general progradation of the shoreline. The marine intertidal and subtidal sediments were deposited under high energy conditions with both high wave action and tidal currents.

The general eustatic sea level changes (Vail & Todd, 1981) and the local tectonic basin extension and down-faulting in the Fenno-Scandian Border Zone (Rolle et al., 1979; Gravesen et al., 1982) have controlled the facies evolution and deposition on Bornholm during the ?Tithonian-Berriasian-Valanginian.

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Dansk sammendrag

Aflejringer fra Rabekke og Robbedale Formationerne fra ?Tithonien-Berriasien er beskrevet i fire facies associationer, og aflejringsmiljøet er blevet tolket.

Skyttegård Leddet (Rabekke Formationen) og Østerborg Leddet (Robbedale Formationen) blev aflejret i en række miljøer nær ved en liniær kystlinie: Mindre floder, sumpe, laguner og fladvandede marine områder under en generel transgression. De fladvandede marine intertidale og subtidale sedimenter blev dannet ved lav bølgeenergi med en tidevandsdominans.

Det regressive Langbjerg Led (Robbedale Formationen) og dele af den overliggende Jydegård Formation blev aflejret i laguner, på en barriere strand og andre fladvandede marine områder under en generel progradering af kystlinien. De marine sedimenter blev dannet under høje energiforhold med både høj bølgeenergi og tidevandsstrømme.

Facies udviklingen og aflejringen på Bornholm er både blevet kontrolleret af de generelle eustatiske havniveauændringer og den lokale tektoniske basinudvidelse og nedforkastning i den Fennoskandiske Randzone.

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Marine seismic investigation of the shelf around the Faroe Islands

P. Hedebol Nielsen, Regin Waagstein, Jóannes Rasmussen
and Birger Larsen

Nielsen, P. Hedebol, Waagstein, R. Rasmussen, J. and Larsen, B.: Marine seismic investigation of the shelf around the Faroe Islands. *Danm. Geol. Unders., Årbog 1981:* 101–109, København, 1 okt. 1982.

Shallow seismic profiling shows that the basaltic shelf around the Faroe Islands extends roughly to the 200 m depth contour. Outside the basaltic shelf the basalts are overlain by sediments of presumed Tertiary age which dip outwards at a low angle.

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The Faroe Islands are surrounded by a broad shelf which is part of the Faroe-Iceland-Greenland ridge in the northern Atlantic Ocean. It is generally assumed that the ridge consists largely of volcanic rocks surrounded by sediments. More than 3 km of Lower Tertiary basalt lavas are exposed on the Faroe Islands (Rasmussen and Noe-Nygaard 1969). Based on gravimetric and deep reflection seismics it seems likely that the Faroe shelf rests on continental crust (Bott and Watts 1971, Bott and others 1974, Nielsen 1976).

The shelf around the Faroe Islands has been subject to several investigations in the last few years. A detailed bathymetric survey has been performed inside the 200 m depth contour (Rasmussen 1977). The shelf, including the banks to the southwest, has been sampled by dredging (Waagstein and Rasmussen 1975, Waagstein 1977). A magnetic and bathymetric survey covering the shelf including Bill Bailey Bank and Lousy Bank (Nielsen 1977) is complete and the results are now being compiled. This survey supplements earlier studies by Dobinson (1970), Schrøder (1971) and Fleischer and others (1974). The shallow structure of the shelf has also been investigated by a few seismic reflection profiles (Stride and others 1967, Talwani and Eldholm

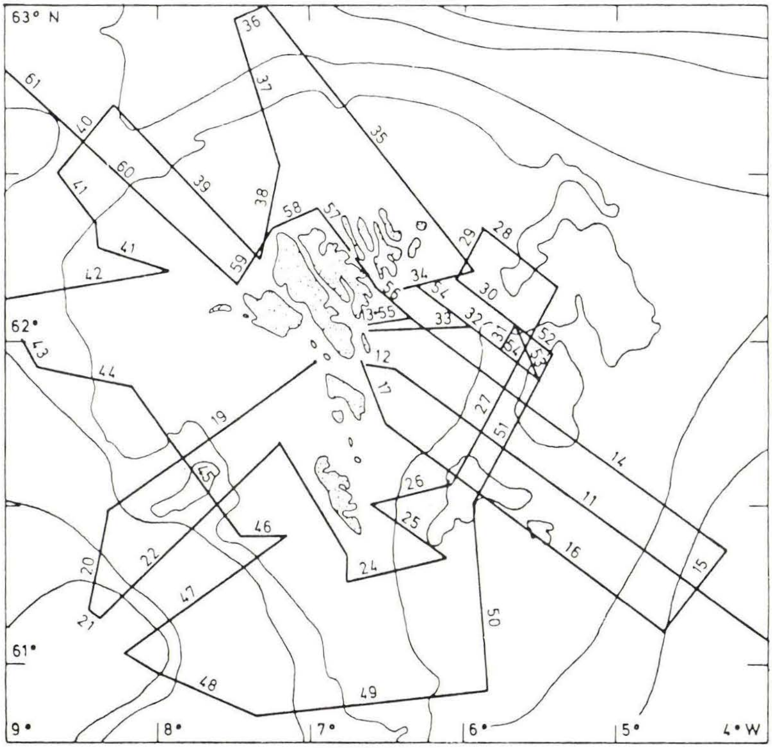

Fig. 1. A sketch of the survey lines made by »Dana« around the Faroe Islands during the summer 1979. (Line 18 in the sounds Nólsoyarfjørður and Skopunarfjørður has been omitted for clarity).

1972, Himsworth 1973, Korsakov 1974, Talwani 1974). Some of the above studies have been reviewed by Bott (1975) and Waagstein (1977).

In order to further elucidate the geological structure of the upper parts of the shelf, and especially to map the extent of basalts on the sea floor, the Faroese government and the Geological Survey of Denmark carried out a seismic survey on the research vessel »Dana«, 6–22 July 1979, with equipment on loan from the Geological Survey of Greenland. About 2300 km of shallow seismic profiles were obtained (Fig. 1).

This initial report describes the survey and presents some preliminary results.

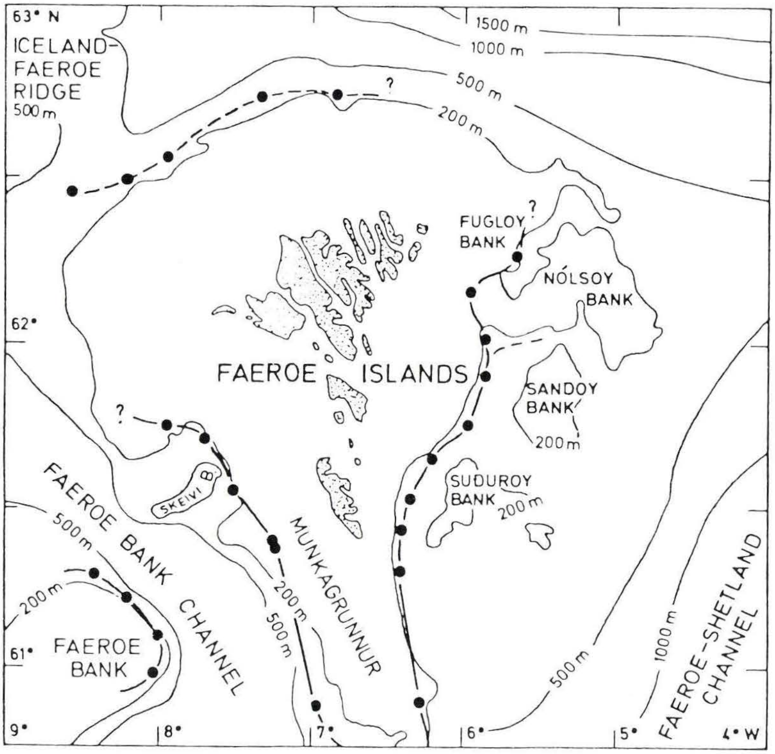

Fig. 2. The map shows the boundary of the Faroese basalt areas according to the measurements made on board »Dana«; see the text for details.

Methods

The sea bottom was investigated chiefly by seismic methods, using the principles of the recording echo sounder. A 10–20 cu inch airgun (Bolt), operated at 120 atm, or a 4 KJ nine electrode sparker array (EG & G 402), was used as a sound source. The sound signal reflected from the sea floor or from layers in the substrate was detected by a short hydrophone streamer (EG & G 265). After amplification and filtering of the seismic signal, the reflections were recorded on a facsimile recorder (EPC 3200 and 4500). An example of the records is shown in Fig. 4. The depth was measured by a Simrad SM50 sounder. The local morphology of the sea bottom was also investigated by side-scan sonar (Edo Western 515T/606), but the side-scan system was operative only on the last day of the survey. The magnetic field was measured by a proton magnetometer (Geometrics G803). Position was determined by

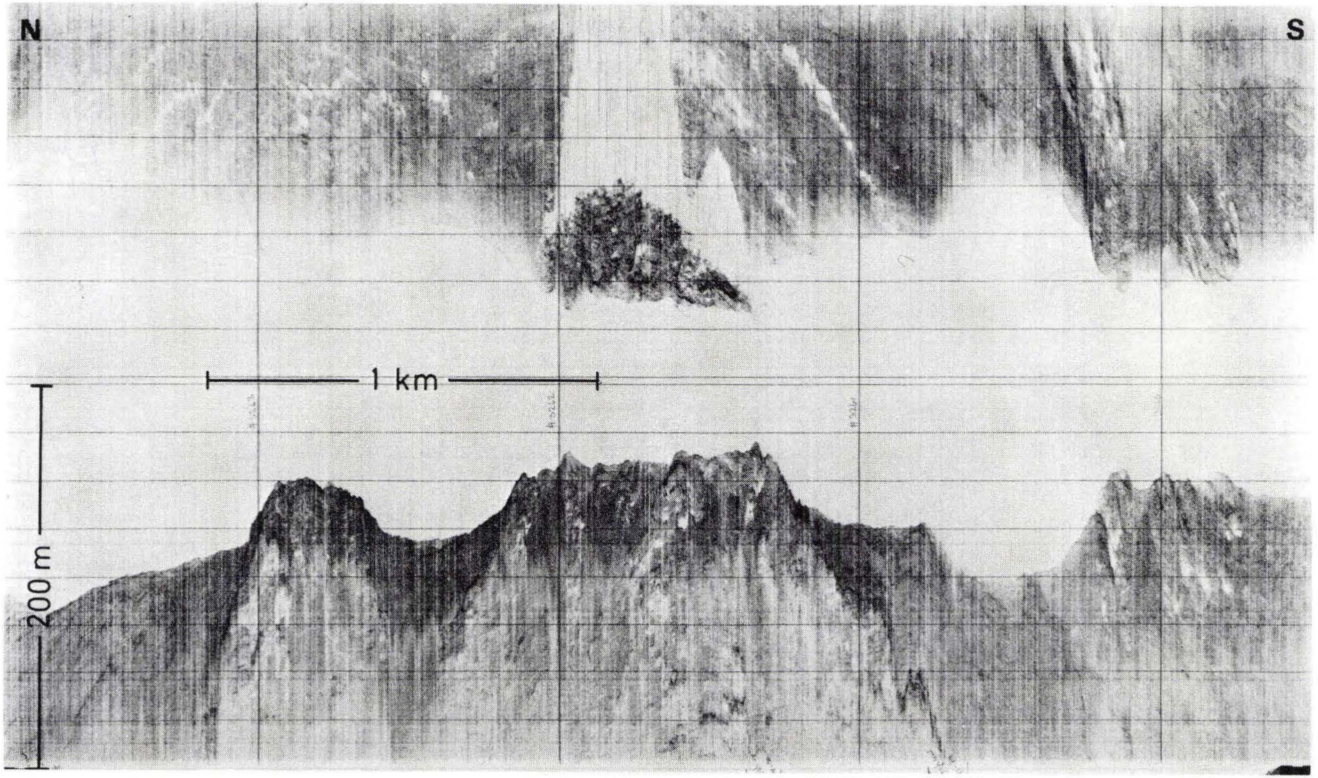

Fig. 3. Side-scan record from Djúpini (line 57).

The side-scan emits a narrow sound beam perpendicular to the course of the ship just above the sea floor. The sound reflected (or rather scattered) from the obstacles on the sea floor is recorded. The record resembles a negative photograph of the sea bottom as illuminated by a projector just above the sea floor.

The darker areas mark the parts of the sea bottom which protrude or for other reasons reflect more sound energy than average. The white area in the upper central part marks the acoustic shadow behind a protruding feature. The lower half shows the bottom on the port side (west) of the ship. Interpreted geologically, the picture probably shows an outcrop of basalt, with an outline controlled by intersecting joints. The dark areas between the outcrops possibly indicate a rather coarse-grained sediment.

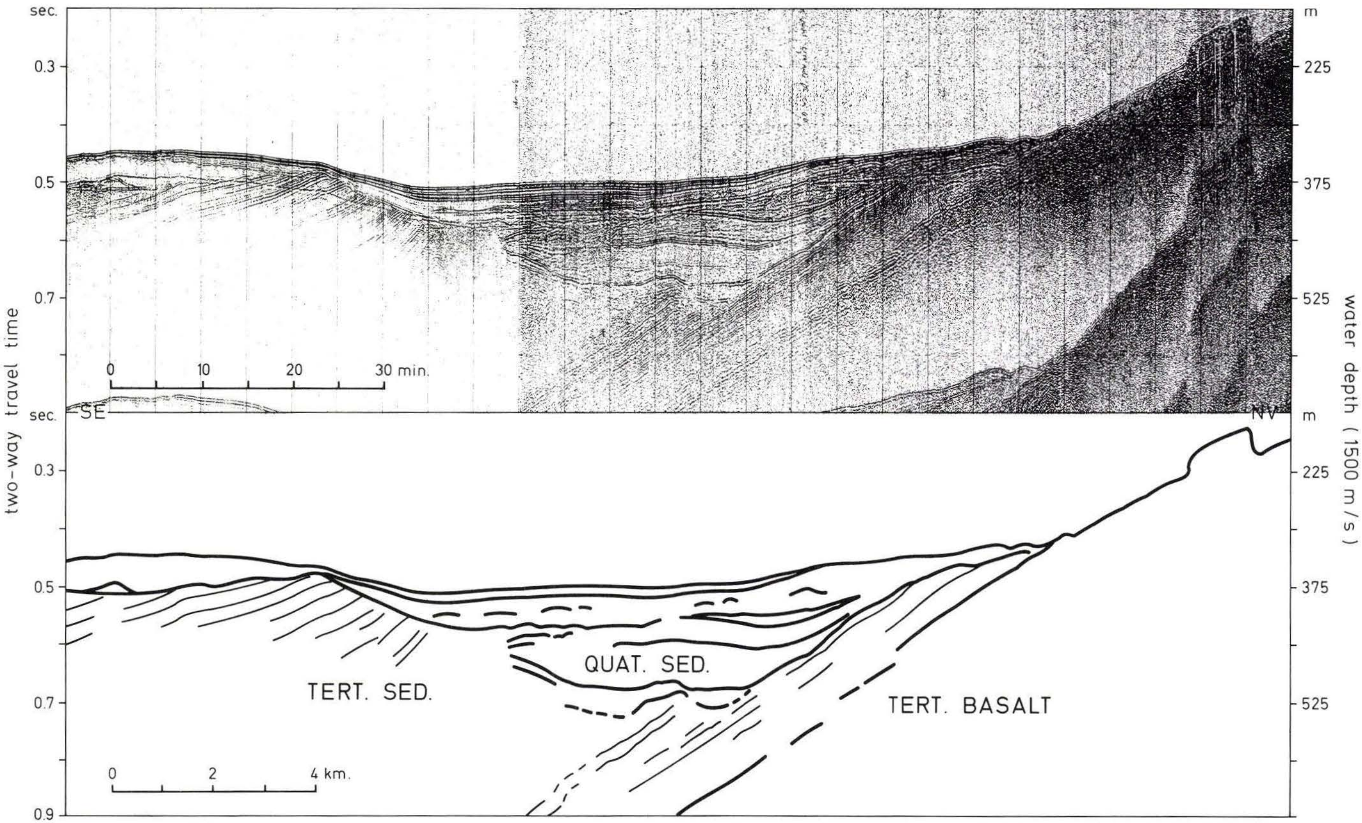

Fig. 4. A part of the seismic recording of line 11 and its interpretation showing the basalt-sediment boundary (east of the Faroe Islands).

an integrated satellite navigator sonar doppler system (Magnavox). The positional accuracy is well within 200 m when the system is working properly, but in many cases the navigator system caused troubles. A description of such marine investigations is given by, i.a. McQuillin and Ardus (1976).

Results

The basaltic shelf. Most of the wide shelf around the Faroe Islands consist of basalt like the Faroe Islands themselves. The submerged basalt area is characterized by strong, short-waved magnetic anomalies and a lack of seismic penetration. The eroded basalt flows often form inclined steps clearly visible on bathymetric and seismic profiles and side-scan records (Fig. 3). The inclination of such steps, and of rare internal reflections in the basalts, suggests that the flows dip towards the limit of the basalts east and west of the islands (Fig. 4).

The top of Faroe Bank to the southwest also consists of basalt.

Young sediments partly fill shallow depressions on top of the basalt but rarely exceed a thickness of 50 m. Glacial overdeepened depressions occur in the fiords between the islands and may be empty (e.g. Skopunarfjørður) or filled with 50–150 m of sediment (e.g. Nólsoyarfjørður, Djúpini).

The limit of the basaltic shelf

The basalt disappears below sediments on the outer shelf or slope around the Faroe Islands (Fig. 2). The basalt contact with the sediments varies in character. To the sourtheast, south and southwest, the top of the basalt falls 2–10°, seldom more, beneath the sediment sequence. The estimated depth of seismic penetration of the overlying sediments is 200–500 m, and the basalt drops below this depth within a few kilometres. The contact is mostly straight and seems to follow the stratification of the basalt (Fig. 4). North of 62° N, the eastern contact becomes flat and irregular. The basaltic basement thus occurs at less than a few hundred metres depth below Nólsoy Bank and is possibly exposed somewhere on the bank. North and northwest of the Faroe Islands (lines 35, 37, 39 and 60), the outermost part of the shelf has an irregular topography (cf. Fleischer and others 1974). The irregular zone is 10–15 km wide and seems to consist of sediments. The sediments show little or no seismic penetration and their thickness is unknown. However, the magnetic data suggest that the basaltic basement occurs at shallow depth until the edge of the shelf. Just beyond the shelf edge a wedge of transparent sediments overlies a basement reflector which is presumed to be basalt. The strong reflector is lost a few kilometres downslope beneath several hundred metres of sediments. The supposed limit of shallow basaltic basement is shown as a stippled line on Fig. 2. Exposures of basalt reappear on the Iceland-Faroe Ridge. Due west of the northern Faroe Islands, shallow basaltic basement extends farther to the west than the survey lines.

The sedimentary shelf

Thick sediments occur on the outer shelf east of the Faroe Islands and can be divided into two major stratigraphic units.

The lower unit consists of well-bedded sediments which dip outwards at a low angle. The oldest strata overlie the sloping basalt sediment contact conformably or nearly so (Fig. 4). The lower unit is clearly seen along the western sides of Sandoy Bank and Suðuroy Bank, and in the channel between the banks. In this area the inclined beds apparently crop out on the sea floor in many places. The channels (broad valleys) separating Sandoy and Suðuroy Banks from each other and from the basaltic inner shelf are cut down into the lower sediments. These channels resemble the marginal and transverse channels described from many glaciated shelves.

The upper sediment units rests unconformably on the lower unit or directly on the basalt. The upper sediments are irregularly bedded and can attain a thickness of up to a few hundred metres in the channels, but in most places they are much thinner. The channel fillings show a high or moderate seismic transparency and probably consist dominantly of fine-grained sediments. The internal structure of the channel fillings indicats several stages of erosion and deposition (Fig. 4). The thin sediment cover on top of Sandoy and Suðuroy Banks and farther east is much less transparent and probably includes a large fraction of coarse-grainedd glacial material. In this area the underlying series is barely visible. The low-transparency layer continues a little down the slope towards the Faroe-Shetland Channel.

Thick sediments also occur on the outer shelf west of the islands in a small area facing the Faroe Bank Channel (Fig. 2). A lower series of outward-dipping sediments also exists here beneath a cover of younger sediments (cf. Stride and others 1967).

Discussion

The regularity of the contact between basalts and lower sediments suggests that the contact follows the bedding of the basalt flows. This impression is supported by observations of the dip of flows on the basaltic shelf. The dip of the contact, i. e. flows, is steeper than the probable original dip of the flows. The basalts are therefore tilted, a finding consistent with the idea of updoming of the basalt plateau (Schrøder 1971, Waagstein 1977).

The conformable contact between basalts and sediments (Fig. 4) indicates that the oldest parts of the lower sediments have also been tilted. Asssuming an early date of doming (Waagstein 1977), the oldest sediments only slightly postdate the basalts dated at 50–60 mill. years, i.e. Lower Tertiary (Tarling and Gale 1968). Some of the sediments are probably tuffaceous (Waagstein and Rasmussen 1975).

The lower sediment unit attains a thickness of roughly 2 km in the vicinity of Sandoy and Suðuroy Banks, according to gravity (Bott and Watts 1971) and seismic evidence (Korsakov 1974).

The sediments of the upper unit are supposed to be of Quaternary age. The Faroese ice sheet probably reached the 400 m depth contour to the southeast of the Faroe Islands (Waagstein and Rasmussen 1975). The large areas of poor seismic penetration on the eastern sedimentary shelf are therefore probably covered by glacial drift.

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Vegetational development in the Faroes from 10.000 BP to the present

Jóhannes Jóhansen

Jóhansen, J.: Vegetational development in the Faroes from 10.000 BP to the present. *Danm. geol. Unders. Årbog 1981:* 111–136, 3 pls., København, 1. oktober 1982.

In this paper three pollen diagrams from the Faroe Islands are presented; one from Saksunarvatn and two from Hovi. They cover the time from 10.000 BP to the present. The first vegetation was a fell field vegetation. In the middle of the Preboreal, Betula nana immigrated, had a short maximum and subsequent decline due to climatic changes. From the end of the Preboreal and to the present, grasses and sedges are by far the most dominant pollen taxa. From Boreal and up to man's arrival, Juniperus and Salix phylicifolia covered large areas of the lowland. During the Atlantic and the Subboreal, Calluna became important. Besides, a tall herb vegetation persisted until the land occupation by man. One of the diagrams from Hovi shows the development from 1350 BC to the present.

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In this paper three pollen diagrams from the Faroe Islands are presented and the vegetational development from 10.000 BP is described. Late Weichselian deposits have not been found. The localities are Lake Saksunarvatn and Hovi A and B (fig. 1).

Methods and pollen identification

The material was obtained by coring and by taking samples from an open profile. This is described more closely later, where the three pollen diagrams are discussed.

The preparation technique has been the same for all samples. They have been treated by the method described in Fægri and Iversen's Textbook of Pollen Analysis (1966): KOH, HF, HC1, acetolysis, ethanol, benzene and, finally, silicone oil. An Ortholux microscope was used, and normally about 600 pollen and spores were counted pr. sample.

Pollen identifications. *Betula.* At Hoydalar it was found, by size measurements of *Betula* pollen diameter, that the local *Betula* population was *Betula*

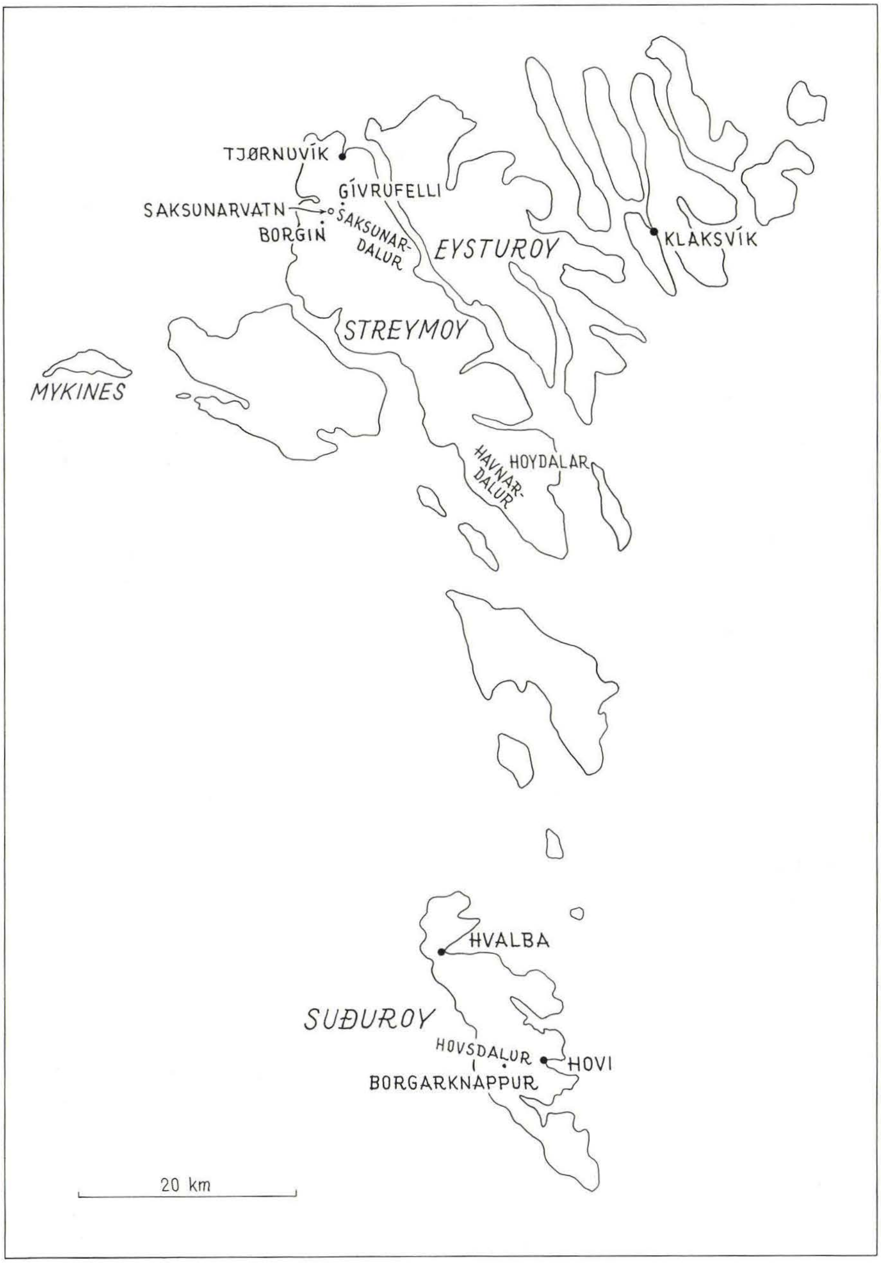

Fig. 1. Faroe Islands with the localities mentioned in the text.

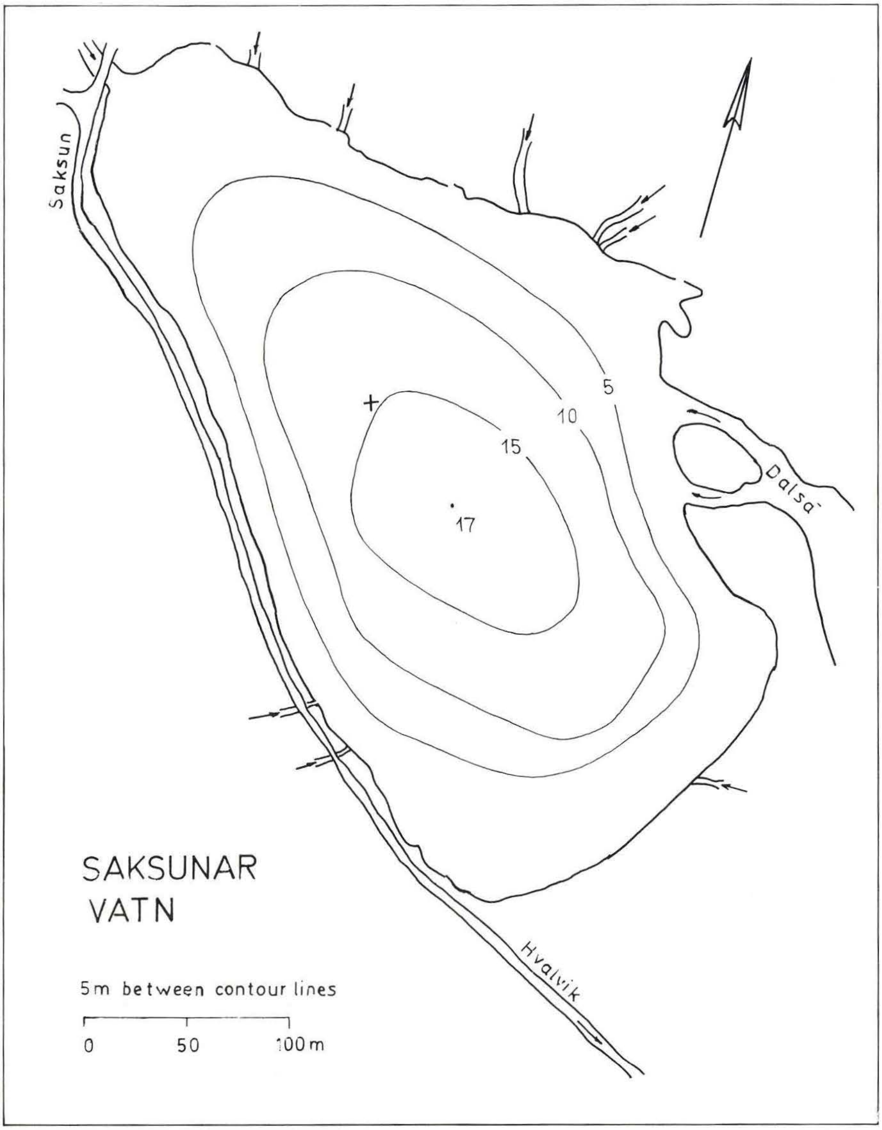

Fig. 2. Sketch plan of Lake Saksunarvatn with bottom topography. Coring point at x. From S. í Dali, Uppmáting av vøtnum í Føroyum, 1977.

nana (Jóhansen 1968). As the peaks of the *Betula* curve in the two diagrams presented here are of the same age, I found it unnecessary to repeat the size measurement procedure. Further, because the samples, when counted, had been stored for different lengths of time (from 0 to 10 years), as well as at different temperatures (+ 5 to about + 15°C), a repetition would have yielded unreliable results. I have not been able to separate *Oxyria* and *Rumex acetosa* on morphological criteria. I presume that most of the oldest pollen of this type is *Oxyria* and most of the youngest is *Rumex acetosa.*

Dryopteris in the diagrams also includes *Athyrium.* The perine was always lacking.

The other pollen taxa which are identified to species level, genus or higher taxonomic rank can be seen in the diagrams, or in the complete list of pollen and spore types not drawn in the two diagrams. In the diagram Hovi B, all pollen taxa are included.

Lake Saksunarvatn

Lake Saksunarvatn is situated in the 10 km long Saksunardalur on Streymoy which runs in NW-SE direction. The lake is 17 m deep and its height above sea level is 23 m. A sketch plan (fig. 2) shows the bottom topography, size of the lake and the coring point (Dali 1977). Saksunardalur is peat covered, while the area around the lake is rather bare with rock outcroppings, scree and a thin peaty layer here and there. A block diagram (fig. 3) gives an impression of the topography of northern Streymoy and Eysturoy (Schou 1949). The highest mountains around Saksunarvatn – Borgin and Gívrufelli – are both 640 m high.

Sampling methods

The coring was made from a pontoon, and a core of 36.75 m was obtained without reaching solid rock or moraine. The material was taken up into 1 or 0.5 m long iron tubes with a diameter of 78 mm. The cores were transferred to plastic tubes, sealed with wax at both ends and closed. The tubes were later cut longitudinally into two halves. One half was stored in a cool room for eventual future use. From the other half, samples for pollen, macroscopic and chemical analysis, and samples for radiocarbon datings were taken. In this paper only the result of pollen analysis and the radiocarbon datings (Table 1) will be described and discussed.

The profile

The entire core was 36.75 m. Only 21.75 m has been used in this study. The uppermost 15 m of sediment had to be discarded because of serious irregularities during sedimentation. Due to erosion in the catchment area, heavy inwash of terrestric material of different ages has taken place. This was

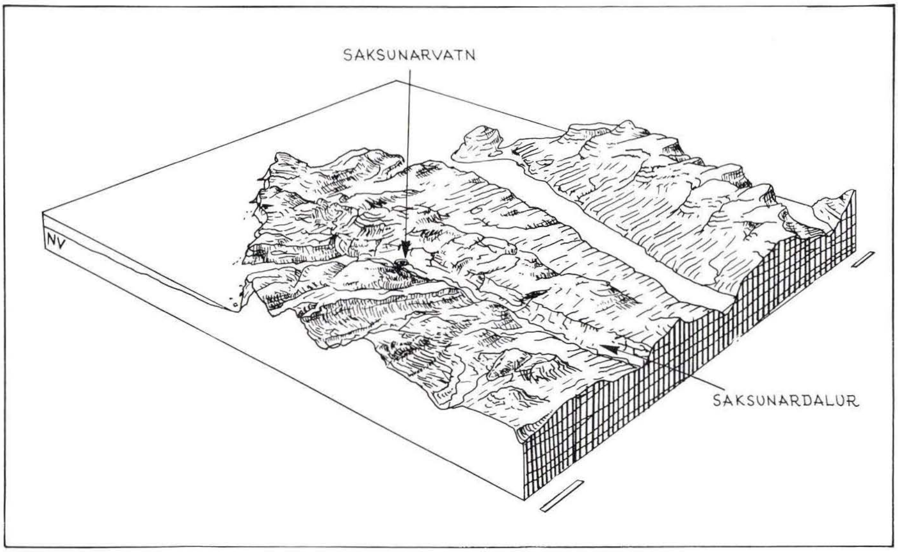

Fig. 3. Block diagram of the northern part of Streymoy and Eysturoy. From A. Schou. Atlas over Danmark, 1949.

documented through close radiocarbon datings and has been described in an earlier paper (Jóhansen 1977). In this paper I shall therefore deal only with the profile from 15 m downwards (Plate 1). From 15 m down to 29.85 m the material consists of homogenous brown lake mud or gyttja. At 29.85 – ca. 30.30 m, a layer of black volcanic ash (from Iceland) was found. Under the ash layer, from 30.30 – ca. 30.75 m there was a layer of clay. Under the clay layer, we again have brown lake mud down to about 32.30 m, where it gradually begins to change into clay. (In the paper mentioned above, the depth of the ash layer was unfortunately incorrectly stated).

The pollen diagram

The pollen diagram (Plate 1) has been divided into 5 local pollen assemblage zones, S 1–5.

The lowermost part of the profile – from 34.00 m to 36.75 m – is quite minerogenic and contains no pollen and cannot be dated.

Table 1. The radicarbon datings from Saksunarvatn, (all uncalibrated) drawn on the diagram Plate 1. Depth of water, 14 m included.

Saksunarvatn		
K–2157	28.94–29.01 m	2890 ± 100 BP
K–2321	30.99–31.07 m	3320 ± 100 BP
K–2322	32.02–32.07 m	3680 ± 100 BP
K–2323	33.00–33.10 m	3780 ± 100 BP
K–2158	34.70–34.81 m	4140 ± 100 BP
K–2324	34.93–35.03 m	4310 ± 100 BP
K–2325	36.24–36.28 m	4520 ± 100 BP
K–2326	38.10–38.20 m	4930 ± 100 BP
K–2327	39.11–39.21 m	5330 ± 100 BP
K–2328	40.33–40.41 m	5790 ± 100 BP
K–2329	40.97–41.07 m	6190 ± 100 BP
K–2330	42.04–42.12 m	7240 ± 100 BP
K–2331	43.05–43.13 m	8230 ± 100 BP
K–2159	44.75–44.83 m	9180 ± 140 BP
K–2332	45.22–45.32 m	9380 ± 130 BP
K–2160	45.99–46.10 m	9390 ± 150 BP

Zone S 1

Depth 31.25 – 34.00 m. Age ? – 9300 BP

Betula nana – Sedum – Salix – Oxyria/Rumex acetosa – Poaceae.
Betula nana dominates with up to 40% of the total pollen and spore sum. *Sedum* is important with max. 25%. *Oxyria* lies at 3% at the bottom, has a peak of 18% and decreases to 2% at the upper end of the zone. *Salix* (leaves of *Salix herbacea* have been found at this level) rises from 0 at the bottom to 9% in the middle of the zone and decreases at the upper end to 6%. *Poaceae* are of no importance, except for sample 44 where the percentage is 24. In the lowermost sample, *Armeria* lies at 16%. *Dryopteris* lies at 5% in most samples, highest – 16% – at the bottom, falling to 2% in the next spectrum, and then 5%.

Number of taxa: 50, (5 pollen spectra).

Zone S 2

Depth 30.25 – 31.25 m. Age 9300 – 9000 BP

Poaceae – Cyperaceae
This zone is a transitional zone between S 1 and S 3.

Betula nana is extinct. Grasses and sedges dominate from now on. *Sedum* is still important with 10%. In the beginning of the zone, *Plantago maritima* and *Selaginella* occur for the first time. *Dryopteris* goes up to 11%.

Number of taxa: 34 (3 pollen spectra).

Zone S 3

Depth 28.50 – 30.25 m. Age 9000 – 7500 BP

Juniperus – Poaceae – Cyperaceae

Poaceae and *Cyperaceae* dominate with about 60% together.

Juniperus, which in the two preceding zones occurred sparsely (1–2%), increases here to 8%. *Dryopteris* lies at 10–12%, while *Sedum* decreases to 5%. *Huperzia* is at its minimum – 1%. In this zone *Thalictrum (alpinum)* becomes rather common – up to 6%.

Number of taxa: 52, (6 pollen spectra).

Zone S 4

Depth 26.50 – 28.50 m. Age 7500 – 5800 BP

Juniperus – Calluna – Poaceae – Cyperaceae

Juniperus lies at 5%, but decreases to 3%. From the beginning of this zone, *Calluna* becomes a member of the flora around Saksunarvatn. Starting from 1%, it increases to 5%. *Ericaceae* go from 3% to 8%. The Ericaceous pollen has not been specified apart from *Calluna,* but probably includes mainly species of *Vaccinium. Dryopteris* has its Flandrian maximum – 17%. *Succisa* occurs for the first time. Two pollen of *Hedera* were found.

Number of taxa: 51, (6 pollen spectra).

Zone S 5

Depth. 15.00 – 28.50 m. Age 5800 – 3000 BP

Calluna – Juniperus – Poaceae – Cyperaceae

Poaceae and *Cyperaceae* lie at 40% and 20% respectively.

Calluna is almost steady at 5%. *Juniperus* decreases, but very slowly. In the lower part of the zone, two pollen grains of *Hedera* and three of *Ilex* were found.

Number of taxa: 61, (26 pollen spectra).

Table 2 gives a list of pollen and spores not drawn in the diagram, expressed as percentages of the total pollen and spore sum.

Total number of taxa from Saksunarvatn: 74 (45 pollen spectra).

Table 2. Pollen and spores from Saksunarvatn not drawn in the diagram, plate 1, expressed as percentages of total pollen and spore sum.

												Zone S 5							
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Land herbs																			
Ambrosia																			
Artemisia																			
Atriplex										0.2									
Botrychium		0.2				0.4						0.4				0.2			
Brassicaceae				0.7							0.2	0.2			0.4				
Caryophyllaceae	0.4	0.2	0.2	0.5				0.4			0.5	0.2	0.4	0.4		0.2	0.4		
Chenopodiaceae																			
Cystopteris																			
Epilobium						0.4				0.2									
Equisetum									0.2			0.2			0.5				0.
Galium		0.2																	
Geranium		0.2										0.2							
Hypericum																			
Koenigia																			
Labiatae					0.2		0.2		0.4		0.2		0.2		0.5				0.
Lotus																0.2			
Pinguicula																			
Polypodium																			
Pteridium		0.2																	
Rosaceae	0.4	0.9	0.2	0.5	0.4	0.4	0.5		0.2		0.4		0.2			0.5			0.
Sagina sp.				0.2															
Saxifraga sp.		0.2	0.2	0.2								0.2				0.2	0.2		0.
Saxifraga nivalis						0.2						0.2							
Saxifraga oppositifolia																			
Saxifraga rivularis						0.4													
Saxifraga stellaris						0.2						0.2							
Scrophulariaceae				0.2					0.2										
Sphagnum	1.6	2.9	1.8	0.4	1.4	1.8	0.7	1.4	0.5	0.4	0.7	4.8	1.6	0.2	0.2	1.8	2.0		2.
Thymus						0.2													
Urtica dioica																			
Indet.	0.2	0.9	0.4		0.5						0.5		0.7			1.4			0.
Corroded	1.3															0.2			0.
Aquatics																			
Callitriche																			
Eleocharis palustris																			
Isoetes echinospora														0.2	0.2	0.2	0.2		
Isoetes lacustris		0.2	0.2										0.2		0.7	0.2	0.4	0.4	0.
Menyanthes																			
Myriophyllum alterniflorum	0.2						0.2	0.2											
Potamogeton			0.2														0.5		
Trees																			
Alnus	2.9	1.4	1.1	0.5	1.8	1.1	1.3	1.8	2.2	1.4	1.4	1.4	1.3	0.7	1.1	0.5	0.9	1.6	1.
Corylus	2.0	4.5	1.1	1.4	2.3	0.5	2.7	1.3	3.1	1.3	2.7	2.2	2.0	1.1	4.0	1.8	1.8	1.6	2.
Fraxinus									0.2				0.2						0.
Hippophae																			
Quercus	0.2	0.2	0.2	0.5						0.2			0.4	0.4		0.4	0.4	0.4	
Picea																			
Pinus	1.8	0.7	3.4	0.4	0.5	0.5	1.3	0.5	0.5	0.5	0.7	0.7	1.4	0.2	1.1	0.5	0.7	0.5	1.
Tilia								0.2		0.2							0.4		
Ulmus	0.2		0.4	0.2	0.2	0.2				0.4		0.5	0.2	0.4		0.2	0.5	0.5	0.
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

							Zone S 4						Zone S 3					Zone S 2			Zone S 1				
0	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
																					0.2				
2															0.2					0.2			0.4	1.1	0.2
																								0.5	
2												0.4			0.2	0.2					0.2	0.2	0.2		
						0.4		0.2				0.2	0.2		0.5			0.2	0.4	0.7		2.0	0.9	0.7	
	0.2	0.4				0.4	0.2		0.2	0.2	0.2		0.2	0.2				0.2	0.2	1.1	1.3	0.4	0.4	0.4	0.5
																0.2									0.2
										0.2		0.2											0.4		
																	0.2								
	0.2	0.9		0.4	0.4					0.4			0.4				0.9	0.2					0.2		
2	0.2										0.4													1.1	0.2
																							0.2		
					0.2													0.2	0.2	0.2					
2			0.4		0.2		0.2													0.2		0.2			
														0.2											
									0.2																
								0.2						0.2	0.2		0.2								
2		0.5		0.4			0.4		0.2			0.2	0.2				0.2								
						0.2																	0.7	0.4	
2				0.2						0.2	0.2			0.2	0.5						0.2		0.2		
						0.2																0.2			
																			0.2			0.2	0.2	0.4	
																						0.2			
2																							0.7		
	0.2	0.2								0.4					0.3					0.2	0.2		0.2		0.2
0	1.4	1.8		2.7	2.7	2.0	1.4	2.5	0.7	1.4		1.4		0.2					0.2	0.4	0.5				0.7
																							0.2		
		0.5		0.9			0.4					0.4	0.4				0.2								
							0.7										0.5				0.2	0.4	2.3	0.7	
											0.2														
														1.6	0.2										
			0.2						0.2		0.4				0.2										
.5		0.5			0.2	0.7	1.1		1.3		0.4	0.4		0.2											
							0.2				0.5														
												0.2	0.2	0.4	0.2	0.4		0.4	0.4	0.4		0.5	0.2		
			0.4					0.4			0.4					0.2									
.5	1.1	3.1	1.6	2.3	0.9	1.3	1.4	1.4	1.1	0.9	0.4	1.3	0.7	0.5	0.5						0.4				1.1
.6	2.7	2.5	1.1	3.2	3.1	1.4	2.5	1.4	2.3	2.2	3.4	3.1	3.1	2.7	2.7	3.4	2.9	2.9	1.6	1.8	4.0	0.9	0.7	0.7	1.8
	0.2	0.2				0.2																			
																									0.7
	0.5		0.4	0.4	0.2			1.1	0.2	0.2	0.9	0.2	0.2		0.7				0.2						0.2
												0.2													
.1	0.5	0.2	0.7	0.7	0.9	1.6	2.0	1.4	0.7	1.4	2.3	1.6	1.8	1.6	1.4	1.8	3.6	2.9	2.5	4.8	3.8	4.7	1.8	2.7	1.6
.2				0.2								0.2													
.9	0.4	0.9	0.2	0.2	0.4	0.2	0.2	0.4	0.4	1.1	0.4	0.4		0.5	0.2	0.7	0.7	0.2	0.2		0.2				
0	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

Inferred vegetational history

The lowermost 2.75 m of the profile was devoid of pollen and spores, as mentioned earlier. This means that for a time, the area around Saksunarvatn was ice-free but carried no vegetation. Naked rock and moraines were the terrestric environment. We do not know how long this period lasted because no radiocarbon datings could be made on the material. The carbon content lay between 0.04–0.1% (measured at the radiocarbon dating laboratory by H. Tauber). The two lowermost samples which have been dated were from depths 31.27 and 32.06 m, respectively, and the difference in age was insignificant, indicating a high sedimentation rate.

Zone S 1

The first plant immigrants arrive. The number of taxa in the lowermost spectrum is only 16. However, some of these taxa, *Poaceae, Cyperaceae* and *Dryopteris,* represent many plant species. The plants we find are typical pioneer plants like *Sedum, Huperzia, Oxyria, Armeria* (the dimorphic form) and *Salix herbacea.* The soil has been base-rich and favourable to colonization. Evidence of an ice-free period without plants, mentioned above (the clay without pollen), suggests that the plants immigrated from neighbouring countries, but it cannot be stated conclusively whether or not some of them had survived the glaciation in the Faroes.

The widespread occurrence of *Betula nana* – a plant now extinct from the Faroes – is interesting. The percentage lies at about 25% of the total pollen sum and, in one sample, 40%. It has probably not had an areal coverage of that size. From Greenland it is known to be strongly overrepresented. Iversen (1947) has compared the pollen spectra of recent gyttja in two lakes at Godthåbsfjord with the vegetation around the lakes. He found that in lake 1, *Betula nana* was overrepresented with a factor of 4 and, in lake 2, with a factor of 2. Others (Fredskild 1973, Pennington 1979) have also found that *B. nana* is overrepresented in Greenland.

Nevertheless, there can be no doubt that *B. nana* had a wide distribution in the Faroes in the late Preboreal. The history of *B. nana* demands some consideration. It will be discussed on page 132.

Six pollen grains of *Hippophae* have been found. They are supposed to be long-distance transported.

Zone S 2

B. nana has probably disappeared completely. The increase of sedges which had already started in the preceding zone is strengthened and could indicate moister conditions. The grass heaths so well known today are being established. Still much bare ground is left – much more than today, as shown by the importance of *Sedum*. In the screes and rock fissures, species of *Dryopteris* were growing abundantly.

Zone S 3

During the Boreal and Atlantic, the grass heaths became the dominant plant community – at least with regard to pollen production. In the grass heaths of the Faroes today, the most important grass species are *Anthoxanthum odoratum, Deschampsia flexuosa, Agrostis tenuis, Festuca rubra* and *Festuca vivipara*. Further, the following plants are common: *Carex pilulifera, Carex binervis, Carex nigra, Luzula multiflora,* and *Leontodon autumnalis*. The composition of the Boreal grass heaths has probably remained the same until today, but from pollen analysis alone, we cannot be certain.

The high proportion of pollen of *Cyperaceae* was most likely due to *Carex echinata, Carex demissa, Carex nigra, Eriophorum angustifolium* and *Scirpus caespitosus,* all of which are extremely common in wetter areas today.

The most notable change in this zone is the rise of *Juniperus*. From this and other diagrams (Hoydalar, Jóhansen 1975) and Hovi (this paper) and from wood remains, it can be seen that *Juniperus* was widespread in the Faroes during the Boreal, Atlantic and Subboreal. This expansion must be taken as evidence of climatic amelioration, causing *Juniperus* to flower more profusely. This does not necessarily mean that the summer temperature was higher than today, as *Juniperus* grows as far north as Disko in Greenland, where the average temperature in the warmest month, July, is 8°C, while the Faroes today reach 11.1°C for Aug. (warmest month). But it must mean that the summer temperature was higher in this zone than in the two preceding zones.

The other herbs encountered are all common today, and climatically and edaphically they are rather indifferent.

Zone S 4

Calluna now came to the area around Saksunarvatn and attains 5% of total. This is not a sign of climatic deterioration, but indicates that leaching had now led to the formation of acid soils: peat and peat-like soils. *Calluna* in the Faroes clearly prefers southern and southwestern slopes. This is seen today in Saksunardalur where it grows in abundance on the SW slopes, but is lacking on the northern and northeastern side of the valley.

Juniperus has its Flandrian maximum in this zone, indicating favourable temperature conditions. It is, however, not possible to give any figures for the temperature.

A marked increase of *Sphagnum* spores (Table 2) shows that wet areas were spreading.

The other plants do not give any significant information about climatic or edaphic conditions. They were widespread during the entire Flandrian.

Zone S 5

During this long span of time – 2800 C-14 years – only small changes occur. The herb flora was surprisingly constant throughout the zone. It was a stable period where grass- and moorlands were widespread. *Calluna* has a small increase, indicating a steady expansion of moorland. The pollen percentage is low – max 11%. *Calluna* is pollinated by *Taeniopteris ericae,* a species of the Thrips group (Hagerup 1950) and may thus be underrepresented in the pollen rain.

Juniperus has been growing on drier hills and slopes, but never became important in Saksunardalur. The rather small percentages of *Juniperus* in the pollen diagrams from the Faroes including Hoydalar and Hovi (16% max, mostly lower, about 10%), are in contrast with the large quantities of *Juniperus* wood remains which occur in the Faroese peat from this period – Late Atlantic and Subboreal. Jessen (1923) mentions that *Juniperus* wood is found in all low-lying bogs, and that it has been found as high up as 375 m at Klaksvík. It has probably to some degree been sterile copses of *Juniperus* which have grown widely, and were overgrown by peat during the Subboreal. Three radiocarbon datings on *Juniperus* wood from Hvalba, Suðuroy, have been made and gave the following ages: 3380 ± 100 BP, 3660 ± 100 BP and 4210 ± 100 BP (K-999, K-1000, K-1001). The stems were twisted, and clearly the plants had the same prostrate growth as is known from the present *Juniperus communis nana.*

Four pollen of *Hedera* and three of *Ilex* in this and the previous zone (Plate 1) must be considered long-distance transported. From this profile, about 25.000 pollen grains have been counted which gives one *Hedera* pollen per 6.500 pollen grains, and one *Ilex* per 8.000 pollen grains. In comparison, Iversen (1944) found 32 pollen of *Hedera* per 10.000 pollen of trees. As the AP sum for the Atlantic period in Denmark will be very close to the total pollen sum, that means that one *Hedera* pollen was found per approximately 300 pollen grains in Denmark. From these figures, I find it unlikely that *Hedera* and *Ilex* were of local origin in the Faroes.

Further I have, among about 200.000 pollen from the Faroes, only found one *Hedera* pollen apart from these four from Saksunarvatn.

On the other hand, it can not be excluded that one or both of these plants were in fact growing near Saksunarvarn. In that case, the maximum summer temperature has been at least 2.4°C higher than today (Iversen 1944).

Hovi A

The locality at Hovi, Suðuroy, is a former lake which has been filled up, with the recent surface of the bog at 12 m a.s. It is situated in the Hovsdalur, a typical cirque valley (fig. 4) where the highest mountain is Borgarknappur, 574 m. The depth is 840 cm, and moraine was reached at the bottom. The diagram presented shows the pollen content from 100 cm, down to bottom at 840 cm. The material is gyttja from the bottom at 840 cm up to 280 cm, from 280 cm to 100 cm, brown herbaceous peat with *Equisetum* rhizomes. At the depth of 800 cm, there is a black, volcanic ash layer. This is the same as has been found at Hoydalar and Saksunarvatn, dated to 9140 BP and 9180 BP (both ± 160) respectively. This layer has been found in many places in the Faroes (unpublished) and has been petrographically described (Waagstein & Jóhansen 1968). Because a Hiller sampler was used, no samples for C-14 datings were taken.

The pollen diagram

The pollen diagram has been divided into four pollen assemblage zones, Hovi A 1–4 (Plate 2).

Hovi A 1. Depth 780–840 cm

Betula – Huperzia selago – Sedum

Betula ca. 20%, *Huperzia selago* 20–40%, *Sedum* about 14%, decreasing to 4% at the upper part of the zone. *Salix (herbacea?)* lies at 10% at the bottom, but decreases to 5%, and is under 0.5% at the end of the zone. *Caltha, Apiaceae, Dryopteris* type, *Poaceae,* and *Cyperaceae* are all represented with 6–9%. *Myriophyllum alterniflorum* has a maximum of 28%.

Number of taxa: 41, (7 pollen spectra).

Zone Hovi A 2. Depth 690–780 cm

Poaceae – Cyperaceae – (Empetrum – Ericales)

Cyperaceae and *Poaceae* increase to about 20–25%. There is a fall in *Huper-*

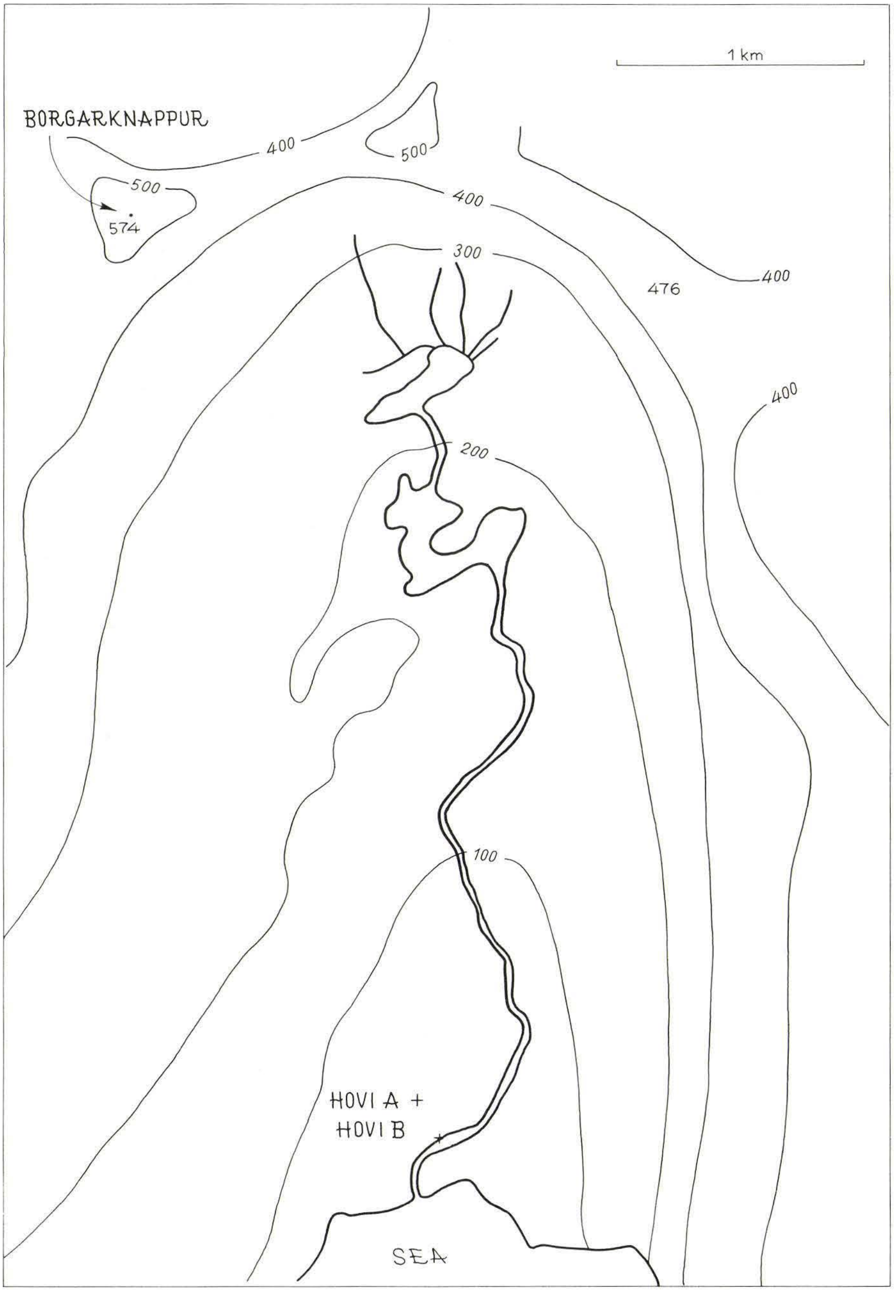

Fig. 4. Hovsdalur.

zia, Sedum, Caltha and *Apiaceae,* and *Myriophyllum alterniflorum.* A remarkable feature is the large amount of *Empetrum, Calluna* and *Ericaceae* pollen. It must be considered of secondary origin – probably from some unknown interglacial deposit which has now disappeared. The occurrence of *"Hystrix"* also points in that direction.

Number of taxa: 34, (6 pollen spectra).

Zone Hovi A 3. Depth 360–690 cm

Poaceae – Cyperaceae – Juniperus – Salix

Dominating are *Poaceae* and *Cyperaceae,* about 30% each. *Juniperus,* which was introduced in the preceding zone, lies at 5–6% throughout zone 3. The *Salix* pollen curve is rising again after the minimum in zone 2. It is considered to be pollen of *Salix phylicifolia,* the leaves of which have been found. The percentages lie at 5%. *Filipendula* increases to about 17% and is important throughout this and the next zone. *Dryopteris* and *Apiaceae* lie at constant levels, 4% and 8% respectively. *Isoetes echinospora* and *I. lacustris* have their maxima in this zone, and are almost totally lacking above and below.

Number of taxa: 45, (11 pollen spectra).

Zone Hovi A 4. Depth 100–360 cm

Ericales – Poaceae – Cyperaeceae

In this zone we have a rise of *Ericales* pollen. At this time, the pollen is local and contemporary, quite analogous with the development at Hoydalar and Saksunarvatn. *Salix* is still important, while *Juniperus* decreases.

Number of taxa: 39, (12 pollen spectra).

Total number of taxa at Hovi A: 74, (34 pollen spectra).

Table 3 gives a list of pollen and spores not drawn in the diagram, expressed as percentages of the total pollen and spore sum.

Inferred vegetational history

Zone Hovi A 1

The oldest part of the diagram corresponds closely to the diagrams from Saksunarvatn and Hoydalar (Jóhansen 1975). Also at Hovi, a pioneer vegetation with *Huperzia, Sedum, Salix herbacea* has prevailed in the Preboreal. *Betula nana* has been growing all over the Faroes during this period. I have found large quantities of B. nana pollen at *Hovi, Hoydalar, Saksunarvatn* and *Havnardalur* (unpublished, see map, fig. 1.). I have not found macrofossils, as

Table 3. Pollen and spores from Hovi A not drawn in the diagram, plate 2, expressed as percentages of the total pollen and spore sum.

	Hovi A 4												Hovi A 3						
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Land herbs																			
Ambrosia																			
Armeria		0.2																	
Artemisia	0.2			0.2						0.2									0.
Atriplex																			
Botrychium															0.2				
Brassicaceae			0.7	0.4	0.2				0.2		0.4		0.2	0.4	0.5		0.2	1.4	
Caryophyllaceae	0.9	1.6			0.2	0.4	0.2	0.4		0.2			0.2	0.2		0.2			0.
Cystopteris		0.2																	
Epilobium																			
Equisetum	1.1	0.4	0.4		0.2		0.2			0.2		0.4			0.2			0.7	0.
Geum	0.2																		
Hypericum														0.2					
Koenigia																		0.2	
Liguliflorae		0.7	0.4	0.4	0.4		0.2				0.2						0.2	0.2	0.
Ligusticum														0.2				0.2	
Liliaceae								0.2											
Lotus													0.2						
Lycopodium alpinum		0.2		0.5															
Plantago lanceolata								0.2											
Polypodium	0.5	1.3	0.5	0.9	0.4	0.4	0.2	0.9	0.5	0.5	0.9	0.2		0.5	0.5				0.
Rhinanthus															0.2				0.4
Rosaceae				0.5		0.4													
Sagina																			
Saxifraga nivalis														0.5					
Saxifraga oppositifolia															0.2	0.2			
Saxifraga rosacea	0.2		0.2											0.4					
Saxifraga stellaris																			
Saxifraga sp.																			
Scrophulariaceae		0.2	0.2											0.4	0.2	0.4			0.
Selaginella			0.2					0.2											
Thalictrum				0.2					0.2		0.4				0.2				
Tubuliflorae			0.2										0.2						
Urtica																			
Concealed	1.1			0.2															
Corroded			0.5	0.2							0.2			0.2					0.
Indet.		0.4																	
Aquatics																			
Callitriche														0.7		0.2	0.2		
Eleocharis palustris	1.4								6.6	4.1		0.9	1.8		4.9	5.6		1.4	3.2
Menyanthes		0.2			0.4					0.2									
Potamogeton							0.4				0.5		1.1	2.2		0.2	0.7	0.7	0.
Sparganium												0.2							
Trees																			
Acer		0.2																	
Alnus	0.5	1.6	0.4	0.4	0.2	0.2	0.5	1.1	1.1	1.6	0.4	0.5	1.6	0.7	0.4	0.7	0.2	0.9	1.
Corylus	0.5	0.7	0.7	0.5	0.2	1.1	1.1	1.4	1.4	1.8	0.9	1.4	0.9	2.2	2.3	2.0	1.4	0.2	1.
Fraxinus													0.2						
Pinus	0.9	1.3	0.2	0.5	1.3	1.5	1.3	0.7	1.1	1.1	0.4	1.4	0.7	0.5	0.9	0.5	0.7	0.9	0.
Populus																			
Quercus	0.7	0.2		0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.4	0.9	0.4	1.4	0.2	0.7	0.7	0.
Sorbus								0.2											
Tilia												0.2				0.2			
Ulmus		0.2			0.2					0.2	0.4	0.4	0.4	0.4	0.4	0.5		0.7	0.
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

			Hovi A 2						Hovi A 1				
21	22	23	24	25	26	27	28	29	30	31	32	33	34
										0.2			
		0.2							0.4			0.4	0.2
									0.2	0.2			0.2
					0.2				1.3	0.5	0.4	0.4	0.7
0.2					0.2		0.2		0.7	0.4	0.2		1.1
		0.4	0.1		0.1		0.1		0.5	0.2	1.3	0.7	0.4
		0.2	0.2	0.2		0.2		0.2		0.2		0.5	0.4
0.2	0.7	0.4			0.2	0.2							
										0.2			0.2
									0.4	0.2	0.5	0.5	0.7
0.2	0.2		0.2								0.2	0.2	
						0.2	0.2					0.5	
0.2	0.2			0.2	0.4		0.4						0.2
	0.2		0.4	0.4		0.5		0.2	0.2		0.2	0.2	0.2
		0.2											
					0.2				0.2	0.7	1.4	0.7	0.5
													0.5
													0.2
													0.2
													0.4
									0.2	0.2		0.4	0.2
		0.2									0.2	0.5	
	0.2	0.2	0.2										0.5
	0.2					0.2	0.4						0.5
			0.7					0.2	1.3			0.2	
						0.4	1.3	0.2		0.2	0.7		0.4
									0.4			0.2	0.5
												0.5	
3.6	1.3	5.3		0.5									
0.2		0.2											
0.5	0.9	1.1	0.2	0.2	0.2	0.5		0.2					
1.4	0.5	3.6	6.3	3.5	2.9	2.0		0.7			0.5		
									0.2				
0.9	2.5	2.3	2.2	1.8	1.3	1.3	1.3	1.3		2.2	1.8	0.9	3.1
													0.2
0.2	0.4	0.9	0.2										
	0.2												
0.2	0.7	0.4	0.5		0.5	0.4	0.2	0.2					0.2
21	22	23	24	25	26	27	28	29	30	31	32	33	34

the material was obtained by coring, which did not yield very large samples. See discussion of *Betula nana* on page 132.

Zone Hovi A 2

With respect to the contemporary vegetation, this zone is identical with zones S 2 and H 3 (Hoydalar). The grasses and sedges became dominant. The remarkable thing in this zone is the large amount of *Empetrum* and *Ericales* pollen-tetrads. As mentioned, the cysts of Dinoflagellates, called *Hystrix* are also found. None of these can be of primary origin, but must have been washed out from older deposits. There are Tertiary deposits in the mountains around Hovi – the Coal bearing Sequence (Rasmussen & Noe Nygaard 1969). The pollen and microorganisms in this zone might perhaps be of Tertiary age, but the almost complete absence of Conifer pollen does not make a Tertiary origin very likely. It should probably be referred to some interglacial deposit which has now disappeared or, at any rate, is not known.

Zone Hovi A 3

During this period, the Faroe Islands have had the most extensive cover of shrubs of any time since the last glaciation. Just as at Hoydalar and Saksunarvatn, *Juniperus* has its maximum occurrence. Even though there are no C-14 datings here, this zone is broadly synchronous with S 3–5 and H 4: 9.000 – 3.000 BP. *Juniperus* has grown on all drier habitats in the Hovi valley. Wood remains are very common in the peat layers here, and are found up to heights of 200 m. On more moist soil and along the riversides, *Salix phylicifolia* has grown. Large quantities of leaves have been found in the deposit at Hovi, and fossil *S. phylicifolia* has been found by Jessen and Rasmussen (1922) and Rasmussen (1948). This plant has thus been very common in the Mid Flandrian. As is seen in the Hovi B diagram, it suffered a severe decrease when people settled at Hovi and, today, is restricted to a few localities (Hansen 1966).

A few pollen grains of *Sorbus* and *Populus* have been found both at Hoydalar and Saksunarvatn as well as Hovi. It is very difficult to draw definite conclusions from a few pollen grains (cfr. *Ilex* and *Hedera* at Saksunarvatn) but taking into account the fossil and recent record of it from Shetland (Jóhansen 1975, Spence 1979) and recent from Iceland (Grøntved 1942), they might be expected in the Faroes. During this period there was also an expansion of tall herb communities where *Filipendula ulmaria* was dominant. *Caltha,* members of *Apiaceae* and ferns of *Dryopteris* type were also important.

Zone Hovi A 4

The edaphic changes which are seen in other parts of the Faroes at this time (ca. 2.000 BC) are also seen at Hovi. *Calluna* is slowly increasing to about 10%. Other *Ericaceae* pollen are also increasing. This is a sign of acidification of the soil. However, willow shrub and the tall herb vegetation persisted during the rest of the time represented in this diagram, and exist until people arrived at Hovi in the Viking age (Diagram Hovi B, Plate 3).

To conclude the Hovi A diagram, it can be stated that, while confirming results from Hoydalar and Saksunarvatn, it displays some differences, especially the great importance of willow and tall herb communities.

Hovi B

The uppermost part of the Hovi profile, Hovi B, is from an open section. The length of the profile is 100 cm and the material is herbaceous peat. The age of the bottom of the profile is 1350 BC, and the top is of the present day. No attempts have been made to divide the diagram into assemblage zones. I have only drawn one horizontal line, which I call the landnam horizon. The date of this horizon is approximately AD 900. The radiocarbon datings are corrected according to Clark (1975), Table 4.

Table 4. The radiocarbon datings from Hovi B. Calibration according to Clark (1975).

Hovi B		
K–2659	2–6 cm $C^{13} = -25.5‰$	1.12% of modern
K–2950	20–22 cm $C^{13} = -26.6‰$	580 ± 65 BP AD 1385 Cal.
K–2951	32–36 cm $C^{13} = -26.4‰$	910 ± 70 BP AD 1060 Cal.
K–3067	39–40 cm $C^{13} = -25‰$	1190 ± 70 BP AD 770 Cal.
K–2952	60–62 cm $C^{13} = -24.9‰$	1770 ± 75 BP AD 235 Cal.
K–2953	80–82 cm $C^{13} = -25.0‰$	2330 ± 80 BP BC 440 Cal.
K–2660	97–100 cm $C^{13} = -23.8‰$	3040 ± 80 BP BC 1350 Cal.

The pollen diagram

The lowermost part of the diagram (Plate 3), is a continuation from Hovi A. *Juniperus* lies at 5%, but decreases slowly and, after 400 BC, it only occurs sporadically. *Salix (phylicifolia)* also decreases at the boundary between Subboreal and Subatlantic. This is an indication that we also have a climatic deterioration in the Faroes at the Subboreal-Subatlantic transition. The tall herb communities were still widespread. These communities consisted of *Angelica silvestris, Archangelica officinalis,* and ferns which cannot be identified, but *Dryopteris* and *Athyrium* were probably the most common. *Sedum,* most probably *S. roseum,* was common and so were *Filipendula* and *Caltha. Polypodium* was growing on the drier hills around the bog. On the bog surface, grasses and sedges dominated.

The landnam and the period afterwards

I have placed the landnam horizon at the level where *Plantago lanceolata* occurs for the first time. This happens sometime between AD 850 and 900, i.e. Viking age. This is in very good accordance with written sources, namely the Icelandic Færeyingasaga. There, it is stated that Hovi is a Viking age settlement, where one of the Norse chieftains, Havgrímur, lived. The first Norse colonization in the Faroes is generally supposed to have taken place about AD 825.

Barley (*Hordeum*) pollen is not found until the level of Medieval age. Where the fields were placed is not known, but they have probably been in the oldest part of the present village, which lies 1 km away from the bog. There was no cultivation near the locality until much later, and the bog today is still uncultivated, being used as pasture for sheep.

Plantago lanceolata pollen is found in Faroese deposits from about AD 600–650 (Tjørnuvík and unpublished results) and indicates the arrival of the first inhabitants, as it is always found together with cereals and other anthropochorous plants, e.g. *Rumex obtusifolius* and *R. longifolius.* Being a wind-pollinated plant, it appears very quickly in pollen samples and is therefore a good indicator of the first settlements. Another indication of settlement AD 600 in the Faroes was found at Mykines (Jóhansen 1979). But at Hovi, it is not found before AD 850–900.

The changes in the natural, spontaneous vegetation at Hovi were profound. The tall herbs were almost exterminated from the vicinity in a very short time. The members of Apiaceae disappeared, *Sedum roseum* could not withstand the extensive grazing which now began, and is today only found on cliffs and gorges which are impassible for sheep.

Caltha was widespread in the Faroes from the beginning of the Preboral. This is seen at this locality, diagram Hovi A, and also at Hoydalar. In Saksunarvatn, *Caltha* pollen is not found in the lowermost samples, but from about 9500 BP, it was also established there. It was very common at Hovi – up to 10% of the total pollen during the time up to the landnam, where it suffered near extinction. The leaves of *Caltha* are very attractive to sheep and cattle and where they have access to the plant, they will browse on it and very soon destroy it. Today *Caltha* is one of the most conspicuous plants in the Faroese meadows, where it flowers from the end of May to the beginning of June. These meadows are kept free from sheep during the summer by enclosures. If this was not the case, *Caltha* would be one of the first plants to succumb. This was actually the case at Hovi where *Caltha* was not protected from sheep and cattle, which the Norsemen brought with them. In wet places where sheep cannot reach it, *Caltha* can still be found in natural habitats as far up as 450 m (Rasmussen 1923).

Filipendula ulmaria behaves in the same way as *Caltha.* Very shortly after the landman, it was exterminated at this locality. Today it is found here and there (Hansen 1966). The large fluctuations of *Calluna* and *Ericaceae* and *Empetrum* are remarkable, but so far I have no explanation for them. The fluctuations are probably caused by very local changes in the conditions on the bog surface.

Remarkable also is the rise of *Potentilla* above the settlement level. I suppose it is *P. erecta,* which is so common today, but *P. palustris* is also found at Hovi even if it is rare in the Faroes (Hansen 1966). The rhizomes of *Potentilla erecta* have been used for tanning leather. It has been dug at all villages almost up to the present day. It is strange that it did not suffer more seriously from all this collecting, but the fact is, that it is one of the most widespread plants in the Faroes today (Hansen 1966). Also in Tjørnuvík (Jóhansen 1971), *Potentilla* rises after the landnam.

Rumex acetosa has also a distinct rise above the landnam horizon, but falls quickly and is of no importance later. Even if *Rumex acetosa* most probably is a native species, it seems to be favoured by man. Note however the difficulty in separating *Rumex acetosa* and *Oxyria* mentioned earlier. It is not attractive to sheep due to its acid taste. During the Medieval age and up to the present day there are no large fluctuations. There are no signs of cultural recession in the 14. century. The plague, which according to tradition – but not historically proved – devastated the Faroes in 1348–50, has not left any mark in this diagram and may very well never have reached the Faroes. The *Hordeum* pollen curve begins at this level and has its maximum about 200 years later.

Summary and conclusion

The oldest known flora in the Faroes after the last glaciation is of Preboreal age. No Late Weichselian deposits have been found. The vegetation was a fell field vegetation with hardy species. It can thus be stated that the first flora, although Preboreal of age, is quite analogous to the Late Weichselian flora of the southern neighbouring countries. *Betula nana* immigrated in the middle of the Preboreal , but disappeared already at the end of the zone. The history of *Betula nana* shall be discussed in some details.

Betula nana was widespread during the Late Weichselian in Northern Europe. The immigration of *B. nana* to the Shetland has been dated to about 10.400 BP and to the Faroes about 9.500 (Jóhansen 1975). Dates are lacking from Iceland, but to East Greenland it arrived about 8.000 BP (Funder 1978). With these dates it is clear that it has immigrated from Great Britain and/or Scandinavia to the North Atlantic islands and Greenland.

The reason for the extermination of *Betula nana* in large areas in Europe was the expansion of forests. This explanation is, however, not valid for the Faroes (nor for Shetland and the Outer Hebrides). In these areas there have never been real forests – only copses and groups of trees here and there and, in the case of the Faroes, only shrubs of willow and juniper. Edaphically, *B. nana* is very tolerant. It grows mostly on peaty soils, but in the Late Weichselian the soils were unleached and mineral, and it still grows on mineral soils f.ins. in Teesdale (Godwin 1975). The only explanation seems to be a change from a subarctic, continental climate towards oceanic conditions.

When we look at the present distribution of *Betula nana* in the North Atlantic (fig. 5), it is remarkable to see that the dwarf birch has disappeared from all of the most oceanic areas, where it was widespread in the Late Weichselian. It is extinct in Ireland, the Outer and Inner Hebrides, the Orkneys, Shetland and the Faroes. In the Scottish Highlands, it is uncommon in the western parts (Perring and Walters 1962). In Norway it is extremely common in the continental parts, but fades out to the oceanic southwest (Nordhagen 1943). It is common all over Iceland (Grøntved 1942). Concerning Greenland, it is found at Scoresbysund on the eastern coasts and, on the western coasts, from Godthåbsfjord to Disko. It is by all authors (e.g. Sørensen 1933, Trapnell 1933, Gelting 1934, Böcher 1938) characterized as a strictly continental plant, which avoids the coastal areas.

In the Faroes, *B. nana* must have grown under continental conditions, with cold winters and mild summers in zone S 1 and Hovi A 1. The peak of *Myriophyllum alterniflorum* in this zone both at Hovi and Hoydalar suggests higher summer temperatures than in the later zones. There can be no doubt that there was a great deal of ice left in the sea around the Faroes, and

Fig. 5. Recent distribution of *Betula nana* in Northern Europe and part of Greenland.

probably also on land in the Preboreal, which caused low winter temperatures. The overall climatic amelioration in the Preboreal, together with the sea ice, thus created conditions for *Betula nana* in the Faroes. The rather sudden decline of *B. nana* is remarkable. The reason must be that dwarf birch has lived in a very delicate equilibrium with the surroundings, especially the climate. When the threshold was exceeded by, e.g. milder winters with no continuous snow cover, which is important for *B. nana,* and unstable springs and cooler summers, the consequences for this plant were catastrophic.

During Boreal, Atlanticum and Subboreal a vegetation of shrubs grew very widely in the lowland. This scrub was first and foremost represented by

Juniperus communis. Also willow, *Salix phylicifolia* was very common. Possibly scattered stands with *Populus (tremula)* and *Sorbus (aucuparia)* occurred, but the pollen evidence is not strong as mentioned on page 128. The same is the case with *Hedera* and *Ilex.* They are both westerly, oceanic plants and a few pollen of them have been found at Saksunarvatn so they may have grown in the Faroes. This is discussed on page 128, where the pollen grains are considered long distance transported, although no definite conclusions are drawn.

Far the largest amount of pollen comes from grasses and sedges. Grass heaths have been the dominant plant community in the Faroes from the Boreal. Moorlands evolved from the same time but especially from the Atlantic onwards they became widespread. *Calluna* became important on drier slopes, while on wetter ground different species of Cyperaceae: *Carex, Scirpus* and *Eriophorum* dominated. Together with these communities, pollen of many tall herbs indicate a vegetation of base rich flushes e.g. *Filipendula, Caltha, Angelica, Archangelica.*

About AD 600–650 there is the first evidence of man's arrival. This evidence has been published previously (Jóhansen 1971, 1978). These people were after all probability Irish hermits. In Mykines it could be demonstrated that they cultivated *Avena.* In the present work the first landnam indication is from Viking age, AD 850–900 as demonstrated in the Hovi B diagram. The Norsemen cultivated *Hordeum* which was demonstrated with reasonable certainty in the above mentioned work from Mykines. (There was a clear change from *Avena* cultivation at 600–650 to *Hordeum* cultivation some time later, dates on the start of *Hordeum* cultivation could however not be obtained). During Medieval age up to recent time the only corn was *Hordeum.*

The influence of the inhabitants with their sheep and cattle on the original vegetation was profound. The scrub disappeared almost completely, likewise the rich tall herb vegetation. They are today only found in sheltered places which are inaccessible to the sheep. Together with man also many new plants were introduced: *Plantago lanceolata,* which is quite naturalized (Hansen 1966), *Rumex longifolius, R. obtusifolius, R. crispus* and many ruderals which only grow at or near villages.

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Dansk Sammendrag

Med de tre pollendiagrammer, der præsenteres her og dem, der tidligere er publiceret fra Færøerne, har vi nu et forholdsvis godt overblik over vegetationsudviklingen siden sidste istid. Senglaciale aflejringer kendes ikke. Først fra Præboreal findes den første pollenflora.

For 10.000 år siden voksede der en fjeldurtsflora med pil (*Salix*), stenurt (*Sedum*), og andre. Lidt senere omkring 9.500 før nu, var der en kort periode med dværgbirk (*Betula nana*). Fra Boreal og op til i dag var græsser og halvgræsser dominerende. Af træagtige vækster blev ene (*Juniperus*) sammen med pil (*Salix phylicifolia*) de vigtigste. I Atlantikum blev hedelyng (*Calluna*) fremtrædende. Omkring 600 e.Kr. skete der et landnam, som formodes at være foretaget af irske munke. I Hovi skete det dog først i vikingetiden omkring 900 e.Kr. Foruden de tidligere nævnte planter, var der en flora af høje planter: mjødurt (*Filipendula*), skærmplanter, store bregner, engkabbeleje (*Caltha*), og potentil (*Potentilla*). Næsten alle disse planter gik kraftigt tilbage ved landnamet undtagen potentil. Lancet vejbred (*Plantago lanceolata*), og ukrudtsplanter som f.eks. skræpper indførtes. Mens de første indbyggere – irske munke – dyrkede havre, indførte vikingerne bygdyrkning.

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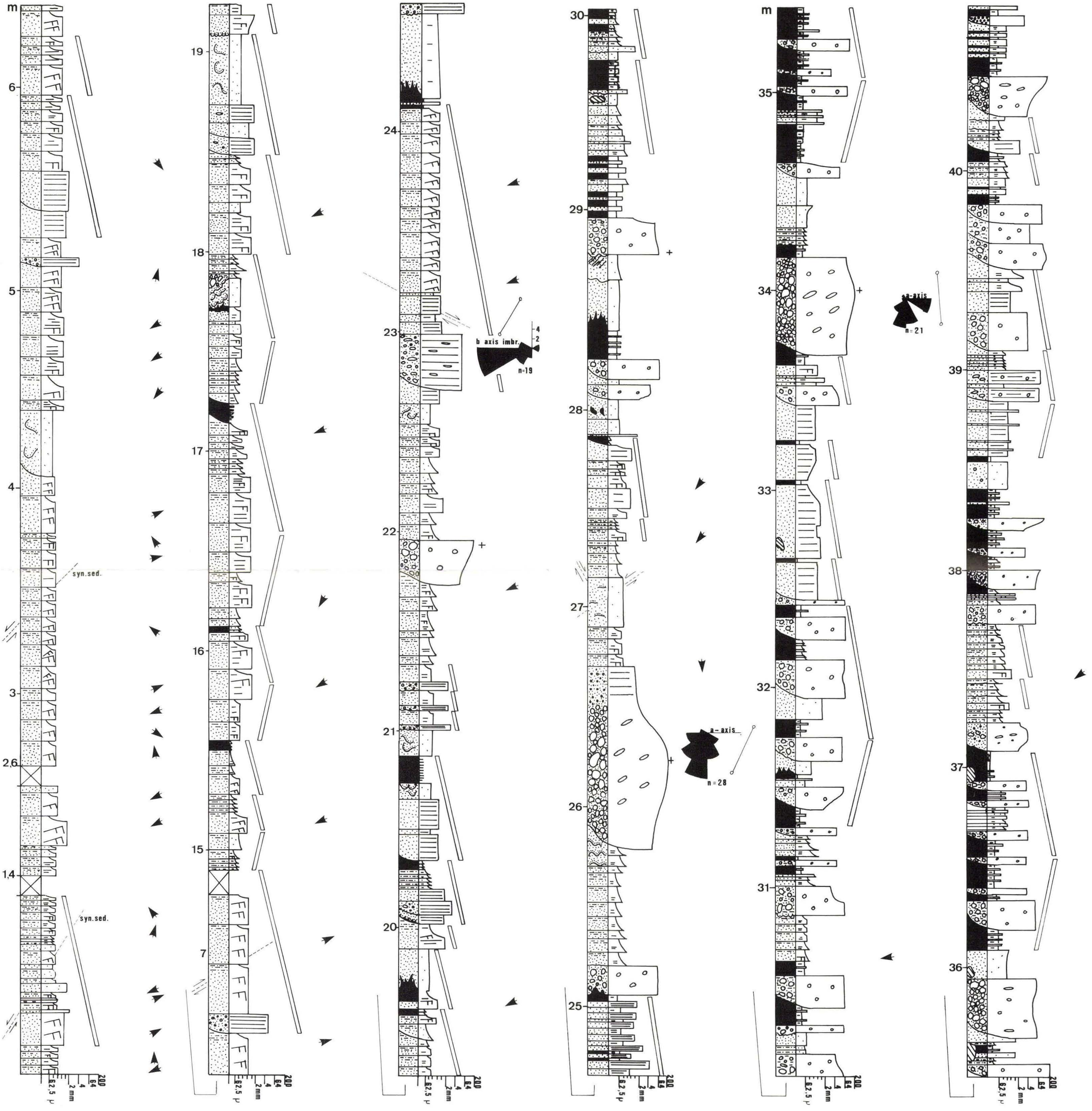

PLATE 1

NIELS BALSLEV JØRGENSEN 1980

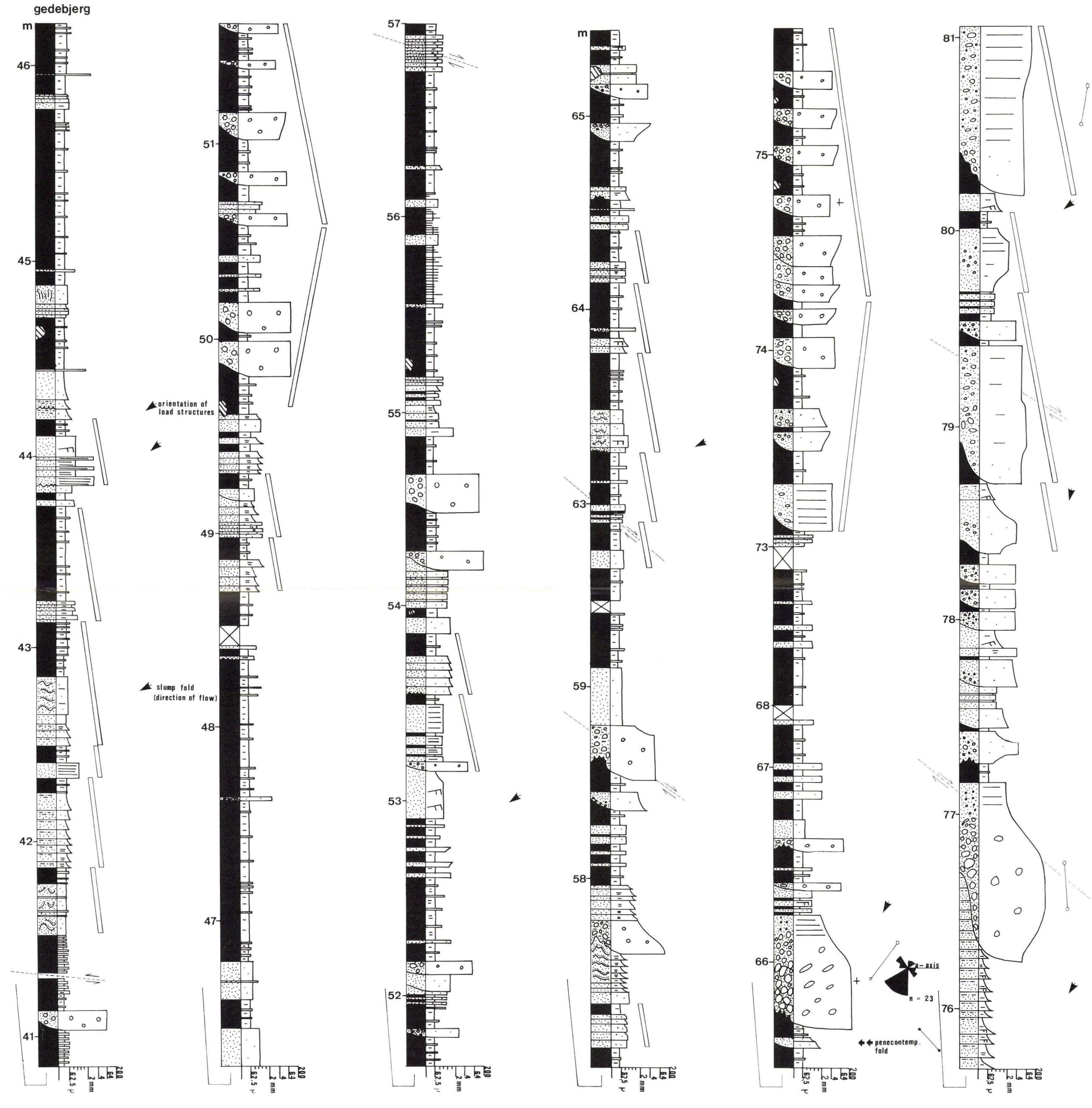

PLATE 2

NIELS BALSLEV JØRGENSEN 1980

gedebjerg

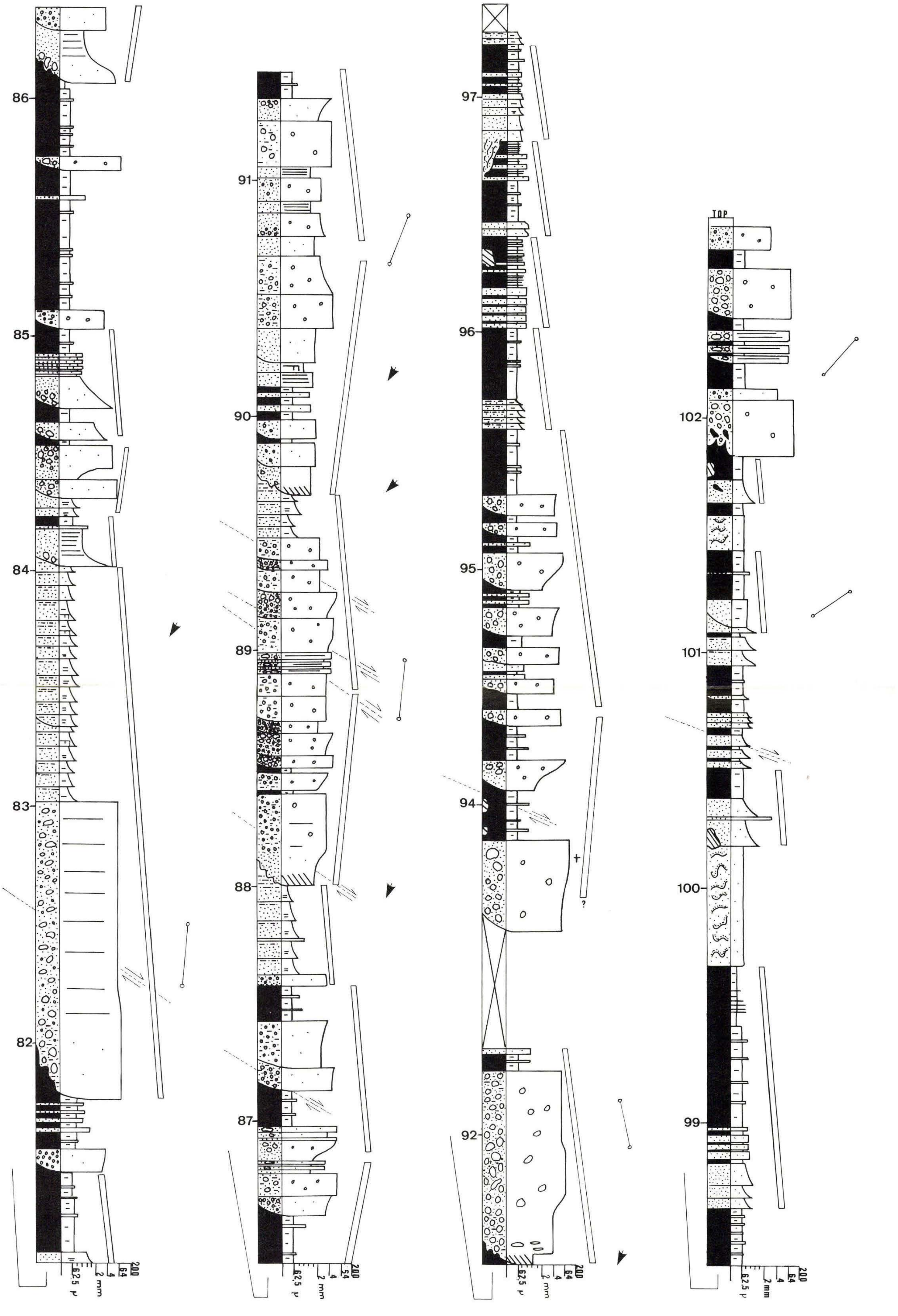

PLATE 3

NIELS BALSLEV JØRGENSEN 1980

SAKSUNARVATN, FAROE ISLANDS

GEOLOGICAL SURVEY OF DENMARK

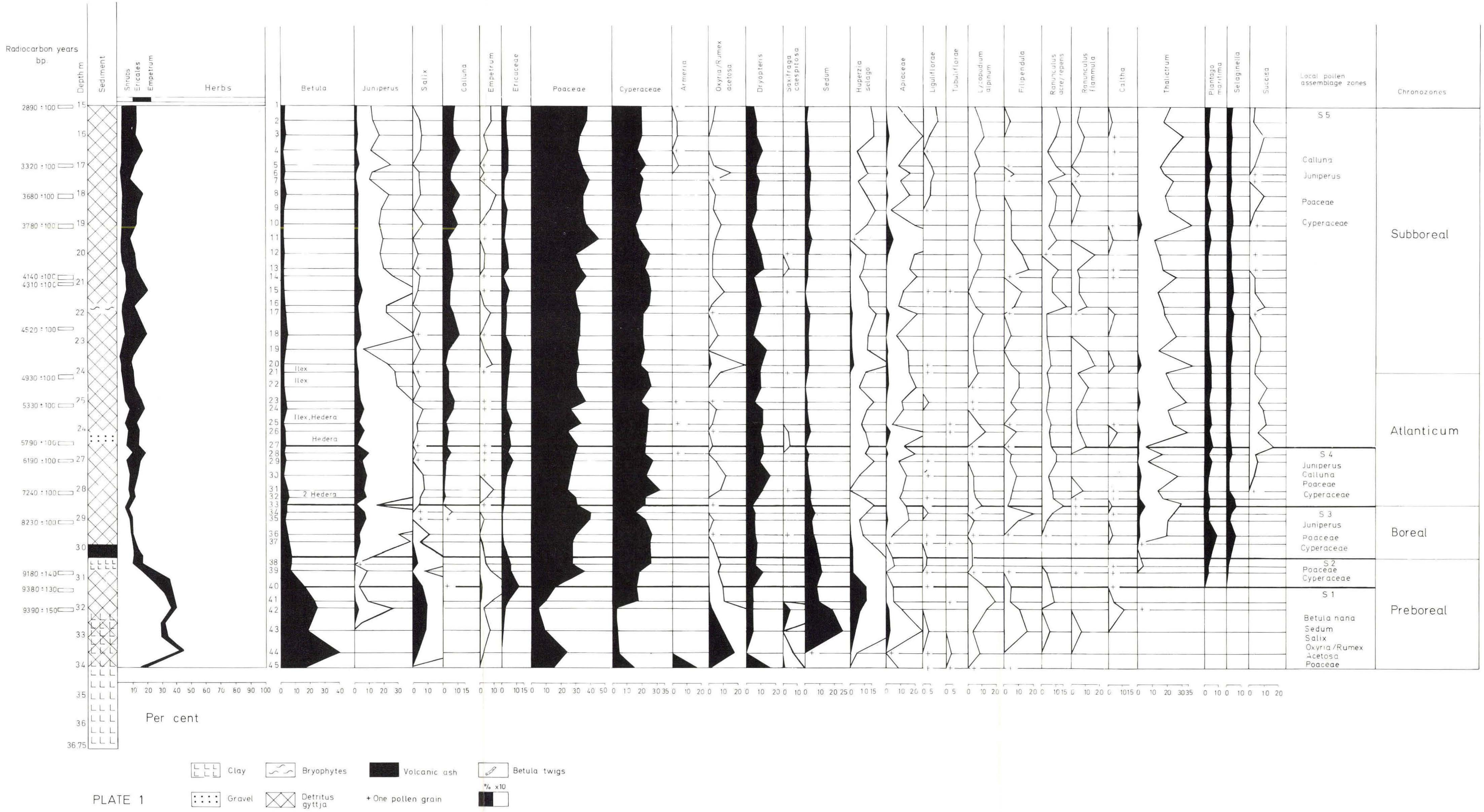

PLATE 1

HOVI A FAROE ISLANDS

GEOLOGICAL SURVEY OF DENMARK

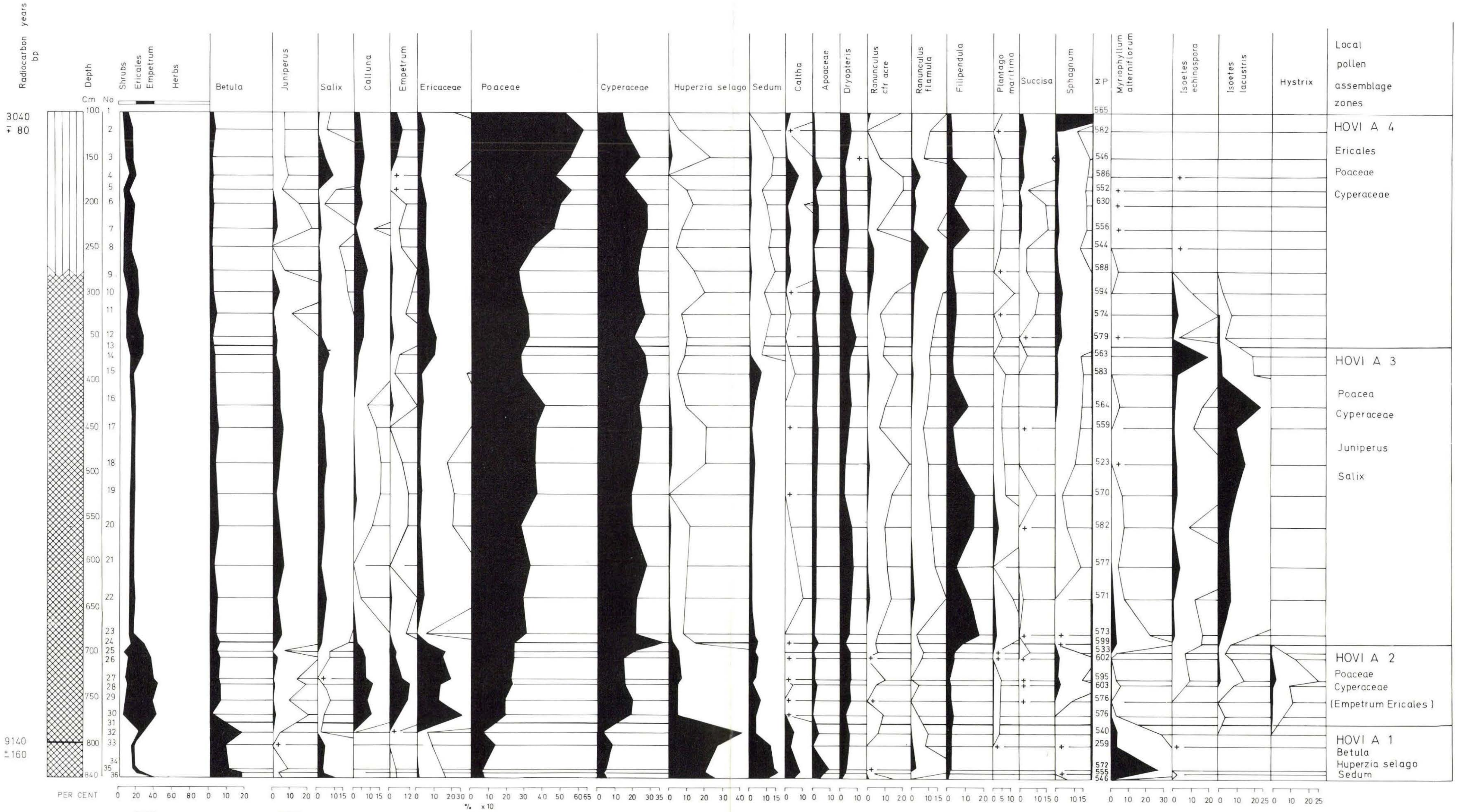

PLATE 2

▨ DETRITUS GYTTJA

▦ HERBACEOUS PEAT

▩ VOLCANIC ASH LAYER

\+ ONE POLLEN GRAIN

HOVI B, FAROE ISLANDS

GEOLOGICAL SURVEY OF DENMARK

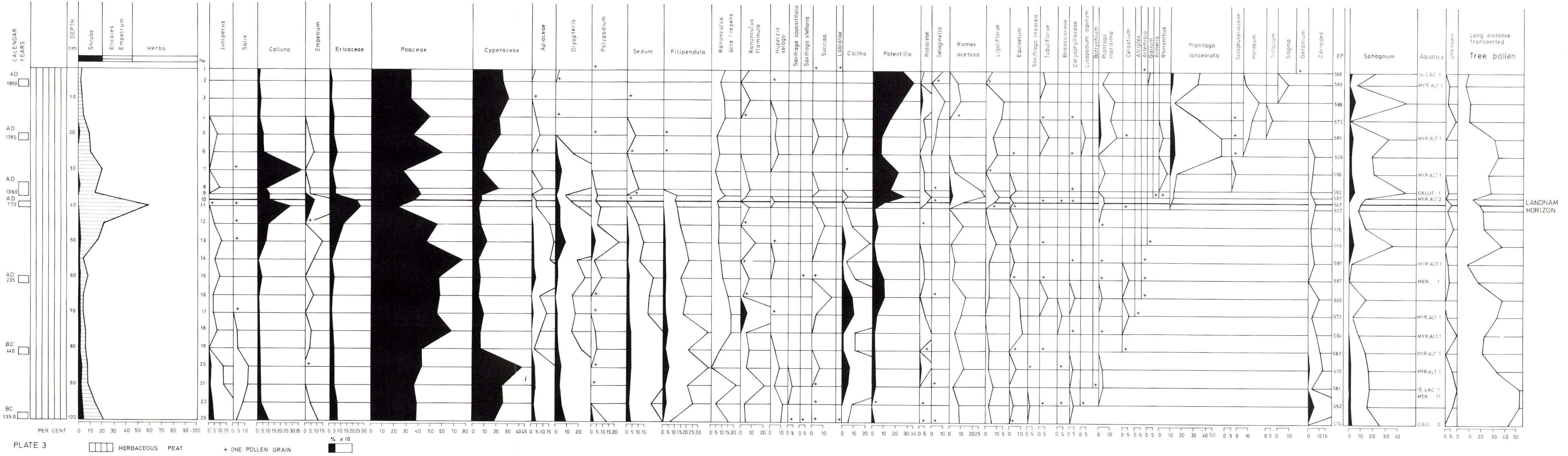

PLATE 3