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Changes in biotic conditions and metal deposition in the last millennium as reflected in ombrotrophic peat in Draved Mose, Denmark

Bent Aaby and Jens Jacobsen

Aaby, B. and Jacobsen J. 1979: Changes in biotic conditions and metal deposition in the last millennium as reflected in ombrotrophic peat in Draved Mose, Denmark. *Danm. geol. Unders., Årbog 1978*, pp. 5-43, pls. 1-3, København. 1979.

Surface samples of *Sphagnum magellanicum* and samples from peat columns in a profile from the raised bog Draved Mose, Denmark, have been studied to illuminate palaeobotanical changes and past and present deposition rates of metals. A *Sphagnum imbricatum* sociation dominated extended areas of the bog in the Middle Ages, whereas it is not found at present. The extinction of the sociation is closely related to the formation of hummock and hollow structures. In hollow areas the eradication was related to increased wetness while increased dryness caused the extinction on hummocks. Surface samples were separated into annual layers, and increment and dry matter production were calculated. The exposure of the *Sphagnum* patches to the prevailing wind direction has a considerable influence on increment rates and dry matter productivity. The possibility of using the metal-uptake in the annual peat layers as a recorder of the present deposition rate has been evaluated. Some trace metals and Mg seem to be sorbed and retained in quantities reflecting the present deposition level. Cs-137 and tritium-analyses have been used to elucidate the leaching process in the bog. Based on C-14 dates and the chemical composition of the peat columns, the mean annual storage of elements (A.D. 1300-1973) has been calculated. The relations between storage and past deposition rates are discussed.

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Knowledge about the present deposition of macro- and microelements has greatly increased due to a growing interest in their effects on man and his environment. While a number of different analytical methods are available for measuring the present deposition of elements, it is more difficult to obtain information about previous deposition levels. Only a few sources furnish such data; thus herbarium material of lichens collected back to A.D. 1882 has been analysed (Persson et al. 1974). Recently, peat bogs have attracted attention in this respect because they contain a huge amount of organic matter accumulated chronologically over decades. The ombrotrophic type of peat bog is especially suitable as precipitation and atmospheric dust provide the only sources of nutrient supply. Knowledge of the deposition mechanism and the movement of elements within deep peat deposits is still rather scarce (Damman 1978), and these informations are essential for determining the amount of chemical elements deposited in the past.

The chemical composition of peat has previously been studied from different points of view. Superficial peat samples have thus been analysed to determine the concentration of trace elements (Rühling and Tyler 1971; Tyler 1972; Pakarinen and Tolonen 1976a, 1976b; Sonesson 1973), Clymo (1965) studied the rate of organic matter loss in relation to water level and peat composition, and local vegetational changes related to the chemical environment during bog development were illuminated by e.g. Chapman (1964) and Tallis (1973).

The vertical distribution of trace elements in ombrotrophic bog profiles was studied by e.g. Tanskanen (1972), Sillanpää (1972), Pakarinen and Tolonen (1976), Lee and Tallis (1973) and Damman (1978). It was shown that some leaching or translocation takes place, but the leaching ability of the various elements seem to differ (Rühling and Tyler 1970). There are contradictory observations regarding the vertical distributions of e.g. lead in *Sphagnum* peat. A maximum in the surface layer was reported by Hvatum (1972) in Norway and by Sillanpää (1972) in Finland; whereas a distinct maximum deeper in the peat was found in southern Sweden (Tyler 1972) and in Finland (Tolonen 1974).

The washing out or removal of nutrients and microelements is reflected in the vegetational composition on the bog. Although the nutrient concentration is very low in ombrotrophic water, the increased water mobility in the channels draining ombrotrophic bog areas furnishes the necessary supply of nutrients to some minerotrophic plants. The more nutrient-demanding species thus only grow in the marginal parts of the bog areas (Malmer 1962; Sjörs 1963).

The aim of this paper is to present data on plant remains from peat deposited in the last millennium, to show ecological changes within this period, to estimate the present deposition of chemical elements and give the content of elements in peat at different levels below the surface, and from these data to discuss the mobility and accumulation of some of the elements.

Approach

The surface of the ombrotrophic peat bogs in Denmark is pillow-shaped, with the highest point lying in the centre. The bog accordingly does not interact with the minerogenic ground water from the surroundings, and all moisture is supplied from the atmosphere as rain or snow. The chemical elements are deposited with the precipitation or as dry fall-out. The elements are caught by the vegetation, and each year a new peat layer is formed which contains information about the environment. A peat profile thus provides a record of past changes.

The atmospheric input of elements was analysed in superficial samples of *Sphagnum magellanicum* and *Sphagnum cuspidatum*.

Information about past deposition levels was obtained from three vertical columns in a peat profile where relations between depth and age were calculated from a number of radiocarbon dates.

Past biotic and environmental changes were illuminated by peat stratigraphy, macrofossil analysis, and determination of humification degree.

Sampling site

Draved Mose is situated about 20 km from the North Sea in the southern part of Jutland (see fig. 1). The bog covers approximately 500 ha and is almost circular in shape. Most of the area has been disturbed by peat exploitation during the first part of this century. Only the central part of the bog (3.5 ha) is left in natural condition; the sampling site is located in this area at 19.5 m a.s.l. The undisturbed bog surface is flat with a distinct hummock-hollow structure (fig. 2). A few poorly growing *Betula pubescens* occur on hummocks. The mosaic structure disappears less than 50 m from the former peat excavation areas and is replaced by a uniform vegetation dominated by *Calluna vulgaris, Eriophorum vaginatum* and *Erica tetralix*. The surface slopes in this peripheral part due to artificial drainage

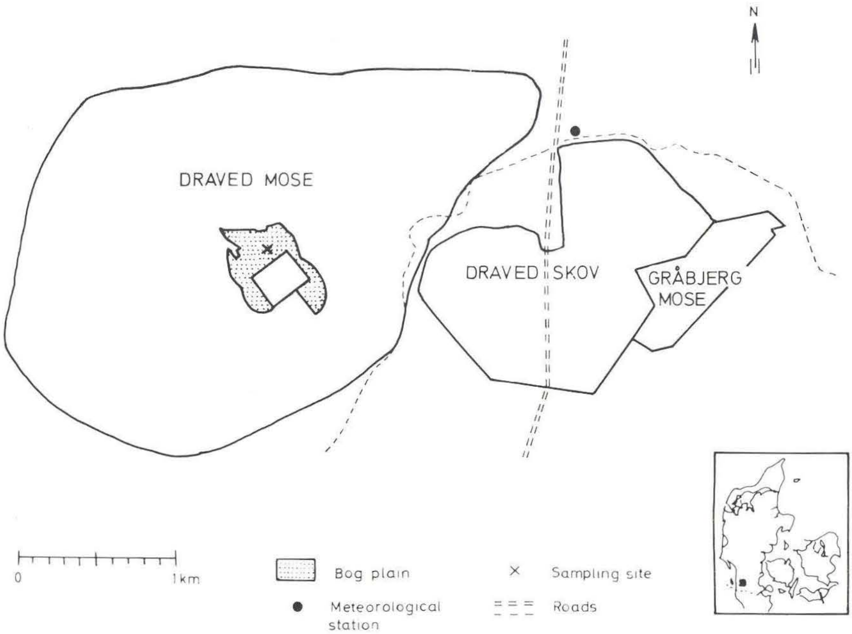

Fig. 1. Location map and the approximate size of the bog area shown in relation to Draved Skov and Gråbjerg Mose.

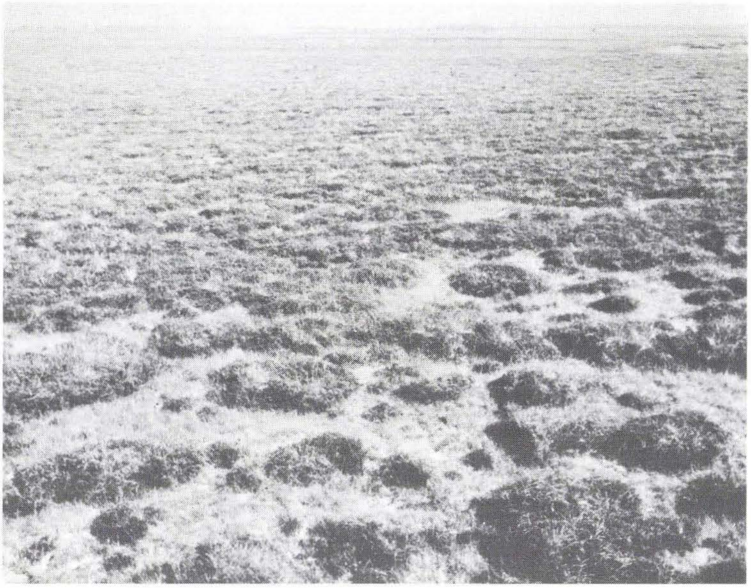

Fig. 2. The investigation area in the central part of the bog with a distinct pattern of hummocks (dark areas) and hollows (light areas).

from the neighbouring exploitation area. Only a few birch trees grow on the sloping parts of the bog plain.

The thickness of the peat in the central area is about 5 m. The formation of ombrotrophic peat began in late Atlantic time (Aaby and Tauber 1975) and ombrotrophic conditions have thus existed for more than 6000 years in this area. About 1 m of gyttja from an ancient lake is found below the peat. The bog is located on Saale till which is covered by aeolian sand blown up from the surrounding out-washed plains in late Weichselian time (Andersen 1966).

Meteorological data were measured at Draved just outside the bog; at Tønder, 10 km south of the bog; and at Askov, 50 km to the north. All the stations lie at approximately the same distance from the North Sea (table 1).

Vegetation at the sampling area

The hummocks were dominated by a *Calluna vulgaris – Eriophorum vaginatum* sociation whereas a *Rhynchospora alba – Sphagnum cuspidatum* sociation dominated the central part of the hollows. Close to the margin of the hollows a *Rhynchospora alba – Sphagnum cuspidatum* sociation with *Sphagnum tenellum* dominated. A *Sphagnum magellanicum – Calluna vulgaris* sociation was found in the marginal area of the hummocks.

Table 1. Yearly precipitation, and yearly temperatures. Mean values for the coldest and warmest months are shown in brackets.

Precipitation,	period	DRAVED	TØNDER	ASKOV
	1886-1925	–	750	733
	1931-1960	–	780	790
	1952-1977	837	803[1])	797[2])
Temperature,	period			
	1886-1925	–	7.6°C	7.2°C
			(0.4;15.8)°C	(-0.1;15.6)°C

1) Data from St. Jyndevad meteorological station.
2) Observation period 1957-1977.

A detailed description of the sociations found on the bog plain has been published by Hansen (1966).

Methods

Field work

Sampling from the bog surface

Superficial *Sphagnum* material was collected for analysis of the present input of chemical elements. In general only collections of two *Sphagnum* species were used to facilitate comparisons of data from different localities and from different years. *Sphagnum magellanicum* growing on hummocks was considered to represent the input to the hummock vegetation whereas *Sphagnum cuspidatum* was used for the hollow species.

The first sampling took place December 16, 1971, after the vegetative growth had stopped. The next sampling was in late winter (March) 1974 prior to the new vegetative period. The sampling was restricted to a rather small area (25 ×25 m) in the centre of the bog (fig. 1) and took place in periods of frost. This procedure definitely facilitated the accuracy of the field work and the later calculations.

Hummock sampling: A square of about 15 × 15 cm was cut out of the frozen *Sphagnum magellanicum* hummock and the area could easely be measured. The samples were placed in boxes to prevent secondary disturbance. The samples melted during transportation and were refrozen in the laboratory. The samples were separated in annual layers. To cut off a whole year's matter, some points are needed on the *Sphagnum* stem which can be referred to a relatively short growing period of the year. The most distinct point is the limit between material produced in late autumn (and winter, if mild) and that produced from the start of a new vegetative season in early April. Because of this fact the sampling in 1974 took place in March. The one-year period does not correspond to the calendar year but runs from April to April. For practical reasons, the period is named by the calendar year of the vegetative season.

Hollow sampling: Another procedure was used for *Sphagnum cuspidatum*. From investigation of the annual growth of *Sphagnum* from hollows (Overbeck and Happach 1957), it is known that in one year the stems may grow more than 12 cm. Only the capitulum and the uppermost part of the stem is erect, whereas the rest of the plant is weak and rests on the substrate. Thus a single plant does not have a fixed position from year to year but moves around in the hollow area. The slender stems were easily broken, and it was impossible to state the annual growth of single plants; accordingly no separation of annual production was possible. Instead, from 200 cm² a sample was taken which contained the capitula and a certain amount of dying or dead stem material. This fraction was named by the previous year. Below the first sample, another sample of *Sphagnum cuspidatum* peat was taken. Each of the samples had a thickness of 1.5 cm which was approximately the annual increment of *Sphagnum cuspidatum* mats in Draved Mose (Hansen 1966).

Sampling from the profile

In September, 1973, an open profile was excavated in two hummocks and the intervening hollow in the same area where the surface samples were taken. Prior to the excavation, the distribution of hummock and hollow areas was examined in an area of 7 × 6 m around the sampling site (fig. 3). Peat stratigraphy was

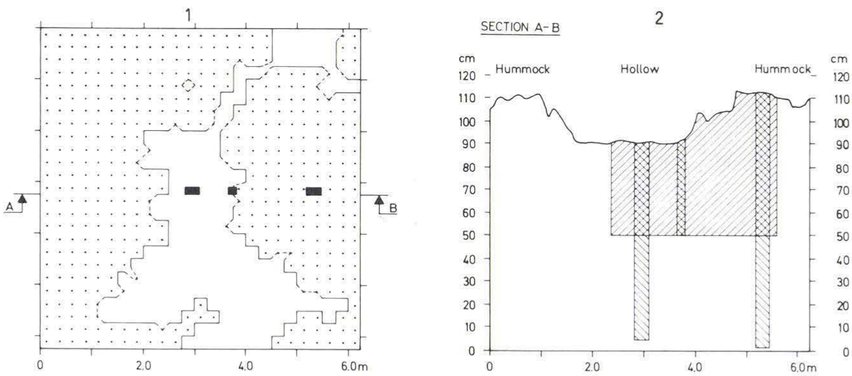

Fig. 3. Profile 1973: 1: The distribution of hummocks (dotted area) and hollows around the profile and the location of the peat columns (black area). 2: A vertical section of the profile showing the two hummocks and the intervening hollow. The three sampling sites are shown with parallel lines. Also part of the profile shown in fig. 4 is indicated by parallel lines, having another direction.

measured in the open section (fig. 4). pH and Eh profiles were measured in the hollow and the hummock peat by direct inserting of the respective electrodes, and continous series of samples 10 × 10 × 2 (or 3) cm were collected at three places: in the hollow, at the transition from the hollow to a hummock, and on the hummock (fig. 3). The peat slices were stored in polyethylene bags.

Laboratory work

The surface samples were dried immediately at 37-38°C. The samples were ground prior to analysis.

The peat slices from the columns were divided into material for C-14 dating, for determination of humification degree, for analysis of ash content, and for chemical analysis. The material used for chemical research was dried at 37-38°C whereas material used for other properties was dried at 80° for 2 days.

Macrofossil analysis

Three small subsamples were taken from each of the peat slices to show the general composition of the peat (plate 1). The untreated subsamples were mounted in glycerol jelly, and the *Sphagnum* stem leaves and branch leaves were determined to species or section. The results are given in an arbitrary scale because not every leaf or leaf-fragment could be identified with certainty. In addition, epidermis cells from *Ericales* and *Rhynchospora alba* were counted. *Eriophorum angustifolium* and *Eriophorum vaginatum* epidermis cells cannot be separated. Hence, the frequency of *Eriophorum* cells does not give any ecological information, and accordingly these data are omitted in plate 1.

Degree of humification

The method applied has been modified by Bahnson (1968) from the method developed by Overbeck (1947). It consists of a colorimetric determination of an alkaline extract of the peat. A description of the method in English has been published earlier (Aaby and Tauber 1975).

Ignition residue

The peat was ignited at 1000°C. 550°C data from similar peat types in a profile about 20 m to the west of the present investigation area (Aaby et al. 1979) show that the 1000°C ignition residues are approximately 5% smaller than the 550°C values.

Chemical analysis

Subsamples were digested in a mixture of HNO_3 and $HClO_4$, (4:1) and the metal analyses were carried out on the resulting wet ashing solution by atomic absorption spectrophotometry and flame emission (Perkin Elmer, Model 460, equipped with a HGA -74-graphite furnace). Na and K were measured by flame emission, Ca, Mg, Mn, Fe, Li, and Zn by flame absorption, and Cd, Cr, Cu, Ni, Pb, and V by graphite furnace absorption technique.

Interstitial water was pressed out of the surface samples and filtered through a 0.01 μm membrane filter by means of N_2-pressure. The resulting solutions were then acidified (0.15% HNO_3) and analysed according to the methods mentioned above.

The cation exchange capacity was determined on subsamples from the columns by a rapid method normally used in soil chemistry (Bascomb 1964). Some of the results were checked by the traditional NH_4Ac-method; no significant discrepancies were found.

The chemical data from hollows and hummocks are expressed in relation to dry weight of organic matter (DM) and, in addition, the hummock data are shown as annual net-uptake (mg m^{-2} y^{-1}).

Radiometric analysis

C-14: The measurements were made on samples dominated by *Sphagnum* material. Prior to analysis, the samples were boiled with 1% HCl and distilled water. The measurements were made by the C-14 laboratory of the Geological Survey of Denmark and the National Museum.

Cs-137: Freeze-dried bulk samples were analysed for Cs-137 by gamma ray spectrometry using germanium (lithium) detectors. To achieve the necessary sensitivity the samples were counted overnight. The measurements were made by The Danish Atomic Energy Commission, Risø.

Tritium: The wet bulk samples were treated at 2-5 atm. N_2 in a pressure membrane apparatus equipped with a 0.45 μm filter. The interstitial water thus obtained was distilled once to remove the yellow-brown humus colour. After distillation 8 ml were mixed with 12 ml scintillator (Instagel), and the tritium-content measured by liquidscintillation spectrometry on this mixture. The measurements were made by The Isotopic Centre, affiliated to the Academy of Technical Science.

The Cs-137 and tritium analyses were corrected for radioactive decay to the day of sampling.

Discription of peat columns

The deposits were described according to the system of Troels-Smith (1955). In addition, the degree of humification (H) is given in a 10 degree scale (v. Post 1924). The composition of the *Sphagnum* material is shown on the macrofossil diagrams (plate 1). The layer nos. refers to plate 1.

Hollow peat column

Layer no.	Level	
1.	0- 5 cm	Tangled, yellow *Sphagnum* peat with *Cyperaceae* remains. Tb^{1}3, Th^{1}1, Tl^0+, Dl^0+. *Rhynchospora alba* remains are frequent together with a few *Oxycoccus quadripetalus* and *Eriophorum angustifolium* (H2).
2.	5-11 cm	Tangled, light yellow *Sphagnum peat.* Tb^{0}4, Tl^0+, Th^0+. *Rhynchospora alba, Oxycoccus quadripetalus* and *Andromeda polifolia* were present (H1).
3.	11-15 cm	Tangled, yellow *Sphagnum-Cyperaceae* peat. Tb^{0}4, Tl^0+, Th^0+, Dl+. *Eriophorum angustifolium* and *Rhynchospora alba* were rather frequent. (H2).
4.	15-18 cm	Yellow-grey *Sphagnum* peat. Similar to layer 3, but distinctly darker and not as tangled. Tb^{1}3, Th^{1}1, Dl+. (H3).
5.	18-26 cm	Yellow *Sphagnum* peat. Tb^{0}4, Tl^0+, Th^0+, Dl+. The layer was similar to layer 2 but a little darker. (H2). Thin, darker bands were present (H3).
6.	26-55 cm	Brown *Sphagnum* peat. The upper limit was rather distinct. Tb^{2}4, Tl^2+, Th^2+. *Oxycoccus quadripetalus* and *Calluna vulgaris* were found (H5).
7.	55-60 cm	Light brown *Sphagnum* peat Tb^{1}4, Tl^1+, Th^1+, Dl+. One *Andromeda polifolia* leaf was found. (H4).
8.	60- cm	Brown *Sphagnum* peat. Tb^{2}4, Tl^2+, Dl+. Two *Eriophorum vaginatum* tussocks were present. (H5).

The macrofossil analyses (plate 1) and the peat stratigraphy (fig. 4) indicate that a *Sphagnum imbricatum* sociation has dominated the vegetation in this area for centuries. At about A.D. 1530 (see no. K 2290 in table 2) the *Sphagnum imbricatum* sociation was replaced by a *Sphagnum cuspidatum* – *Sphagnum tenellum* sociation. *Sphagnum tenellum* only dominated the vegetation for a brief period, and then it changed to a *Sphagnum cuspidatum* – *Rhynchospora alba* sociation, which is still found in the area.

The vegetational change about A.D. 1530 showed that a typical hollow was formed at that time and has persisted since then.

Hollow/hummock peat column

Layer no.	Level	
1.	Not indicated	Tangled, yellow, pale *Sphagnum* peat with *Cyperaceae* remains. $Tb^{0}3$, $Th^{0}1$, $Tl^{0}+$, *Rhynchospora alba* remains are frequent together with a few *Oxycoccus quadripetalus* stems. (H2).
2.		Tangled, yellow, pale *Sphagnum* peat. $Tb^{0}4$, $Tl^{0}+$, $Th^{0}+$. *Rhynchospora alba, Oxycoccus quadripetalus* and *Eriophorum angustifolium* were present. (H1-2).
3.		Yellow-greyish *Sphagnum* peat. $Tb^{1}3$, $Th^{1}1$, $Tl^{1}+$. *Rhynchospora alba* and *Eriophorum angustifolium* material were frequent. (H3).
4.		Dark chocolate brown *Calluna-Cyperaceae-Sphagnum* peat. $Tb^{3}1$, $Tl^{2}2$, $Th^{2}1$. *Eriophorum vaginatum* leaf basis and wood from *Calluna vulgaris* were frequent. (H6).
5.		Yellow *Sphagnum* peat containing *Cyperaceae* remains. $Tb^{1}4$, $Tl^{1}+$, $Th^{1}+$, Dl+. *Rhynchospora alba, Eriophorum vaginatum* and *Oxycoccus quadripetalus* were present (H2-3).
6.		Similar to layer no. 5 but with a darker colour. (H3).
7.		Light, yellow-brown *Sphagnum* peat. $Tb^{1}4$, $Tl^{1}+$, $Th^{1}+$, Dl+. *Rhynchospora alba* and *Andromeda polifolia* (one leaf) were present (H3).
8.		Brown *Sphagnum* peat. The upper limit is rather distinct. $Tb^{2}4$, $Tl^{2}+$, $Th^{2}+$. *Calluna vulgaris* and *Eriophorum vaginatum* were found. (H5).
9.		Similar to layer 8, but a little less tangled and a little darker (H5-6).

A *Sphagnum imbricatum* sociation dominated the deepest peat layer (no. 9 on plate 1). This vegetation was replaced by a *Sphagnum tenellum – Sphagnum cuspidatum* sociation (layer no. 7). *Sphagnum tenellum* dominated only for a short period after which a *Sphagnum cuspidatum – Rhynchospora alba* sociation with *Sphagnum tenellum* was found. Today *Sphagnum tenellum* developes on drier places in hollows, preferably close to the margins of hollows (Hansen 1966; Müller 1965). The rather permanent appearance of *Sphagnum tenellum* thus indicates that the marginal part of the hollow was drier than the central area where *Sphagnum tenellum* was rare. A *Sphagnum rubellum – Calluna vulgaris* sociation with *Eriophorum vaginatum* dominates layer no. 4 showing that a hummock had transgressed into the hollow area during a period of increased dryness on the bog surface. Although the *Sphagnum cuspidatum – Rhynchospora alba* sociation did not change in the hollow during the dry period, the lowered water table is reflected in the hollow peat as darker layers (layer nos. 3-4 in the hollow column) which is connected to the dark layer no. 4 in this column (fig. 4). Later, the humidity in the upper peat layers increased again (layer nos. 1-3), and the marginal area of the hummock became overgrown by a *Sphagnum cuspidatum – Rhynchospora alba* sociation with *Sphagnum tenellum.* This vegetation is still found on the locality. The center of the hummock thus seems to have had a rather stable location in time and only the marginal areas have transgressed or retreated depen-

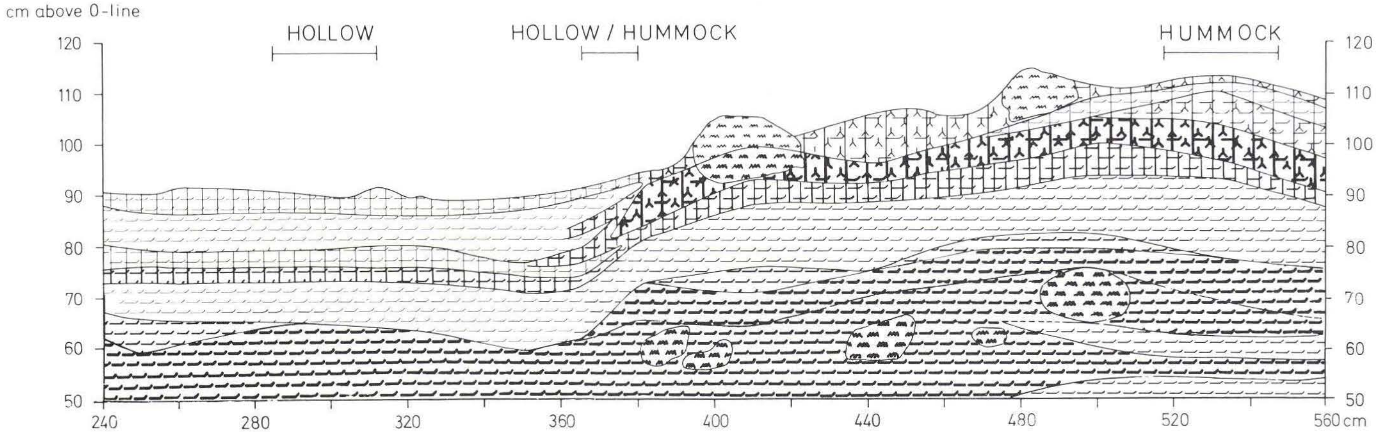

Fig. 4. Part of profile 1973 with peat stratigraphy and peat composition. The peat symbols are explained on plate 1. The degree of humification is shown by the thickness of the symbols. The composition of the symbols is in accordance with Troels-Smith (1955).

ding on the humidity in the upper peat layers. This result agrees with previous investigations on the bog (Hansen 1966; Aaby 1975).

Hummock peat column

Layer no.	Level	
1.	0-1.5 cm	Tangled, light brown *Calluna-Cyperaceae-Sphagnum* peat. Tb^{1}1, Tl^{1}2, Th^{1}1, Dl+. Leaves from *Oxycoccus quadripetalus* and wood material from *Calluna vulgaris* and *Oxycoccus quadripetalus* were present together with *Eriophorum vaginatum* remains. (H3).
2.	1.5- 4 cm	Tangled, yellow, pale *Sphagnum* peat with *Cyperaceae* roots. Tb^{0}3, Th^{0}1, Tl+. The layer contained roots of *Eriophorum vaginatum* (H1).
3.	4- 8 cm	Light, yellow-brown *Sphagnum* peat containing roots from *Ericales* and *Cyperaceae*. Tb^{1}2, Tl^{1}1, Th^{1}1, Dl+. *Oxycoccus quadripetalus* and *Calluna vulgaris* remains and *Eriophorum vaginatum* roots and leaves were present. (H3).
4.	8-16 cm	Chocolate brown *Calluna-Cyperaceae-Sphagnum* peat. Tb^{3}1, Tl^{2}2, Th^{2}1. *Calluna vulgaris* remains were frequent. (H6).
5.	16-20 cm	Light brown *Sphagnum-Cyperaceae* peat. Tb^{2}2, Th^{1}2, Tl^{1}+, Dl+. Leaf basis and roots from *Eriophorum vaginatum* were frequent at some places. *Oxycoccus quadripetalus* leaves were found. (H4).
6.	20-31 cm	Yellow brown *Sphagnum* peat. Tb^{1}4, Tl^{1}+, Th^{1}+, Dl+. Remains from *Oxycoccus quadripetalus, Calluna vulgaris* and *Eriophorum vaginatum* were found. (H3).
7.	31-33 cm	Light brown *Sphagnum* peat Tb^{1}4, Th^{1}+. *Eriophorum vaginatum* roots were present. (H4).
8.	33-40 cm	Chocolate brown *Sphagnum* peat. Tb^{2}4, Tl^{2}+, Th^{2}+, Dl+. *Calluna vulgaris* and *Oxycoccus quadripetalus* wood were present. (H5).
9.	40-50 cm	Similar to layer no. 8 but a little darker. (H6).
10.	50-55 cm	Warm brown *Sphagnum* peat. Tb^{1}4, Th^{1}+. (H4).
11.	55-58 cm	Chocolate brown *Sphagnum* peat. Tb^{2}4, Tl^{2}+, Th^{2}+, Dl+. *Calluna vulgaris* and *Andromeda polifolia* remains were found. (H6).
12.	58-63 cm	Similar to layer no. 10. (H4).
13.	63-76 cm	Similar to layer no. 11. A rather large *Eriophorum vaginatum* tussock was present. (H6).
14.	76-79 cm	Similar to layer no. 10. (H4).
15.	79-96 cm	Similar to layer no. 11. A rather large *Eriophorum vaginatum* tussock was present. (H6).
16.	96-106 cm	Similar to layer no. 10. (H4).
17.	106- cm	Similar to layer no. 11. (H6).

Earlier, a fairly homogenous *Sphagnum imbricatum* sociation dominated and *Sphagnum rubellum, Calluna vulgaris, Andromeda polifolia, Oxycoccus quadripetalus* and *Eriophorum vaginatum* had only a minor representation in the vegetation (layer nos. 5-17 on plate 1).

At about A.D. 1700 (see no. K 2286 on table 2) the vegetation changed distinctly. The open *Sphagnum imbricatum* 'Lawn' (Barber 1978) disappeared and was replaced by a *Calluna vulgaris* – *Eriophorum vaginatum* sociation. *Sphagnum rubellum* and *Sphagnum molle* became frequent later (layer no. 2 and 3).

The plant remains found in layer nos. 1-5 indicate that a typical hummock vegetation appeared about A.D. 1700 and has persisted in this area since then.

Calculation of time/depth scales of the hollow and hummock profiles

Four hummock samples and two hollow samples were radiocarbon dated in order to calculate time/depth scales (table 2). The dating results were calibrated relative to the American bristlecone pine chronology (Damon et al. 1973) in order to get approximate absolute ages for the samples.

The hummock time/depth scale (fig. 5) was calculated from the means of two successive dates; the youngest mean was calculated using the age 1973 for the

Table 2. Radiocarbon dates.

No.	level b.s.	C-14 date before year 1950	Calendar year A.D.
Hummock			
K2286	14- 16 cm	130 ± 100	
		230 ± 100	
	average	180 ± 100	1710 ± 108
K2287	46-48 cm	580 ± 100	1360 ± 104
K2288	73-76 cm	1020 ± 100	950 ± 105
K2289	106-109 cm	1150 ± 100	
		1260 ± 100	
		1380 ± 100	
		1230 ± 100	
	average	1260 ± 100	720 ± 102
Hollow			
K2290	24-26 cm	400 ± 100	
		380 ± 100	
	average	390 ± 100	1530 ± 113
K2753	63-66 cm	1140 ± 80	
		1140 ± 80	
	average	1140 ± 60	840 ± 69

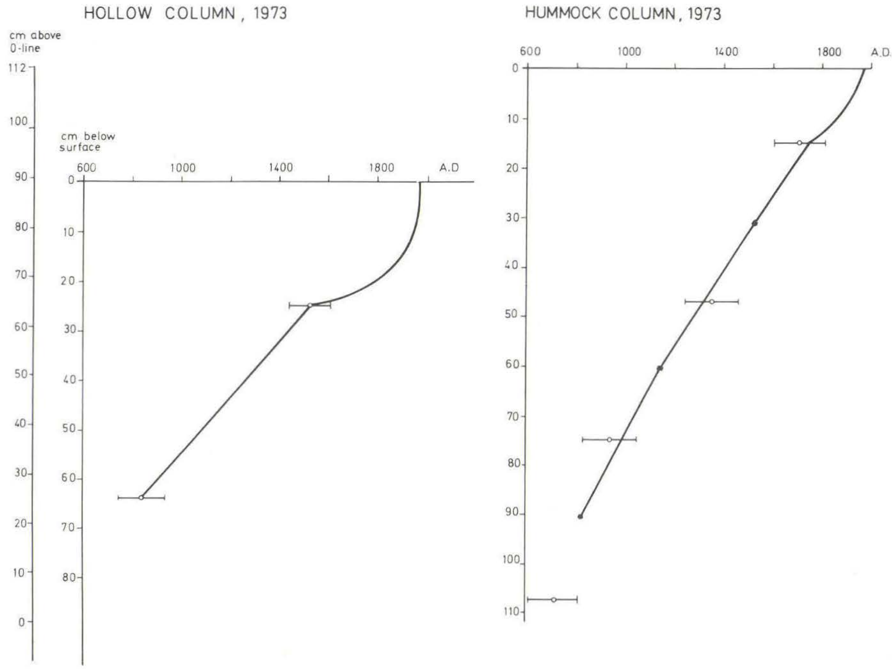

Fig. 5. Relations between age and depth in the hummock and hollow peat columns. The calibrated C-14 dates are shown as the mean value ± estimated standard deviation. The dots are mean values of two C-14 dates.

bog surface level. The mean ages apply to the mean level within the averaged interval. This procedure was used to reduce the statistical error on the individual C-14 dates. The straight lines connecting the mean values were used for dating the peat layers from 15-90.5 cm b.s. The dating of the topmost peat at 0-15 cm is somewhat uncertain. If the uppermost mean value is connected by a straight line to the 1973 level, the strongly humified *Calluna-Cyperaceae-Sphagnum* peat at 8-16 cm (see plate 1) will have a higher rate of accumulation than the upper, less decomposed layer at 0-8 cm. This result is not in accordance with the knowledge about rates of peat formation in young peat layers (Aaby and Tauber 1975; Aaby et al. 1979; Florschütz 1957; Nilsson 1964). Instead, an arbitrary curve was drawn between the 1973 level and the straight line at 15 cm. By using this curve for calculating the time/depth relations, the dark layer at 8-16 cm will show a lower growth rate than the lighter peat lying above and below (see table 3).

The hollow time/depth scale was calculated in another way because only two levels were C-14 dated. The mean rate of peat formation below 25 cm is calculated directly from the calibrated dates (table 2), whereas the ages of the upper peat layers are estimated based on increment rates from an adjacent profile with a

Table 3. Rates of peat accumulation. The calculation methods are explained in the text.

Hollow Depht	$mm\ y^{-1}$	Hummock Depht	$mm\ y^{-1}$
0- 5 cm	6.25	0- 5 cm	0.83
5-10 cm	2.77	5-10 cm	0.72
10-15 cm	0.77	10-15 cm	0.50
15-20 cm	0.44	15-31 cm	0.77
20-25 cm	0.21	31-61 cm	0.80
25-64.5 cm	0.57	61-90.5 cm	0.92

similar peat composition (Aaby et al. 1979). This scale was used without changes in the 1973 profile to date the upper 25 cm because the layer 25 cm below the surface (dated to A.D. 1530) has the same age in the two profiles. Calculated peat accumulation rates are shown in table 3. Accumulation rates in the hollow increase from 0.57 to 6.25 mm y^{-1}; the hummock rates are nearly constant.

Yearly productivity and increment rates of *Sphagnum magellanicum* collected from the bog surface

Eleven samples were collected from 5 hummocks.

Sample no. 1 was collected from hummock no. 1. The hummock was rather small, and the sample was located in a rather low, open area with a horizontal surface. *Sphagnum rubellum* dominated with a few *Calluna vulgaris*.

Sample no. 2 was taken from hummock no. 2. This hummock was larger than hummock no. 1, and the sample was located in a rather sheltered, open *Sphagnum magellanicum* vegetation which had a horizontal surface. *Sphagnum magellanicum* dominated with a few *Calluna vulgaris*.

Sample nos. 3-7 were taken from a large hummock (no. 3). The samples were all lying in an open *Sphagnum magellanicum* vegetation on the northern slope of the hummock approx. 10-15 cm above the hollow level. The *Sphagnum* vegetation was somewhat sheltered from westerly winds by *Calluna vulgaris* plants. *Sphagnum magellanicum* dominated with a few *Oxycoccus quadripetalus*.

Sample nos. 8 and 9 were taken from a large hummock (no. 4). They were not sheltered, and the surface was sloping to the north. The vertical distance to the hollow level was about 10-15 cm and *Sphagnum magellanicum* dominated.

Sample nos. 10 and 11 were located on a rather small hummock (no. 5). The samples were taken from the lower part of an open westsloping *Sphagnum magellanicum* vegetation with a few *Oxycoccus quadripetalus*. The samples were situated about 10-15 cm above the hollow level.

Four samples of *Sphagnum cuspidatum* were taken from 2 large hollows in 1974.

Each hummock sample could be separated into 2 sub-samples representing the organic matter produced in two successive vegetative seasons.

The dry matter production of *Sphagnum magellanicum* was calculated for the individual seasons (table 4). The productivity varies considerably from one hum-

Table 4. Annual dry matter productivity of *Sphagnum magellanicum* on raised bogs.

Draved mose, hummock	no. 3,	1973	: 906 gm^{-2}	(37°C)	(n = 5)
	no. 4,	–	: 730 gm^{-2}	–	(n = 2)
	no. 5,	–	: 645 gm^{-2}	–	(n = 2)
	no. 3,	1972	: 578 gm^{-2}	–	(n = 5)
	no. 4,	–	: 535 gm^{-2}	–	(n = 2)
	no. 5,	–	: 530 gm^{-2}	–	(n = 2)

Kaltenhofer Moor, Germany (Overbeck and Happach, 1957) 252-347 gm^{-2} (20°C)
Peat bog in Rhön, Germany (Overbeck and Happach, 1957) 374-662 gm^{-2} (105°C)
Peat bog in Rhön, Germany (Overbeck and Happach, 1957) 449-794 gm^{-2} (105°C)
Tranerӧds Mosse, Sweden (Damman, 1978) 104 gm^{-2} (37°C)
Russian bogs (Grebenschdschikowa in Overbech and Happach, 1957) 200-270 gm^{-2}

mock to another. High values were found on hummock no. 3, with samples which had been sheltered a little from the dominating west winds. The location on the northern slope of the hummock, rather close to the hollow, protects the *Sphagnum* vegetation from desiccation in drier periods during the growing season; these conditions cause a vigorous peat production. The dry matter production is lower from samples on hummock no. 4 which also was sloping to the north but not sheltered from westerly winds. The sample site facing westwards (no. 5) has the smallest calculated productivity. Because all of the samples were situated at about the same vertical distance to the water level, the distance from the water level cannot account for the different productivity on the three hummocks. The exposure of the *Sphagnum* mats thus seems to have a considerable influence on the dry matter productivity in windy areas.

The values for 1972 are 31% lower than the 1973 values; this difference can partly be explained by weaker growth in 1972 due to lower precipitation (750 mm in 1972, 1023 mm in 1973, cf. Hansen 1969; Overbeck and Happach 1957), partly by stronger decomposition of the 1972 material and partly by the fact that the *Sphagnum* capitulum has a relatively higher dry matter content than the rest of the plant material (Clymo 1965). The data from Draved Mose were compared with data from other ombrotrophic bogs (table 4); the annual productivity varies markedly within each locality and from one bog to another. Temperature, precipitation, lenght of vegetative season, and wind conditions are parameters which may influence the annual dry matter productivity. The very low productivity on Tranerӧds Mosse may have been somewhat below average due to a dry spring, according to Damman (1978). The German and Russian bogs have smaller production values than found on Draved Mose. Greater oceanity in the Draved Mose area may account for this difference.

The average increment of *Sphagnum magellanicum* mats in two vegetative

Table 5. Mean annual increment of ***Sphagnum magellanicum*** mats on ombrotropich bogs. The Draved mose 1973 and 1972 data are based on a period extending from April to April.

Draved mose, Denmark	1973	1972	1972/1973
Hummock no. 3	22.4 mm (n = 5)	19.4 mm (n = 5)	0.87
no. 4	21.6 mm (n = 2)	18.9 mm (n = 2)	0.88
no. 5	19.4 mm (n = 2)	17.8 mm (n = 2)	0.92
no. 3-5, mean	21.6 mm (n = 9)	19.0 mm (n = 9)	0.88
Precipitation	1023.2 mm	750.1 mm	
Draved mose, Denmark (Hansen 1966)			15.2 mm, mean of 3 years
Traneröds Mosse, Sweden (Damman 1978)			7.8 mm, one year
Peat bog in Rhön, Germany (Overbech and Happach 1957)			35 mm, one year
Peat bog in Rhön, Germany (Overbech and Happach 1957)			51 mm, one year

seasons was calculated by measuring the vertical distance between fixed levels on 20 frozen *Sphagnum* stems from 9 samples (table 5). The stems were taken at random in the margin of the sample, and only stems which showed two distinct levels of growth retardation were measured. Prior to calculations the measuring data were multiplied by 0.97 to give the length of unfrozen stems. The measured stems were somewhat crooked, especially in the lower part. The compression was mainly caused by the weight of the snow, and this effect influenced the increment data because only the vertical distance between the fixed points already mentioned (p. 9) was measured.

The annual increment varied from sample to sample within the same hummock and from one hummock to another. The mean increment for all samples was 21.6 mm ($\pm$ 2.18, n=9) in 1973 (table 5). The highest values were found in hummock no. 3 with sheltered samples on the northward sloping margin of the hummock. These samples also showed the highest annual dry matter productivity. The samples from hummock no. 4 were growing a little slower, and the smallest increment was found for hummock no. 5, which also had the smallest annual dry matter production. Exposure thus influences both the annual production of organic matter and the vertical growth of the *Sphagnum magellanicum* mats.

The average increment in 1972 was 19.0 mm ($\pm$ 1.33, n=9). The observed relations between the three hummock increments were identical with the 1973 relations. The 1972 data were generally 12% smaller than the 1973 data. The annual increment of *Sphagnum* mats is influenced by the precipitation (Hansen 1966; Overbeck and Happach 1957) which may account for a part of the differences between the 1972 and 1973 data.

When compared to other data (table 5), it is seen that the present data are in agreement with indirect measurements of *Sphagnum magellanicum* increments on the same bog in 1954-1956 (Hansen 1966). A much lower increment was

Table 6. Concentration of selected elements in the surface layers of 5 hummocks and 2 hollows in 1970, 1971, 1972 and 1973. Mean values in mg (kg DM)$^{-1}$.

Location	Element	Ca	Cd	Cr	Cu	Fe	K	Li	Mg	Mn	Na	Ni	Pb	V	Zn
Hummock 1 (n = 1)	70	1370	1.1	6.4	8.7	1630	3500	-	710	67	770	4.8	47	-	70
	71	1680	0.9	4.9	7.3	750	4400	-	860	116	840	4.1	-	-	57
Hummock 2 (n = 1)	70	1600	1.0	6.4	7.1	1310	3400	-	805	95	700	4.7	47	-	50
	71	1930	0.9	4.3	7.3	1040	3100	-	1130	98	950	4.3	50	-	57
Hummock 3 (n = 5)	72	2500	1.6	3.3	5.9	1200	2300	0.68	740	130	2000	2.3	53	8.2	63
	73	4400	1.4	2.5	5.1	900	3100	0.58	1200	200	1900	1.9	53	7.4	69
Hummock 4 (n = 2)	72	4100	1.7	3.6	6.2	1800	3000	0.90	700	82	2100	2.6	64	10	58
	73	2600	1.4	2.3	4.6	1000	3800	0.50	1300	130	2600	2.4	53	8.0	54
Hummock 5 (n = 2)	72	2700	1.7	3.6	6.6	1400	2700	0.80	1000	73	2100	2.3	50	8.5	63
	73	2200	1.7	2.1	4.1	800	3700	0.60	1200	110	2800	2.2	43	6.3	48
Hollow 1 (n = 2)	72	1200	2.2	3.1	6.6	2700	1700	0.90	1200	73	2300	2.5	176	9.0	99
	73	2100	1.2	1.8	4.2	1100	4300	0.50	1400	43	2400	2.4	112	8.0	73
Hollow 2 (n = 2)	72	1600	2.0	2.9	6.9	2500	1700	0.70	1200	78	1300	2.9	124	9.5	130
	73	1500	0.8	2.2	4.7	1400	3800	0.60	1300	69	1700	2.7	82	6.3	72

found by Damman (1978) on Traneröds Mosse, in southwestern Sweden, whereas the results from a number of German bogs show a higher annual increment. Some of the differences between the data from the latter bogs and Draved Mose may be due to different methods of measuring the increment. The German data show the total length of the plant which is not the case for the Draved data.

Metal elements in the surface layers

The chemical composition of the surface layers is summarized in table 6. Although the variation is marked, the concentrations of each element are within the same order of magnitude.

Hummock 1 and 2 are dominated by *Sphagnum rubellum* and *Sphagnum magellanicum* sociations, respectively. The concentrations of elements in the two sociations in 1970 and 1971 were compared to test if the chemical data are dependent on different *Sphagnum* material (table 7). The comparison shows no significant difference between the samples. This is in accordance with other findings (e.g. Rühling and Tyler 1971). All the samples from hummock 3,4, and 5 consist of *Sphagnum magellanicum*, and although they were exposed differently (see p. 19), the concentration values are nearly the same (table 7). In addition it is shown that samples from hollows have similar concentration values in each of the years, 1972 and 1973 (table 7). A homogeneity of metal concentrations in samp-

Table 7. t-test (paired observations) on the differences between the concentration values of metals in hummock and hollow samples from the years 1970, 1971, 1972 and 1973. It is presupposed that there is no significant difference between the per cent deviations of metals giving high and of metals giving small concentration values. This relation is tested for the linear least-squares fit. DF = Degrees of freedom.

Samples			Linear regression P	Difference P(t)	DF
Hummock	1 - 2,	1970	0.001 ***	0.73	11
-	1 - 2,	1971	0.001***	0.79	10
-	3 - 4,	1972	0.001***	0.12	13
-	3 - 5,	-	0.001***	0.05	13
-	4 - 5,	-	0.001***	0.24	13
-	3 - 4,	1973	0.001***	0.90	13
-	3 - 5,	-	0.001***	0.72	13
-	4 - 5,	-	0.001***	0.22	13
Hollow	1 - 2,	1972	0.001***	0.48	13
-	1 - 2,	1973	0.001***	0.15	13

les from hummocks and hollow, respectively, is thus shown for the years 1970, 1971, 1972 and 1973.

The mean concentration of selected elements in samples from hummocks and hollows was calculated for 1972 and 1973. A comparison of the hummock and hollow data shows that the mean concentration of Fe, Pb and Zn is highest in the hollows in the years 1972 and 1973, whereas the concentration of Ca is highest on the hummocks in the same years (table 8).

The concentration of chemical elements in hummock 3, 4, and 5 was converted to element net-uptake, defined as amount of metal present in the annual layers at the time of sampling (table 9). For immobile elements net-uptake equals deposition. Comparisons of the net-uptake data in 1972 and 1973 show that the values are nearly the same (table 10). A homogeneity of net-uptake values is thus indicated.

The homogeneity of the 1972 and 1973 metal data based on concentration values and net-uptake values was tested using a variance ratio-test (table 11). The differences between the 1972 and 1973 values were highly dependent on the method of comparison. The difference in concentration is for some elements contradictory to the difference in net-uptake. Due to the possibility of translacation the net-uptake might not reflect the true deposition but comparisons between samples based on net-uptake are superior to comparisons bases on con-

Table 8. Homogeneity of selected metal concentration means from hummocks (n = 8) and hollows (n = 4) for the years 1972 and 1973. A variance ratio-test was used.

I. Hummock values > hollow values in 1972 and 1973.
II. Hollow values > hummock values in 1972 and 1973.
III. Hummock values > hollow values in 1973.
IV. Hollow values > hummock values in 1972.

	Metals	Hom. 1972 P	Hom 1973 P
I	Ca	0.02 *	0.04*
II	Fe	< 0.001***	0.01*
	Pb	0.002**	< 0.001***
	Zn	< 0.001***	0.01*
III	Cd	0.07	0.01*
	Mn	0.10	0.009**
IV	K	0.005**	0.17
	Mg	0.002**	0.13

Cr, Cu, Li, Na, Ni and V showed no significant difference between the hummock and hollow values in 1972 and 1973 (P > 0.05).

Table 9. Net-uptake of selected elements in the surfase layers of 3 hummocks in 1972 and 1973. Mean values in mg $m^{-2}y^{-1}$.

Location	Element	Ca	Cd	Cr	Cu	Fe	K	Li	Mg	Mn	Na	Ni	Pb	V	Zn
Hummock 3 (n = 5)	72	1426	0.92	1.88	3.42	710	1350	0.39	420	73	1180	1.34	31	4.7	36
	73	4040	1.26	2.24	4.53	800	2800	0.54	1040	165	1720	1.70	47	6.7	63
Hummock 4 (n = 2)	72	2150	0.88	1.90	3.25	930	1600	0.48	380	44	1100	1.40	34	5.3	31
	73	1850	0.99	1.65	3.30	700	2750	0.36	910	98	1850	1.75	38	5.8	39
Hummock 5 (n = 2)	72	1400	0.88	1.90	3.45	750	1400	0.40	520	38	1100	1.25	27	4.5	34
	73	1400	1.07	1.30	2.55	490	2350	0.35	760	69	1800	1.40	27	4.0	31

Table 10. t-test (paired observations) on differences between the net-uptake values of metals in hummock samples from the years 1972 and 1973. It is presupposed that there is no significant difference between the per cent deviations of metals giving high and of metals giving small net-uptake values. This relation is tested for the linear least-squares fit. DF = Degrees of freedom.

Samples			Linear regression P	Difference P(t)	DF
Hummock	3 – 4,	1972	< 0.001***	0.32	13
–	3 – 5,	–	< 0.001***	0.96	13
–	4 – 5,	–	< 0.001***	0.32	13
–	3 – 4,	1973	< 0.001***	0.29	13
–	3 – 5,	–	< 0.001***	0.23	13
–	4 – 5,	–	< 0.001***	0.08	13

Table 11. Homogeneity of selected metal sample means on concentration and net-uptake from hummocks (n = 8) for the years 1972 and 1973. A variance ratio-test was used.

I. Elements with significantly higher 1973-level (concentration and net-uptake).

II. Elements with significantly higher 1972-level (concentration) but no significant difference in net-uptake.

III. Elements with no significant difference in concentration, but significantly higher 1973 level in net-uptake.

		Concentration (mg(kgDM)$^{-1}$)	Net-uptake (mg m^{-2}y^{-1})
	K	0.002**	< 0.001***
I	Mg	< 0.001***	< 0.001***
	Mn	0.03*	0.01*
	Cr	< 0.001***	0.62
II	Fe	< 0.001***	0.24
	V	0.03*	0.09
	Cu	< 0.001***	0.51
	Ca	0.41	0.04*
III	Pb	0.26	0.02*
	Zn	0.32	0.03*
	Na	0.28	< 0.001***

Cd, Li, and Ni showed no significant differences (P > 0.05) Levels of significance, *P < 0.05, **P < 0.01, ***P < 0.001.

centration values because differences in yearly productivity are taken into account. Although the homogeneity of the concentration data is fulfilled, the comparison based on concentration values might lead to false conclusions as exemplified in the variance ratio-test (table 11).

Cs-137 and tritium-profiles

The Cs-137 profiles are presented in fig. 6. The concentration values, pCi $(gDM)^{-1}$ ($pCi \sim 10^{-12}$ Curie) show a gradual decrease as a function of depth whereas the deposition values, pCi cm^{-2} corrected for bulk density, show, in addition, a maximum in the interval 8-10 cm b.s.

The tritium profile is shown in fig. 7. In general the tritium content increases slightly with depth, and two maxima can be observed. The first maximum corresponds to a light layer (10-12 cm b.s.) just below the uppermost dark layer, and the second maximum (25-33 cm b.s.) is found just below the transitional zone where the degree of humification changes abruptly to higher values.

Distribution of elements in the peat columns

The chemical analyses of the peat columns are summarized in plates 2 and 3. To test the correlation of the individual elements in the profiles, factor analysis was performed using the layers as cases and the concentrations as variables (fig. 8). In both cases only two factors explain approx. 85% of the total variance, and the factor loadings for each element exceed + 0.5 or -0.5.

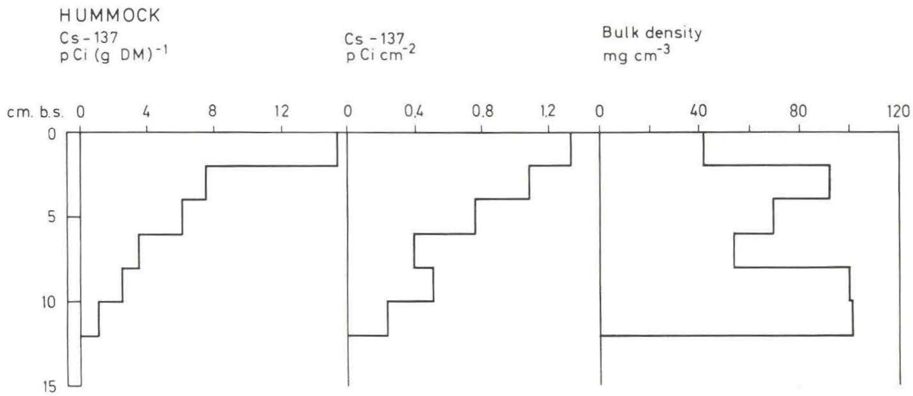

Fig. 6. The Cs-137 profiles shown as $pCi(gDM)^{-1}$ and pCi cm^{-2}. The bulk density values are used to calculate net-uptake values from concentration values.

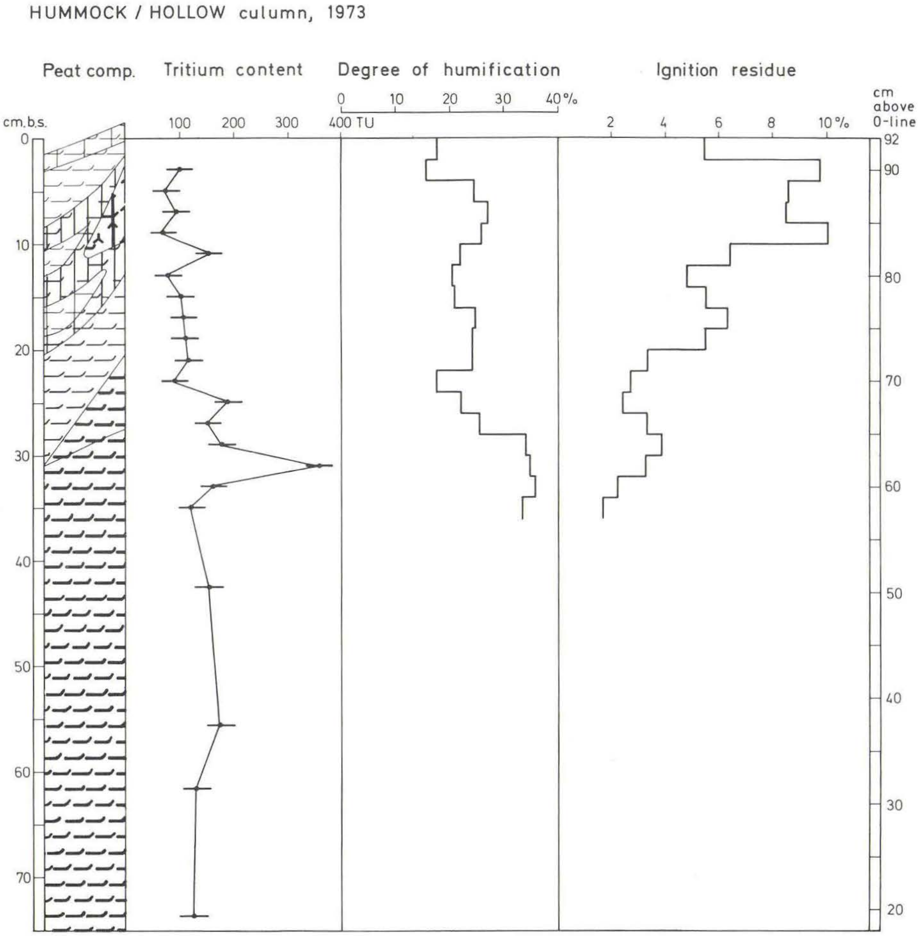

Fig. 7. The tritium profile with degree of humification and ignition residue.

The hollow column (plate 2)

Based on the factor analysis the elements are divided into three groups:

(1). The first group contains elements (high loading on factor 1), which are concentrated in the upper layers and show a distinct decrease with depth Cd, Cr, Cu, Fe, K, Li, Mn, Ni, Pb, V, and Zn. This decrease is especially pronounced for Fe and Mn which form a subgroup in the factor plot (fig. 8). K is positioned between this subgroup and the main group (the heavy metals) while Li is somewhat isolated, probably due to the broader maximum in the upper layers found for this element.

(2). The second group consists of Ca and Na (high loading on factor 2). The

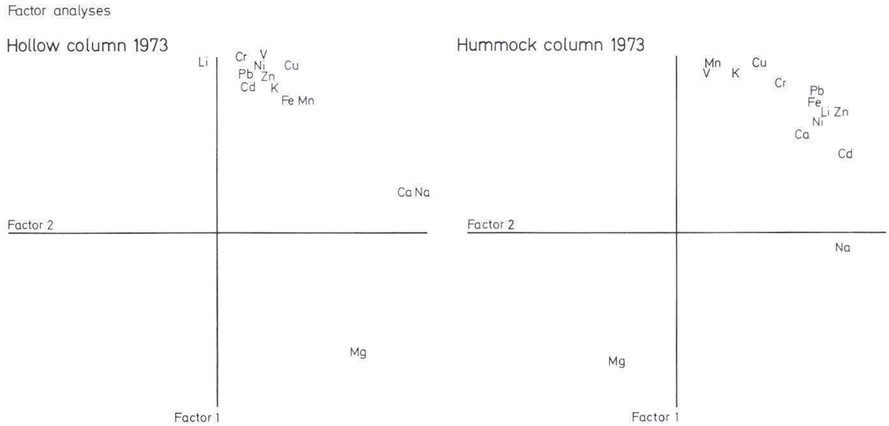

Fig. 8. Factor analyses plot. Method = Principal axes. Rotation = Varimax.

concentration of these elements does not change much with depth. A minimum is observed between 16 and 18 cm b.s.

(3). The behaviour of Mg is unique. The minimum found for Ca and Na is also present in the Mg-profile but the Mg concentration increases with depth (high negative loading on factor 1, see fig. 8).

As the ratio between the elements deposited cannot be assumed to have been constant during extended periods, the factor analysis may not solely reflect processes in the peat column.

The degree of humification shows two minima 4-10 cm b.s. and 17-26 cm b.s., indicating two permeable layers. The ignition residue shows marked variations in the upper 25 cm. Below this level it decreases to a nearly constant value of 1.5%. In the superficial segments of this profile a positive correlation between Fe and ignition residue is observed.

Eh decreases from approx. 200mV in the surface layer to approx. -50mV 15 cm b.s., corresponding to the position of the water level at the time of sampling. In the saturated zone the Eh increases to a value of approx. 50mV. The Eh profile confirms the importance af water logging.

pH increases with depth (4.0 to 4.6), the values being slightly lower than in the precipitation (~5.0).

The hummock column (plate 3)

Although the division of elements in groups is less distinct in the hummock, compared to the hollow, some similarities can be recognized (fig. 8):

(1). The heavy metals, K and Li are concentrated in the upper layers and decrease with depth. Some elements have a distinct maximum in the surface layer (e.g. Mn and K), for others (e.g. Pb and Zn) the concentration in the upper layers is nearly constant while Cd and Ni show a maximum below the surface level.

(2). As found in the hollow, the Na concentration is nearly constant, but the Ca concentration is markedly increased in the upper segment.

(3). For Mg the profile resembles the hollow profile

For all group 1 elements a distinct concentration minimum is observed in the layer 8-10 cm b.s., just above the strongly decomposed segment (10-16 cm b.s.). This minimum is probably caused by a shift in permeability making a nearly horizontal water transport dominating. Mg is concentrated in the layer (8-10 cm b.s.) indicating the importance of Mg in the leaching processes (ion-exchange).

A very pronounced change in concentration is observed in the segment 24-26 cm b.s., corresponding to the upper limit of the water level situated at the hollow surface. This change does not coincide with a sudden change in degree of humification or ignition residue, and thus it can only be explained as a hydrological effect.

As the content of dry matter does not change much in the segments 4-16 cm b.s. and 16-32 cm b.s. (unpublished data), a bulk density correction would not effect the trends.

Discussion

The extinction of *Sphagnum imbricatum* and the formation of hummock -hollow structures

The macrofossil analysis (plate 1) and the peat stratigraphy (fig. 4) indicated that a rather uniform *Sphagnum imbricatum* sociation dominated the bog plain in the Middle Ages. This sociation also had a widespread occurrence and abundance on raised bogs in the British Isles and Northwest Europe in the past (Green 1968; Overbeck and Schneider 1938). The *Sphagnum imbricatum* sociation is extremely rare in the same areas today, and is largely confined to hummock areas in very wet bogs. The rarity of *Sphagnum imbricatum* today is an enigma which has often been debated.

The extinction of the *Sphagnum imbricatum* sociation on Draved Mose is closely related to the formation of hummock and hollow structures. This formation was not a process which suddenly began in the 14th and 16th centuries, but was the result of changes in the surface topography which began about 500 years earlier. Radiocarbon dates show that the level 31 cm above the 0-line in the 1973 profile (fig.5) is contemporaneous in the hummock column and the hollow column. This level is dated to the 10th century and from that time the vertical difference between the two areas increases. Around A.D. 1300 the difference was about 10 cm in the profile, and when the *Sphagnum imbricatum* sociation disappeared in the hollow area at A.D. 1530, (K 2290 in table 2) the difference had reached about 15 cm. These values are calculated from the peat columns. The actual vertical differences in the past cannot be calculated because a number of processes (e.g. breakdown and autocompaction) may have influenced the differences. The humification values and the peat composition in the hummock area and the hollow area are nearly identical until A.D. 1530; hence the processes mentioned cannot have influenced the calculations seriously. During the period A.D. 1000-1500, the vertical differences between relatively low and high areas in the *Sphagnum imbricatum* sociation thus increased, and wetness in some areas reached a level which made *Sphagnum cuspidatum* and *Sphagnum tenellum* able to compete with *Sphagnum imbricatum* at only slightly increased wetness on the bog surface. A change in climate about A.D. 1500 caused increased wetness. The competition between *Sphagnum imbricatum* and the two other *Sphagna* seems to have lasted for a short time only and the best fitted species survived (see plate 1).

The ecological conditions still suited *Sphagnum imbricatum* on the drier places between the hollows. The bog surface relief continued to increase and the hummock area accordingly became drier, as reflected in the humification values (plate 3). About 200 years later, approx. A.D. 1710 (K 2286, table 2), the hummock area was too dry for *Sphagnum imbricatum* to be able to compete with the *Calluna vulgaris – Eriophorum vaginatum* sociation which then occupied the area and has dominated since that time.

The extinction of the *Sphagnum imbricatum* sociation and the formation of hummock-hollow structures is also illuminated in another profile which was excavated in 1978 and located only 20 m to the west of the 1973 profile (Aaby et al. 1979). The vegetational development in the hummock area and the hollow area in the 1978 profile was similar to that found in the 1973 profile except for two cases. (1) the hummock peat was generally formed at drier conditions than the hummock peat in the 1973 profile, and (2) *Sphagnum molle* was part of the sociation which replaced the *Sphagnum imbricatum* sociation in the hollow area. The disappearance of the *Sphagnum imbricatum* sociation from the hollow area in the 1978 profile was radiocarbon dated to about A.D. 1300. Unfortunately, the synchronous layer in the hummock area cannot be calculated at present, because only a single, younger C-14 date is available from this column. Of it is supposed that the relatively dry hummock area had an increment rate similar to the smallest rate found in the *Sphagnum imbricatum* peat in the 1973 profile (0.57 mm y^{-1}), the vertical difference between the hummock area and the hollow area has been approximately 9 cm about A.D. 1300. The vertical difference in the 1973 profile was calculated to 10 cm at the same time (fig. 5). It thus appears that the vertical differences in surface topography on the bog plain reached about 10 cm 650 years ago. This difference made the wetter parts of the *Sphagnum imbricatum* sociation sensitive to competition from a *Sphagnum cuspidatum – Sphagnum molle* sociation or a *Sphagnum cuspidatum – Sphagnum tenellum* sociation.

Only a small elevation of the water level would facilitate the growth of hollow sociations. Increased humidity is indicated by humification changes at about A.D. 1300 in the 1973 and the 1978 profiles. The *Sphagnum imbricatum* sociation persisted in the 1973 profile but disappeared from the 1978 profile. A new period of increased wetness on the bog surface began more than 200 years later, and at that time a hollow was formed in the 1973 profile, and *Sphagnum imbricatum* disappeared at this site.

The humidity on the surface of ombrotrophic bogs is strongly related to climate. Very little information about precipitation in the past is available, whereas more is known about temperatures. A temperature record has been constructed for England back to about A.D. 1100 (Lamb 1966). This record shows two periods with long-term trends towards lower mean annual temperatures. The first decrease began about A.D. 1250 and lasted for more than a century; the next decrease began about A.D. 1500 at the beginning of the so-called 'Little Ice Age'.

The meteorological data are thus in agreement with the results from Draved Mose because a lowering of the annual mean temperatures would affect the evaporation from the surface causing increased wetness on the bog.

In the hummock areas, the *Sphagnum imbricatum* disappeared at about A.D. 1600 in the 1978 profile (Aaby et al. 1979) and at about A.D. 1710 (K 2286 in table 2) in the 1973 profile, or 200-300 years later than in the respective hollow areas. Whereas the extinction of the *Sphagnum imbricatum* sociation in hollows on Draved Mose is closely related to changes in climate, the reasons for the disappearance of the sociation in the hummock areas is more obscure. It is difficult to ascertain whether the unfavorable drier condition was a result of periodically drier climate, or was a result of increased vertical differences between the hollow areas and the hummock areas.

The disappearance of *Sphagnum imbricatum* has been explained by terms of factors which altered the water regimes of the bogs toward increased dryness; either a change in climate (Godwin and Conway 1939; Hansen 1966), a change caused by man, e.g. drainage, burning and grazing (Jonas 1935; Pearsall 1956; Pigott and Pigott 1963), or autogenic bog processes (Morrison 1959). Green (1968) also thinks that a lowering of the water table was a main reason for leading to the present day restriction of the species, but other changes, e.g. a change in trophic status, might have been involved in its disappearance, according to Green (1968). Barber (1978) has shown that the extinction of the species at Bolton Fell Moss was climatically induced due to excessive wetness.

Some of the explanations mentioned above cannot be applied to the changes in

Draved Mose in a satisfactory way. First of all, the *Sphagnum imbricatum* sociation disappeared long before man influenced the bog environment. If man really was responsible for the extinction of *Sphagnum imbricatum*, it would be reasonable to suppose that the disappearance occurred simultaneously on the whole bog. This idea is contradicted by the fact that the extinction lasted for more than 400 years, A.D. 1300 - A.D. 1710. Moreover, there is no information indicating changes in trophic conditions, and there is no indication that a climatic change to greater dryness initiated the extinction. Instead, climatic changes caused increased wetness in restricted areas resulting in formations of hollows which were more fitted for other *Sphagnum* - sociations, as also shown by Barber (1978). Hence, only the disappearance of *Sphagnum imbricatum* in the hummock areas can be explained by increased dryness. Areas which were sufficiently wet for *Sphagnum imbricatum* may have persisted in the transitional zone between the hummocks and hollows. This area, however, seems to have been too restricted for the survival of a *Sphagnum imbricatum* sociation.

The possibility of using the surface layer, as a recorder of the present atmospheric input

Recently the atmospheric bulk precipitation of metals in different parts of Denmark has been determined (e.g. Jørgensen 1974; Hovmand 1977). By comparison with these results the usefulness of the surface layer as a recorder of the atmospheric input can be estimated (table 12).

By measuring bulk precipitation mainly wet deposition and part of the dry fall-out (particles > 10 μm) are determined whereas the deposition caused by absorption and impaction is underestimated. Consequently one expects the metal deposition on the bog to be somewhat higher than bulk precipitation. The metals can be divided into three groups (table 12):

(1) The deposition of Cd, Cu, Mg, Ni, Pb, V, and Zn is nearly the same in the two 'samplers'. The somewhat higher values found in the bog may be attributed to differences in the methods (see above).

(2) The amounts of Fe, K, Mn and to some extent Ca found in the surface layer of the bog are definitely higher than found for bulk precipitation.

(3) The Na content in the bog is destinctly lower than in the bulk precipitation.

In evaluating these results it must be stressed that the use of the net-uptake as a measure of the depostion is based on the following assumptions:

(a) The metals are sorbed quantitatively in *Sphagnum* tissue.

(b) The translocation of metals between the annual layers is negligible compared to the amounts present in the individual layers.

The sorption and retention of heavy metals in the bryophyte *Hylocomium splendens* examined by Rühling and Tyler (1970) are considered to be similar to

Table 12. Comparison of the metal deposition measured af net-uptake in the hummocks and in bulk precipitation.

Metals	Hummocks		Bulk precipitation	
	1972	1973	1972	1973
Ca	1600	3000	1040[1])	1360 [1])
Cd	0.90	1.17		0.5[2])
Cu	3.4	3.7		3.8[2])
Fe	760	710		180 [2])
K	1410	2700	240[1])	445 [1])
Mg	430	940	390[1])	895 [1])
Mn	59	130		9.1[2])
Na	1100	1800	3440[1])	8087 [1])
Ni	1.3	1.6		1.7[2])
Pb	31	41		21 [2])
V	4.8	5.9		3.7[2])
Zn	34	50		46 [2])

1) The values are interpolated, using data from St. Jyndevad, Højer (IHD 1977), and Draved meteorological station.
2) (Hovmand 1977)

that of *Sphagnum* sp. Based on the results of Rühling and Tyler (1970) it seems reasonable to assume that Cu, Pb, and Ni will be totally fixed in the peat under natural conditions. Although the mobility of Cd, V, Zn and especially Mg can be considerable, the similarity between the measurings in table 12 is striking. The fact that only negligible amounts of Cd, Zn, and V occur in the interstitial water (p. 12) also indicates that these metals are almost completely sorbed and retained by *Sphagnum*.

Fe and Mn are predominantly deposited as soil dust (Hovmand 1977) and consequently higher deposition levels in the bog should be expected for these elements (table 12), as part of the dry fallout is underrepresented in bulk precipitation. Dust deposition of Ca may also be important, as liming of the adjacent farmland is very intensive (table 12).

In addition to dust deposition another enrichment process seems to be active for Mn. Assuming that Fe is fully retained in the constantly aerated layers, the expected enrichment of Mn due to dry fall-out can be calculated from the Fe/Mn ratio in agricultural soils (Hovmand 1977). This calculation leads to distinctly lower Mn values than measured as net-uptake although the dust deposition has increased during the last century, judging from the ignition residue values (fig. 7; plates 2 and 3). Thus, a transport of Mn to the surface layers from below must take place. This result is supported by the distribution pattern of Mn in the peat columns (plates 2 and 3). The latter mechanism is without doubt also responsible for the extremely high net-uptake values found for the plant nutrient K (table 12), as reported by other authors (e.g. Damman 1978).

Na is obviously removed from the surface layers in large quantities (table 12) but the differences in Na supply in 1972 and 1973 seem to some extent to be recorded in the corresponding surface layers.

Leaching observations using Cs-137 and tritium as tracers

Significant levels of Cs-137 and tritium from test nuclear weapons have been detected in the atmosphere since the early fifties, with a maximum occurring in 1963 (Cambray et al. 1971; Andersen and Sevel 1974). Analyses of these tracers are used to illuminate the leaching processes in the bog.

Cs-137 has primarily been used as a dating tool in investigations of accumulation rates of sediment. The dating is based on the assumptions that Cs-137 is incorporated in the sediment in a distribution pattern similar to the one found in the bulk precipitation, that the mixing of the sediment is insignificant, and that no appreciable translocation will occur.

In the bog the first and the second assumptions are sustained, and thus the translocation of the univalent Cs-ion can be examined.

When the Cs-137 profiles (fig. 6) are compared to the estimated annual deposition corrected for radioactive decay (half-life 30 years) to the day of sampling (e.g. Pennington et al. 1973), the distribution pattern shows no resemblance. The content of the surface layers are higher than would be expected from precipitation measurings indicating an upward transport in the bog. On the other hand an appreciable amount is also found in layers produced before the year 1950. This can only be explained by leaching. In accordance with this only 4.2 pCi cm^{-2} of the original 14 pCi cm^{-2} deposited (Asker Årkrog, pers. commun.) are left in the uppermost 12 cm of the bog. The recycling and leaching indicated by the Cs-137 measurements are probably important for other cations also, especially those of similar electric potential.

The tritium content in the precipitation ($^3H_20$) shows a maximum of ca. 2000 TU (tritium unit) in 1963 expressed as annual mean (the seasonal variation is very pronounced with a maximum in the summer). Since then a gradual decrease in the concentration has taken place reaching about 100 TU in the year of sampling (1973) (Andersen and Sevel 1974). Consequently, TU values higher than 100 in the interstitial water can be taken as evidence for mixing with a certain amount of 'older' water, i.e. water from around 1963.

The tritium profile (fig. 7) shows that the content in the uppermost 10 cm equals the values expected from precipitation. The increase at 10-12 cm b.s. is believed to be due to mixing with 'older' water retained in the more impermeable (darker) layer placed above. The permeability is negatively correlated to the degree of humification (Malmström 1928). A change in permeability with degree of humification can also explain the maximum found at approximately 30 cm b.s. as 'older' water is slowly mixed with water precipitated in recent years. In the deeper parts of the hollow the tritium content is approx. 150 TU indicating that although 'old water' is stored here, infiltration of water precipitated after the year 1963 must have taken place. The tritium analyses cleary show that the correlation between permeability and degree of humification must be considered when the leaching patterns in the bog are to be evaluated.

The sorption capacity of the peat

Although the metal elements may be bound in different ways in the peat, ion exchange has been demonstrated to be very important (Puustjärvi 1955; Rühling and Tyler 1970). Consequently, changes in cation exchange capacity (C.E.C.) might explain part of the variation in the concentration profiles. Measurings of the C.E.C. (not published), however, showed no substantial variation with depth and no correlation with degree of humification. The C.E.C. varied from 1.2 to 1.4 meq(g DM)$^{-1}$ and exceeded in all the segments the sum of cations; the C.E C.-values resemble those reported by Tyler (1972).

Changes in deposition rates over extended periods

From the comparison of net-uptake and bulk precipitation discussed earlier (p. 34) it can be concluded that the elements Cd, Cu, Mg, Ni, Pb, V, and Zn are retained in the surface layer in quantities reflecting the actual deposition. Fe and Ca may behave similarly whereas Na, K, and Mn are translocated.

As the radiocarbon dates have made it possible to establish a time/depth scale in the peat columns, the mean annual storage in a given period can be calculated. The possibility of using the annual storage as a record of the actual deposition in the past will be discussed in the following with special emphasis on the group of elements retained in the surface layer. A further development of this approach has been reported by Aaby et al. (1979).

The deposition conditions in the hummock/hollow system

The development of the hummock/hollow system has been shown to take place about A.D. 1530 in this area. Since then the deposition conditions have been different on the hummocks and hollows partly because of the discrepancy in vegetation and microclimate and partly because of the different positions of the water table.

Although the trends in the chemical profiles (plates 2 and 3) are similar for the hummock and the hollow, the distribution of the elements differs somewhat. The most important difference is the high concentrations of most of the elements found within the upper zone of water fluctuations in the hummock, which certainly must be attributed to translocation. Among the factors governing this process the following mechanisms are believed to be important:

(1) During a heavy rainfall the infiltration af water might be so quick in the unsaturated zone that the reaction time needed for complete sorption exceeds the actual time of contact.

(2) Due to redox-processes some elements (e.g. Fe) concentrate in the zone of water fluctuation as in mineral soil.

(3) A transport of elements from the hollow into the hummock may appear especially during winter, when ice formation can facilitate such water movements.

Judging from this comparison of the hummock and the hollow, the latter is regarded as the most suitable recorder of the annual input, and although some horizontal movement of elements between the hummock and the hollow cannot be disregarded, it would still be a minor fraction compared to the total deposition.

Estimation of the relative importance of metal sources

Due to escalating industrial activity, transport activity, and energy production, the deposition of heavy metals has increased during the last centuries.

As reflected by the ignition residue and iron content of the peat columns (plates 2 and 3), the deposition of earth dust has increased with time. This is presumably a consequence of intensified mechanisation of the agriculture from the beginning of the 20th century. The chemical composition of the particles deposited on the bog can be estimated from chemical analyses of agricultural soil (Hovmand 1977). Assuming that Fe originates solely from earth dust, these analyses can be used to calculate the metal contribution in the dry fall-out (table 13).

Table 13. Estimation of the input of elements (mg m^{-2}) from different sources in 1972.

Element / Source	Cu	Pb	Cd	Ni	V	Zn	Fe	Mg
Soil dust	0.73	1.8	0.02	0.66	1.7	3.2	760*	140
Sea aerosoles	<0.01	<0.1	<0.01	<0.01	<0.1	<0.1	–	290
»Natural input«	0.73	1.8	0.02	0.66	1.7	3.2	760*	430*
Net-uptake in Hummocks	3.4	3.1	0.90	1.3	4.8	34	760	430
Antropogenous input in %	79	94	98	50	65	91	–	–

*Postulated values.

Another important source of elements is sea aerosols. Supposing that Mg arises from earth dust and sea aerosols only, the amounts of metals originating from the latter source can be estimated from the element ratio in sea water (Turekian 1969). Following this mode of procedure the total 'natural input' of Cu, Pb, Cd, Ni, V, and Vn in 1972 (a climatically rather 'normal' year) was calculated (table 13). It appears that the contribution to the 'natural input' from sea aerosols is negligible except for Mg.

The deposition originating from earth dust can only explain a minor fraction of the net-uptake, and consequently the 'antropogenous input' is dominating (table 13).

Trends in mean annual storage

The mean annual storage of Cd, Cu, Mg, Ni, Pb, V, and Zn in the hollow and the hummock columns have been calculated for the period A.D. 1300-1973. Due to the rather low accuracy of the C-14 dates, a time interval of 100 years was used (table 14). As previously mentioned, mean annual storage can only be expected as a meaningful measure of deposition rates in the hollow column, and in the hummock column prior to the development of the hummock/hollow structure, A.D. 1530.

The trend in the mean annual storage of the elements Cu, Pb, Ni, and V is in accordance with the expected depositional development. The values are almost constant in the period A.D. 1300-1700 and during the last three centuries a gradual increase is observed. As regards the absolute values, it appears that the storage level in the past is significantly lower than the present day 'natural input' (table 13). This discrepancy is presumably a consequence of additional deposition of soil dust due to the present activity of man.

In the segments dominated by an even *Sphagnum imbricatum* vegetation (prior to A.D. 1500) the storage levels in the hollow and the hummock columns are identical.

In most respects the behaviour of Cd is similar but the rather high storage values found in the period A.D. 1300-1700 may indicate that this element is translocated to some extent.

The storage values of Zn in the periods 1300-1400 and 1400-1500 (table 14) in the *Sphagnum imbricatum* dominated part of the hollow, and hummock columns are somewhat different; consequently the method may not be applicable for this element.

As the supply of Mg is dominated by the sea aerosole contribution, complete retention of this element would result in a rather constant storage level increasing slightly in the 20th century due to additional deposition of earth dust. The actual

Table 14. Mean annual storage (mg $m^{-2}y^{-1}$) of elements in hollow and hummock.

Element	Cu		Pb		Cd		Ni		V		Zn		Mg	
Period	Hol.	Hum.	Hol.	Hum.	Hol.	Hum.	Hol.	Hum.	Hol.	Hum.	Hol.	Hum.	Hol.	Hum.
1900-1973	1.36	2.70	14.5	16.4	0.19	0.46	0.34	0.55	0.89	1.11	11.2	31.0	127	182
1800-1900	0.46	0.53	7.4	7.5	0.13	0.17	0.15	0.15	0.34	0.17	4.0	8.9	112	148
1700-1800	0.13	0.33	2.4	5.2	0.06	0.15	0.09	0.12	0.15	0.09	1.8	9.0	57	124
1600-1700	0.07	0.27	1.2	4.2	0.04	0.19	0.04	0.12	0.08	0.10	1.2	8.7	45	155
1500-1600	0.08	0.09	1.3	1.0	0.04	0.07	0.04	0.08	0.07	0.09	1.7	3.0	76	155
1400-1500	0.09	0.09	1.3	0.8	0.06	0.05	0.06	0.04	0.07	0.04	2.1	0.4	136	167
1300-1400	0.06	0.07	1.1	0.8	0.05	0.04	0.05	0.04	0.05	0.03	1.4	0.1	144	126

values do not support this assumption. The absolute values are lower than would be expected from the net-uptake calculations in the surface layers (table 12). Furthermore the very low values found in the period A.D. 1500-1800 are in all probability referable to intensive leaching in the corresponding slightly humified and highly permeable layers.

Similar mean annual storage levels as those found in the present study have been measured on identical peat types from the same bog (Aaby et al. 1979, unpublished data).

Final remarks

This investigation emphasizes that knowledge of stratigraphy, peat composition, permeability (reflected by degree of humification), and increment is essential when the distribution of elements in a peat profile is to be interpreted. Conclusions, based on concentrations and contents only (Sillenpää 1972, Damman 1978), are thus considered to be ill-founded.

The study indicates that the annual storage of Cu, Ni, Pb, and V in the hollow column may be used as a recorder of changes in the deposition rate during extended periods.

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Dansk sammendrag

Overfladeprøver af *Sphagnum magellanicum* og prøver fra tørvesøjler i et åbent profil er undersøgt for at belyse tidligere vegetationsændringer og tungmetallers deponeringshastighed i fortid og nutid.

Ved hjælp af makrofossil analyse og C-14 datering vises at en *Sphagnum imbricatum* sociation har dækket store arealer på mosen i middelalderen, medens den i dag er helt forsvundet. Udryddelsen er tæt forbundet med dannelsen af tuer og høljer. I to perioder, omkring år 1300 og 1530 blev der dannet høljer på mosen og *Sphagnum imbricatum* sociationen blev afløst af en *Sphagnum cuspidatum* - *Rhynchospora alba* sociation. På de mellemliggende tuearealer vedblev *Sphagnum imbricatum* sociationen at dominere ca. 200-300 år længere end i de respektive høljearealer, hvor-

efter den også forsvandt her. Klimatiske ændringer til større fugtighed på mosen var således afgørende for sociationens undergang i høljeområderne. I tuearealerne er det derimod tiltagende udtørring af tørvelagene der betinger udryddelsen af *Sphagnum imbricatum;* men det er vanskeligt at fastslå, hvilke forhold der har været afgørende for denne udtørring. Forøget tørhed kan skyldes øget overfladerelief, d.v.s. større vertikal afstand mellem høljebund og tuetop, klimatisk ændring eller en kombination af disse forhold.

Overfladeprøver er blevet opdelt i årslag og der er målt højdetilvækst og tørstofproduktion. Det kan vises at vindeksponering har stor betydning for tilvæksthastighed og tørstofproduktion.

Ud fra kemiske analyser af overfladeprøver er det undersøgt, om indholdet af metaller i tørven afspejler det aktuelle metalnedfald. Det kan vises at forskellige prøver fra henholdsvis tue og hølje har omtrent samme metalindhold beregnet både som relativ (mg (kg DM) $^{-1}$) og absolut (mg $m^{-2}y^{-1}$) værdi. Kun de absolutte værdier bør anvendes som sammenligningsgrundlag for prøver, idet sammenligninger baseret på koncentrationsværdier kan lede til falske slutninger. Sammenligninger med målinger af metalnedfaldet opsamlet i en tragt (bulk-precipitation) synes at godtgøre, at de undersøgte spormetaller og Mg fixeres i det recente *Sphagnum* materiale.

Cs-137- og tritium-analyser er forsøgt anvendt til belysning af udvaskningsprocessen i mosen. Cs-137 er fordelt i tørveprofilet på en sådan måde at både udvaskning og transport opad i tørvesøjlen må have fundet sted. En lignende translokation må påregnes for de mere mobile elementer, f.eks. K og Mn.

Tritiumanalyserne viser, at infiltrationen af nedbøren primært foregår gennem de lyse, svagt humificerede lag.

Ved hjælp af C-14 dateringerne og den kemiske sammensætning af tørvesøjlerne er indholdet af metallerne Cd, Cu, Mg, Ni, V og Zn i de forskellige årslag beregnet (år 1300-1973). På grund af den relativt grove tidsskala er 100-års middelværdier anvendt.

Relationen mellem tørvens metalindhold og deponeringen gennem tiderne er diskuteret ud fra vurderinger af bidragene til deponeringen fra forskellige kilder (jordstøv, havaerosoler og antropogent materiale). Resultaterne tyder på, at indholdet af Cu, Ni, Pb og V i tørvelagene kan anvendes som et direkte mål for deponeringen helt tilbage til år 1300.

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Pb-210 dating and lead deposition in the ombrotrophic peat bog, Draved Mose, Denmark

Bent Aaby, Jens Jacobsen and Ole Stig Jacobsen

Aaby, B., Jacobsen, J. and Jacobsen, O.S. 1979: Pb-210 dating and lead deposition in the ombrotrophic peat bog, Draved Mose, Denmark. *Danm. geol. Unders., Årbog 1978, pp. 45-68.* København, 1979.

Pb-210 dating has been tested in an ombrotrophic peat bog in S-W Denmark. The favourable conditions in ombrotrophic systems facilitate the evaluation of a continuous time/depth scale, using a combination of Pb-210 and C-14 datings. The age determination has improved the contemporary prospection of the processes in the bog and of the deposition of heavy metals, reflected in the peat. A detailed description of lead deposition is given. – Since A.D. 1300 the lead deposition in Draved Mose has increased from 0.5 mg Pb $m^{-2}y^{-1}$ to about 50 mg Pb $m^{-2}y^{-1}$ (A.D. 1970-1978). It has been made render that approximately 70% of the recent lead deposition derive from alkyl-lead petrol whereas the rest originate from lead manufacturing industries and other sources.

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The impact of toxic substances on man and his environment is very well recognized. Consequently, efforts have been devoted in recent years to acquire more knowledge of the distribution of chemical elements in the environment to be able to control the overall effect of toxic substances.

Lead is conjectured as a neurotoxin, which acts on the central nervous system and is liable to produce disorders of mentation. This results in social and educational effects in populations which appear normal by conventional health criteria (Bryce-Smith et al. 1978).

Deposition of lead has been calculated from e.g. bulk precipitation (Hovmand 1973 and 1976) and from grass crops harvested on fields (Hovmand and Tjell, pers. commun.). Comparisons of deposition levels found by the two methods show that the two »samplers« have different collecting efficiency, the field being the most efficient. This result stresses the importance of methodical considerations when comparing deposition levels.

Present deposition rates of lead must be related to the preindustrial deposition to evaluate the recent level of pollution. Information of deposition rates in the last decades contributes towards an improved estimate of the relative importance of different lead emittants. Deposition rates in the past have been obtained from material collected years ago (e.g. herbarium material; see Persson et al. 1974; Johnsen and Rasmussen 1977; Rasmussen 1977) and from deposition in peat (Damman 1978; Pakarinen and Tolonen 1977) and in sediments (e.g. Benninger 1978).

In general the deposition rates are based on concentration values only as a consequence of an inadequately determined annual increment.

The C-14 dating method produces reliable results at age determination of ombrotrophic peat exceeding 200 years whereas useful information about peat layers younger than 200 years have been highly delayed by a methodical threshold. Pb-210 methods for dating sediments (e.g. Pennington et al. 1976; Pheiffer-Madsen 1979) have shown an advance towards dating young depositive materials. As a result of the Pb-210 dating procedure it has been possible to calculate a detailed time/depth scale over the last 200 years in ombrotrophic peat. Calculation of a continuous lead deposition for extended periods must require investigation areas with very stable environmental conditions. Hence, only few curves of the lead deposition development are available at present.

Extreme stable environmental conditions are known to have existed for centuries in some ombrotrophic bogs in Denmark (Aaby 1976; Aaby and Jacobsen 1979).

In the present study Pb-210 and C-14 dates are used in combination with an accurate slicing technique to calculate the lead deposition rates in the past 600 years.

Investigation area

Draved Mose is situated approx. 20 km from the North Sea, in the oceanic southern part of Jutland between Løgumkloster and Tønder (fig. 1). The bog covers approx. 500 ha and has an almost circular shape. Most of the area has been disturbed due to peat exploitation during the first part of this century. About 3.5 ha of the central bog plain is left in natural condition, and the sampling site is located in this area, at an altitude of 19.5 m a.s.l. Mean annual precipitation was measured at Draved meteorological station 1 km east of the bog to about 830 mm per year (1952-1978, range of variation 530-1240 mm).

The undisturbed area is rather flat and open with a distinct hummock-hollow structure (fig. 2). A *Calluna vulgaris* – *Eriophorum vaginatum* sociation dominates the hummock vegetation whereas a *Sphagnum cuspidatum* – *Rhynchospora alba* sociation is the most frequent in the hollows. A detailed description of the vegetation has been given earlier (Hansen 1966).

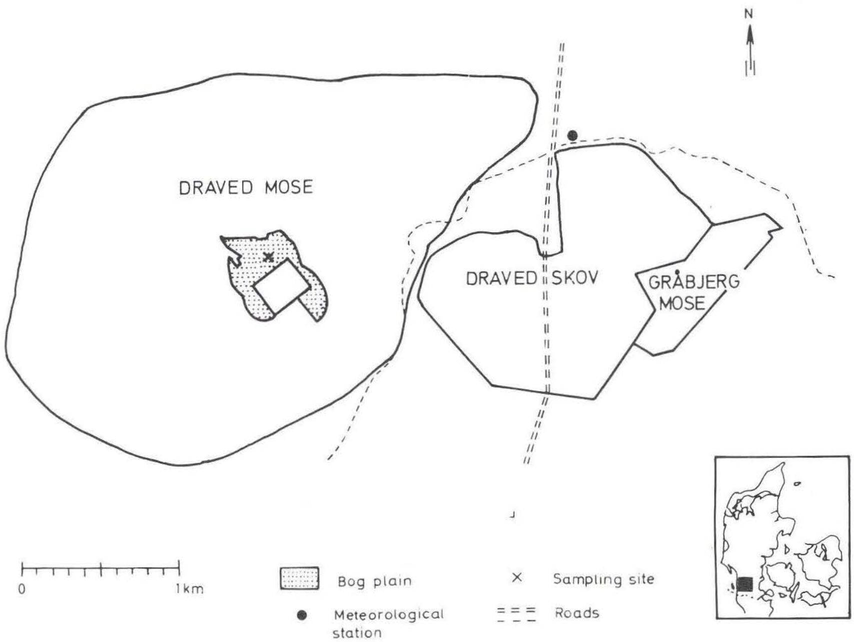


Fig. 1. The localization of the investigation area in Draved Mose.

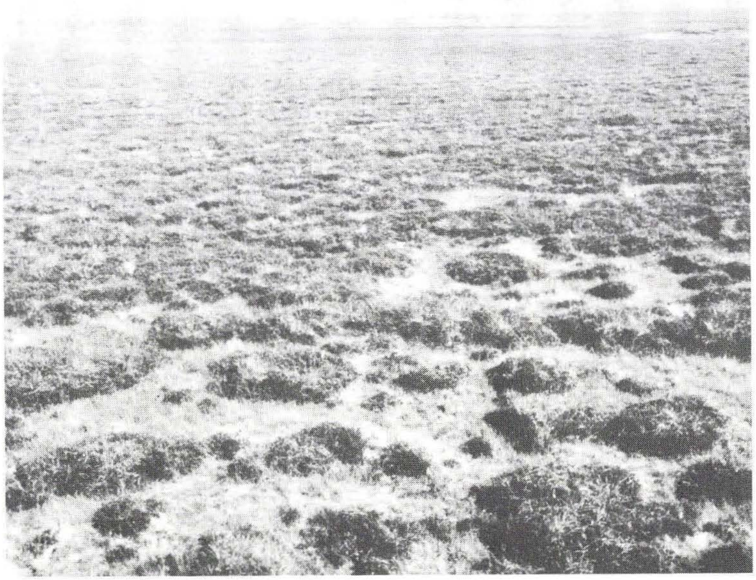


Fig. 2. The sampling site in Draved Mose. The bog surface consists of hummocks (dark areas) and hollows (bright areas).

Methods

Sampling procedure

In September 1978, a profile was excavated from the centre of a hollow to the central part of an adjacent hummock (fig. 3).

After peat stratigraphy analyses, a vertical peat column was taken from the hummock (hummock column I) and another from the centre of the hollow (hollow column I). The columns were stored in polyethylene bags which were prewashed with nitrogen, and after filling more nitrogen was added to prevent oxidation of the stored material.

In addition a peat column (hollow column II) was cut out of the wall close to the previous sampling site. The column was stored in a plastic container.

The area of all the columns were about 150-250 cm^2.

Measurements

Measurements of pH and redoxpotentials (Eh) were carried out in the field using a portable pH-meter, Radiometer type 29, connected to a combinated glass-elec-

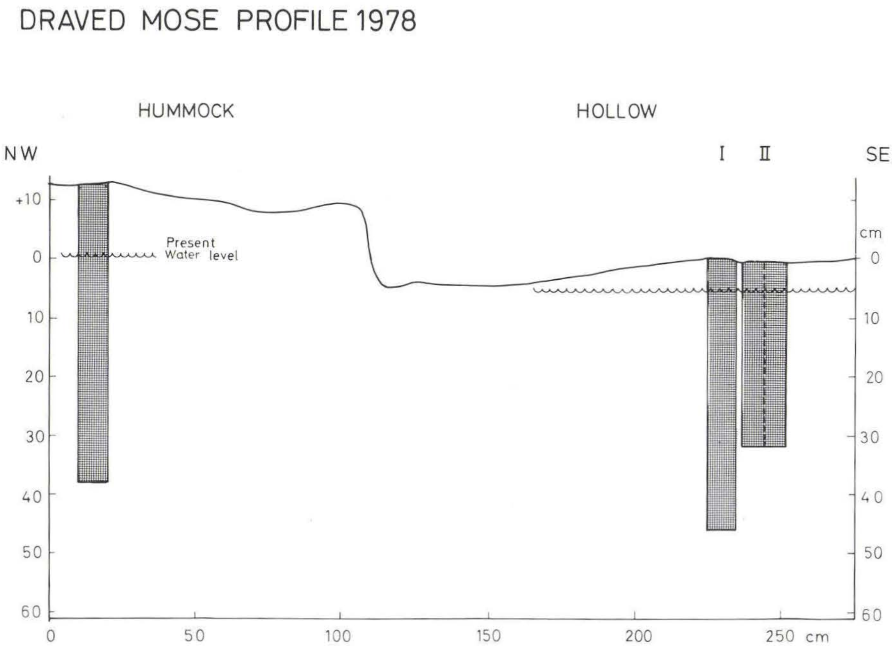


Fig. 3. Excavated profile, 1978, showing the location of the peat columns.

trode for pH measurements and to a special produced platinum electrode with a calomel reference for redoxpotential measurements (Hargrave 1972).

The surface area of the platinum electrode was less than 2 mm^2 which made it possible to carry out Eh-measurements fast and with a minimum of disturbance of the peat material. The electrodes were injected 5 to 10 cm into the water-logged peat just after the excavating of the peat profile. The equilibration time needed for each read-out was less than $2\frac{1}{2}$ min. for both pH and Eh measurements.

Laboratory procedure

Description of peat types and macrofossil analysis

The peat layers have been characterized (p. 53); the degree of humification (H) is given, using the method of v. Post (1924). The composition of the *Sphagnum* material is shown on the macrofossil diagrams (fig. 4 and fig. 5).

The procedure used in determining the frequencies of leaves from different *Sphagna* and epidermis cells of *Rhynchospora alba* and Ericales has been described earlier (Aaby and Jacobsen 1979).

Slicing technique

The entire hummock and hollow columns were frozen to -18^0 C before they were sliced. The freezing procedure facilitates a high slicing accuracy as the ice stabilizes the *Sphagnum* material. Solid *Calluna* twigs and tussocks of *Eriophorum vaginatum* are therefore easily cut without displacing the adjacent *Sphagnum* material. In addition, a high degree of accuracy in volumetric measurements has been secured.

Hummock column I and hollow column I were sawed into approx. 2 cm thick (unfrozen value) segments by hand. The hollow column II was sawed longitudinally into two identical sub-columns. One of these was stored and the other was cut into 3 mm thick slices (unfrozen value) on a circular saw which produced no saw-dust.

Bulk density, ignition residue, and degree of humification

The methods used in determining the ignition residue and the degree of humification have been described by Aaby and Jacobsen (1979). Dry matter (DM) was determined after freeze drying until constant weight. The ignition residues were calculated after heating at 550^0 C for 3 hours.

The volume of the peat material was calculated from frozen peat and multiplied by 0.9 prior to bulk density calculation.

Chemical analysis

Samples from hollow column I were divided into subsamples by vertical cutting. One series of subsamples was filtrated in a N_2 membrane filter apparatus using a 300 μm filter to isolate the interstitial liquid. Homogenous portions of the interstitial liquid were centrifuged at 2340 g for 10 min. separating the »particulate« and the »dissolved« fractions.

The lead concentrations in the unseparated interstitial liquid and in the »dissolved« fraction were determined after digestion in HNO_3. Untreated samples from hollow column I and freeze-dried samples from hollow column II were preweighed, digested in HNO_3. The lead concentration in the wet ashing solution was measured by atomic absorption spectrophotometry using a Perkin-Elmer 460 model connected to a HGA-74 graphite furnace.

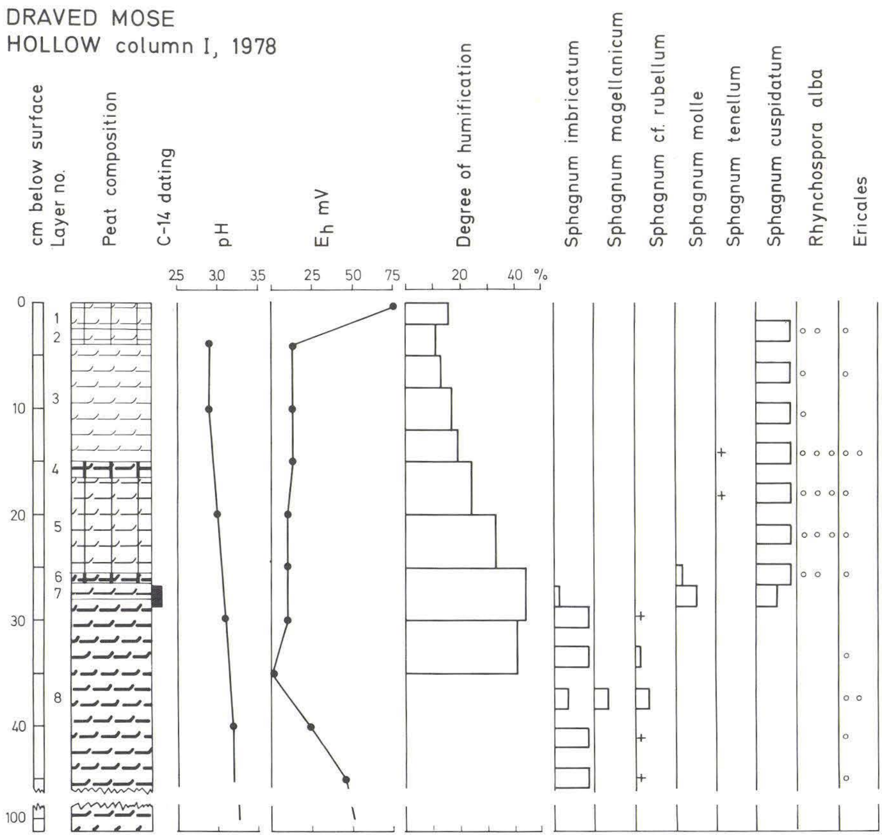


Fig. 4. Hollow column I, 1978. The sediment symbols and the frequencies of *Sphagnum* leaves and Ericales epidermis cells are shown in fig. 5. The thickness of peat symbols indicates degree of humification.

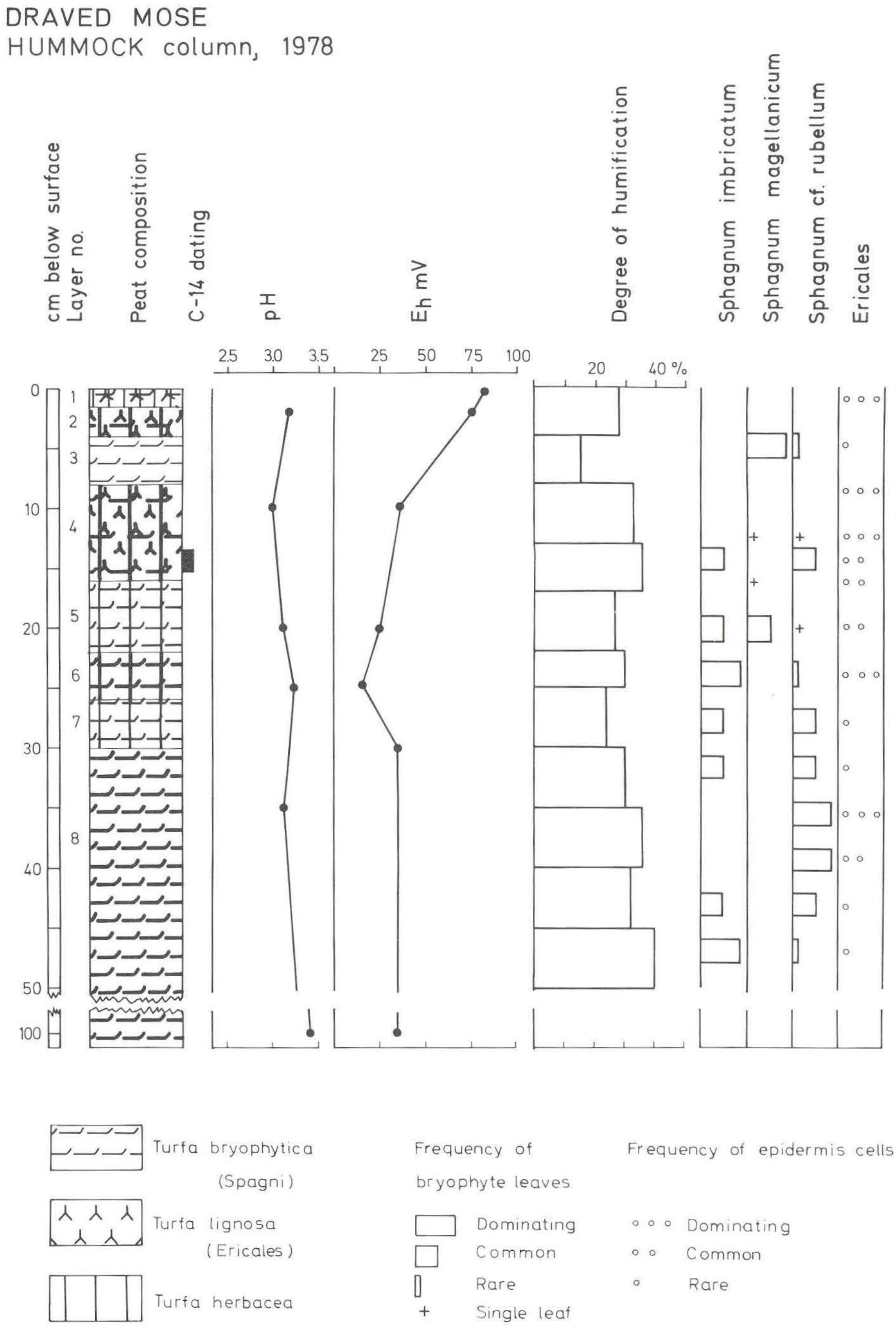


Fig. 5. Hummock column, 1978. The thickness of peat symbols indicates degree of humification.

Dating

The C-14 countings were made by the C-14 Laboratory of the Geological Survey of Denmark and the National Museum using the conventional technique and calibrated to absolute age according to Clark (1975).

The Pb-210 datings were carried out at the Danish Isotope Centre using a modified technique (Pheiffer-Madsen 1979).

History of vegetation at the sampling site

A *Sphagnum imbricatum* sociation with *Sphagnum rubellum* dominated the lower part of the profile (see figs. 4 and 5). Ericaceous plants were rather scarce. About A.D. 1300 (see K. 3127 on table 2) the *Sphagnum imbricatum* sociation was replaced by a *Sphagnum molle-Sphagnum cuspidatum* sociation in the present hollow area (fig. 4). This vegetation shortly afterwards changed to a *Sphagnum cuspidatum-Rhynchospora alba* sociation which has persisted until the present. The vegetational change about A.D. 1300 indicates that a hollow was formed, and from the profile investigations it is concluded that the location of the hollow area has been rather stable in time.

The *Sphagnum imbricatum* sociation dominated until about A.D. 1600 (see K3126 in table 2) in the present hummock area. A *Calluna vulgaris-Eriophorum vaginatum* sociation replaced the former vegetation, and various *Sphagnum* species were restricted to minor patches (e.g. layer no. 3 in fig. 5), as seen on present day hummocks. Also the youngest layers have been formed by the *Calluna vulgaris-Eriophorum vaginatum* sociation, and the actual hummock vegetation has thus existed for about 400 years.

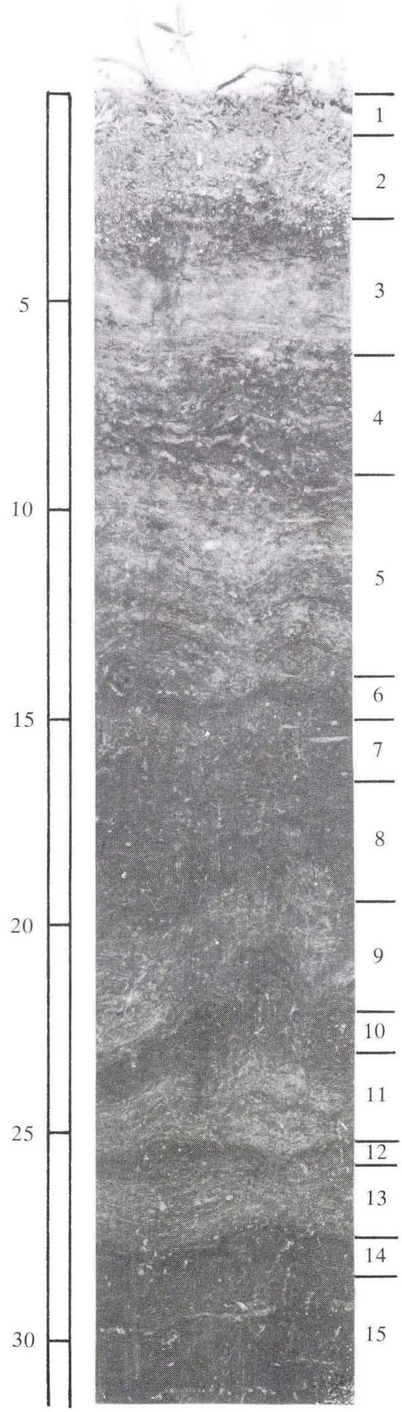
The extinction of the *Sphagnum imbricatum* sociation on the bog has been discussed by Aaby and Jacobsen (1979).

Results

Field measurements

The pH measurements showed small variations only, vertical as well as horizontal (figs. 4 and 5). The mean level is about pH 3 with a slight tendency towards increasing with depth. In the hummock a slightly increased pH was found above the water level. In the deepest part of the excavated profile the pH was between 3.2 and 3.3.

Measurements of Eh seemed to indicate the influence of the water logging.



cm b.s. Layer no.	Description
1	Present vegetation and light yellow *Sphagnum* peat containing *Cyperaceae. Oxycoccus quad., Andromeda poli., Rhynchospora alba* and *Eriophorum ang.* were present (H1).
2	Tangled grey-yellow *Sphagnum* peat with *Cyperaceae. Rhynchospora alba* and *Eriophorum ang.* were present. (H2).
3	Tangled, light yellow *Sphagnum* peat. (H1-2).
4	Similar to layer no. 3, but a little darker. (H2).
5	Tangled, yellow *Sphagnum* peat. *Rhynchospora alba* and *Eriophorum ang.* rather common (H1-2).
6	Distinct dark gray *Sphagnum* peat layer with *Cyperaceae. Eriophorum ang.* remains was frequent. (H5).
7	Light brown *Sphagnum* peat with *Cyperaceae. Rhynchospora alba* and *Eriophorum ang.* roots were found (H3)
8	Similar to layer no. 7, but a little darker. (H4).
9	Similar to layer no. 7. (H3).
10	Distinct dark chocolate brown *Sphagnum* peat with *Cyperaceae. Rhynchospora alba* was present. (H5).
11	Similar to layer no. 7. (H3).
12	Similar to layer no. 10. (H5).
13	Tangled, light brown *Sphagnum* peat. *Rhynchospora alba* was present (H3).
14	Dark chocoloate brown *Sphagnum* peat. Distinct upper limit. (H6).
15	Tangled, brown *Sphagnum* peat. (H5). *Eriophorum vag.* was found.

Sphagnum cuspidatum was the dominating *Sphagnum* species in the upper peat layers (0 – 27 cm b.s.), whereas *Sphagnum imbricatum* was the most frequent downwards.

Fig. 6. Peat stratigraphy and description of hollow column II.

Above the water table redoxpotentials are relatively high (50-100 mV) and below Eh are less than 50 mV. It should be noticed that the Eh values given are at the actual pH conditions. Corrected to pH 7 redoxpotentials varied between 215 and 310 mV.

Lead profile

The lead content on dry matter basis in hollow peat column II varied more than 1.5 order of a magnitude (fig. 7). The uppermost layer (0-4 cm) had a lead content between 32 and 110 μg Pb (g DM)$^{-1}$, ppm. From 4 to 8 cm the lead content reached the highest level, 150-350 ppm. However, the content of adjacent layers varied within 40%, indicating asynchronous deposition and increment rates on perennial basis. A level about 100 ppm was found in the interval from 8 to 14 cm, and below 14 cm the lead content diminished along a smooth gradient to a rather constant level of less than 10 ppm.

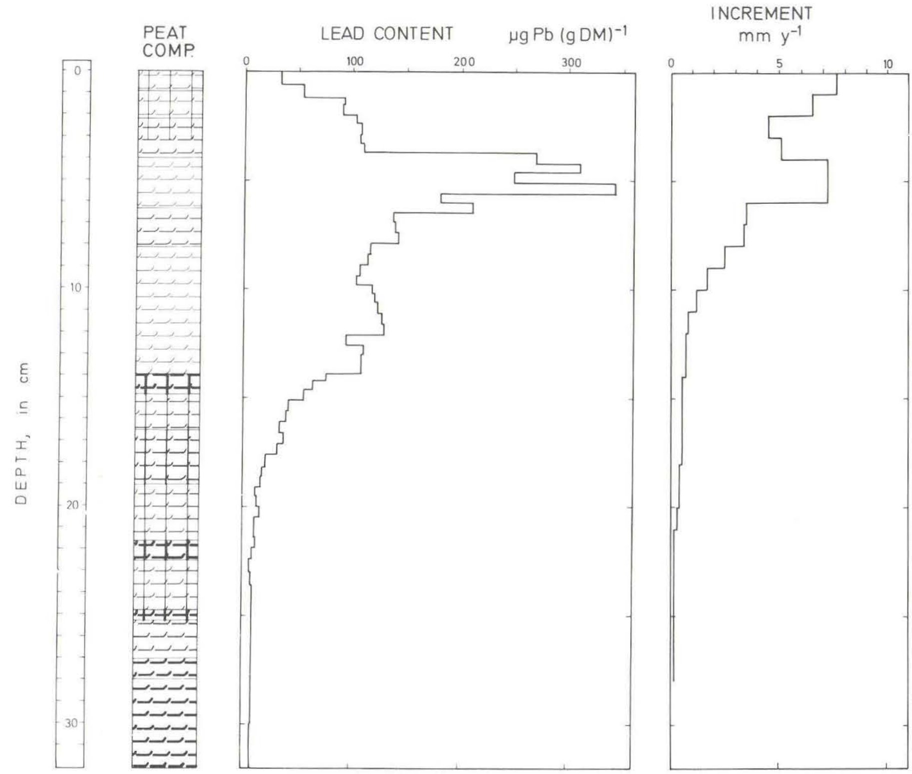


Fig. 7. Peat composition, lead content and increment profile in Draved Mose, hollow column II. Symbols of peat composition are shown in fig. 5. Increment given as 1 cm average.

Table. 1. Chemical state of lead in peat from hollow column I

Depth b.s., cm	Bulk content	collodial, dissolved or particulate (< 5 μm)	Particulate 5 - 500 μm	sorbed or chemically bound	Bulk content	collodial, dissolved or particulate (< 5 μm)	particulate 5 - 500 μm	sorbed or chemically bound
	μg (g DM)-1				‰ of total			
0 - 2	65	0.16	0.90	64	1000	2	13	985
2 - 5	112	0.18	1.14	111	1000	2	10	988
5 - 8	110	0.18	1.20	109	1000	2	11	987
8 - 12	104	0.08	0.87	103	1000	1	8	991
12 - 15	61	0.12	0.86	60	1000	2	14	984
15 - 20	26	0.07	1.16	25	1000	3	45	952
20 - 25	9.6	0.08	0.08	9.4	1000	8	8	984
25 - 30	8.8	0.06	0.06	8.7	1000	7	7	986
30 - 35	8.3	0.04	0.04	8.2	1000	5	5	990

The chemical state of lead in the peat column seemed to be correlated to the degree of humification. Lead in solution, colloidally bound or connected to particles (<5 μm) may be regarded as a semi-mobile fraction. In slightly humified peat (0-20 cm), only 1-2 ‰ of the total lead content is present in this fraction (table 1). Below 20 cm the semi-mobile fraction increased to 5-8 ‰ caused by the higher degree of humification.

The particulate bound lead fraction (5-500 μm) made up 8-14 ‰ in the uppermost 15 cm whereas below 20 cm it amounts to 5-8 ‰. In the peat layer from 15 to 20 cm the particulate lead shows an increased value, 45 ‰, probably correlated to intensive rates of humification and particle formation.

The all-dominating part, 990-984 ‰ of the total lead content, is bound or sorbed to the peat, except for the above-mentioned peat layer from 15 to 20 cm b.s.

The maximal concentration of lead found in hollow column I is less than the corresponding concentration in hollow column II (table 1, fig. 7). The areas of the subsamples in column I were 2-3 cm² compared to areas of 150-200 cm² in hollow column II. Hence the discrepancy in lead concentration can be ascribed to the statistical variation in horizontal distribution as pointed out by Aaby and Jacobsen (1979).

Pb-210 dating

The use of C-14 and Pb-210 as dating elements are based on knowledge of deposition and retention of the radionuclids in the accumulating material. Both isotopes are of non-anthropogenic origin and hence not affected by the activity of man. The C-14 is generated in the upper atmosphere by cosmic radiation of N-14, and Pb-210 is one of the daughter nuclids of U-238. The half-life of C-14 and Pb-210 are 5568 y and 22.26 y, respectively.

Investigations indicate that U-238-containing bedrocks have emitted daughter nuclids with the same ratio during a millennium at least (e.g. Marenco and Fontan 1972). The nuclear weapon let offs during the last decennia have not contributed to a significant increase in emission of U-238 daughter nuclids (Feely 1970).

Due to formation of gaseous Rn-222, which escapes the bedrock, the daughter radionuclids are uniformly distributed in the atmosphere of the originating hemisphere. Thus, a constant amount of Pb-210 has been emitted during an extended period, at least regarding localities of same latitude (Person et al. 1974). By measuring the decrease in areal content of Pb-210 in an accumulating system (sediments, peat, etc.), a calculation on a constant supply rate basis makes it possible to construct a time/depth scale.

As it is more convenient to measure the content of the α-emitting daughter, Po-210, an equilibrium between Pb-210 and Po-210 must be required. The decay of Pb-210,

β-radiation	←	Pb-210	half-life =	22.26 y
		↓		
β-radiation	←	Bi-210	half-life =	5 d
		↓		
α-radiation	←	Po-210	half-life =	138 d
		↓		
		Pb-206	stable	

shows that the equilibrium between Pb-210 and Po-210 is established very quickly. Francis et al. (1970) have shown that Pb-210 and Po-210 are in radioactive equilibrium at the time of deposition from the atmosphere.

Dating of hollow peat column II

As the Pb-210 dating procedure is a relative dating, it is necessary to use a known age-fix-point in order to obtain absolute dates. In the present study the surface of the peat column was fixed at the year 1978 as the sampling was carried out after the vegetative growth had stopped in mid-September this year.

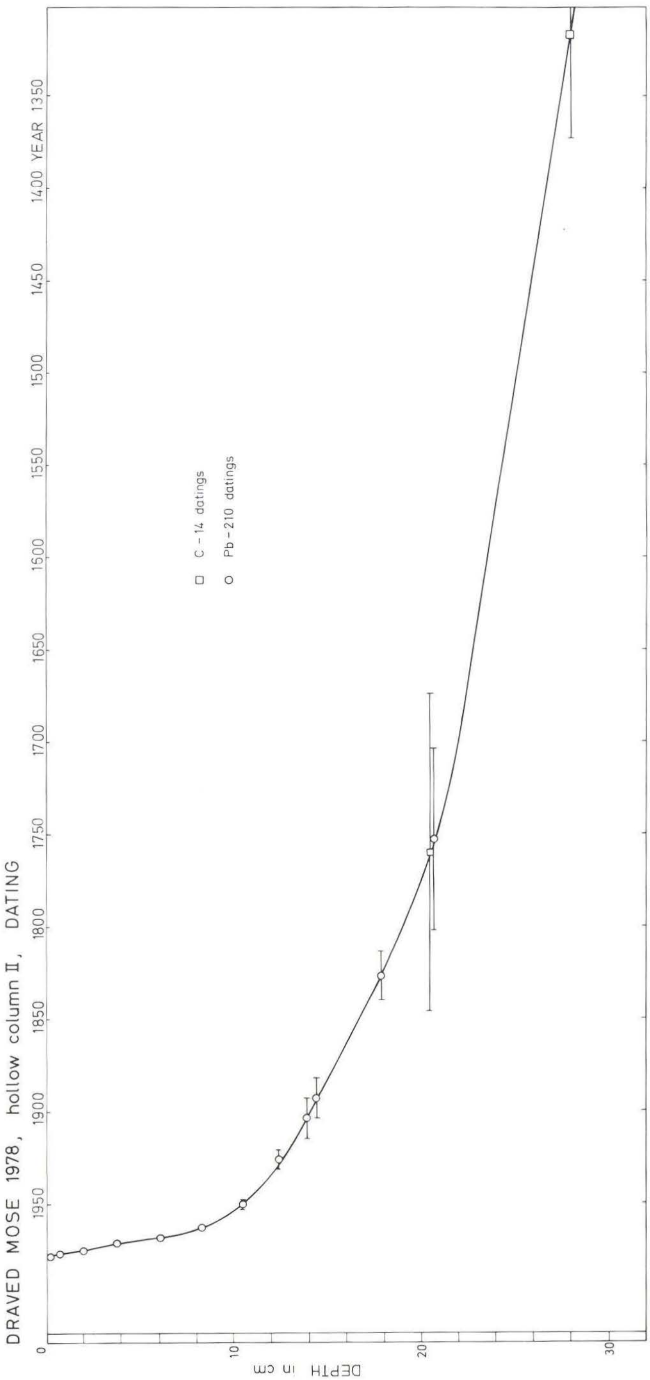


Fig. 8. Age profile in hollow column II. Horizontal bars ±SD.

Table 2. List of C-14 datings.

Location	No. Level b.s.	C-14 date before year 1950	Calendar year A.D.
Hummock	K3126 13.0-15.0 cm	330 ± 65	
		210 ± 65	
	average	270 ± 50	1605 ± 70
Hollow column I	K3127 27.0-29.0 cm	710 ± 70	
		690 ± 70	
	average	700 ± 50	1315 ± 70
Hollow column II	K 3122 19.8-21.2 cm	80 ± 110	
		170 ± 120	
	average	120 ± 75	1765 ± 90

Increased decomposition of the peat with depth and hence decreasing annual content of matrix apparently caused a higher concentration of Pb-210 in the lower part of the dating profile. As the background radiation is low (0.15 dpm (g DM)$^{-1}$), it was possible to obtain datings back to A.D. 1752 ±48 y, corresponding to 20.7 cm. This equalizes about 10 times the half-life of Pb-210.

To justify this extreme Pb-210 dating, two C-14 datings were carried out on material from 20.5 cm depth giving an average dating of A.D. 1765 ± 90 y (table 2). This mean dating is in agreement with the Pb-210 dating (fig. 8).

The applicability of the Pb-210 dating in hollow peat has been compared to datings obtained from other accumulation systems. As an ombrotrophic peat bog receives atmospheric input only, supported Pb-210 is extremely low. In contrast rather high values of supported Pb-210 are found in systems receiving considerable amounts of allochthonous material (Christensen et al. 1978; Benninger 1978). The latter author found in Long Island Sound that about 20% derived from non-atmospheric deposition (including redeposition of sediments). This caused that trustworthy datings could only be obtained 3-5 half-lives back (~100 years). Investigations in Blelham Tarn showed a disagreement between the C-14 datings and the corresponding Pb-210 datings (Pennington et al. 1976). The youngest C-14 datings obtained showed an increased age probably caused by release of organic carbon from agriculture in the watershed, (Pennington et al. 1976). The C-14 datings in Draved Mose seem reliable as no support of C-14 from a hydrological catchment area is present.

Increment rates in hollow column II

Increment rates have been calculated for each 1 cm layer to 20 cm below the surface based on the Pb-210 dates. The mean increment rate in the layer 20.5-28.0 cm (A.D. 1765-1315) is based on C-14 dates only (fig. 7).

The annual increment of the uppermost material was 7.6 mm y^{-1} and is considered to represent the annual vertical gross deposition of organic matter from the *Sphagnum* vegetation. In accordance with this, Hansen (1966) estimated an increment of *Sphagnum cuspidatum* in Draved Mose by measuring the annual internodal growth of *Drosera intermedia* at 6-14 mm y^{-1} (n=4).

Judging from the increment values a considerable compaction takes place in the uppermost part of the aerobic zone, at 0-4 cm. At 4-6 cm depth the increment values are high (7.2 mm y^{-1}) due to lower degree of humification (fig. 6). The layer at 6-8 cm differs from the previous layer by a higher degree of humification and the increment values are approx. 50% smaller. Below 8 cm the increment values decrease gradually, and from 20.5 to 28.0 cm the mean annual increment is 0.2 mm y^{-1}, or only about 3% of the original thickness of one year's deposit.

Calculation of lead deposition

Lead deposition was calculated from measurements of lead concentration, bulk density, and dating in hollow column II representing the period A.D. 1978-1580. Some premises have to be considered:

(1). The physical environments and the micro climate must have been constant during the entire period used for the calculations.

(2). Pb-210-lead must be fixed in the peat similar to C-14-carbon.

Regarding item 1, Draved Mose belongs to the oceanic type of plateau ombrotrophic peat bogs, and hence no arboreal vegetation has been present (fig. 2). Further, the formation of the hummock-hollow structure was completed more than 600 years ago at the sampling site (p. 52). Hence it is concluded that the microtopography and the vegetation has been extremely constant during this period.

As for item 2 several measurements have confirmed that lead is fixed to the hollow peat layer in which the lead is precipitated. Experiments on peat sorption capacity of heavy metals have shown an extremely high degree of fixation ability (unpublished data; Rühling and Tyler 1970). This is in agreement with the adjoining datings of C-14 and Pb-210 about A.D. 1750. According to the chemical state of lead in the peat profile (table 1), less than 2 ‰ of the total lead content is present in the semi-mobile fraction indicating that none or only a minor part of the lead is translocated vertically.

As the calculation of lead deposition rates is based on Pb-210 datings, no time depending disagreements seem possible.

Integration over time and depth using a variable discrete time step is chosen to minimize the uncertainty of the calculations. As the annual increment decreased by a factor 35 from the top to the bottom of the column (fig.7), the time steps used were 50 years during 1600-1700, 20 years during 1700-1900, 10 years during 1900-1950, and 5 years after A.D. 1950 (fig. 9).

The lead deposition during the period A.D. 1600-1800 seems to have been rather constant, about 0.5 mg Pb $m^{-2}y^{-1}$. During A.D. 1800-1900 the deposition rate increased and reached a value of 5 mg Pb $m^{-2}y^{-1}$ around the turn of the 20 th century after which a rapid elevation in lead deposition took place. From A.D. 1900 to A.D. 1950 the rate more than doubled and reached a level of about 15 mg Pb $m^{-2}y^{-1}$. An enormous escalation took place during the sixties, to approx. 60 mg Pb $m^{-2}y^{-1}$, and the deposition seems to have stagnated or even decreased through the seventies to a level less than 50 mg Pb $m^{-2}y^{-1}$.

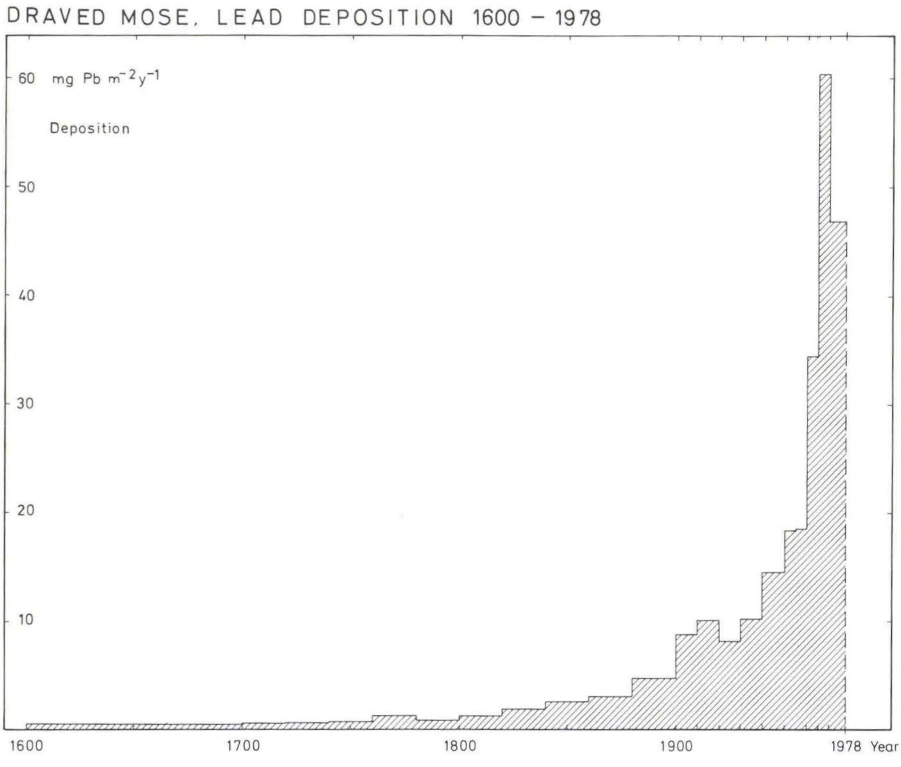


Fig. 9. Lead deposition in hollow column II, Draved Mose A.D. 1600-1978.

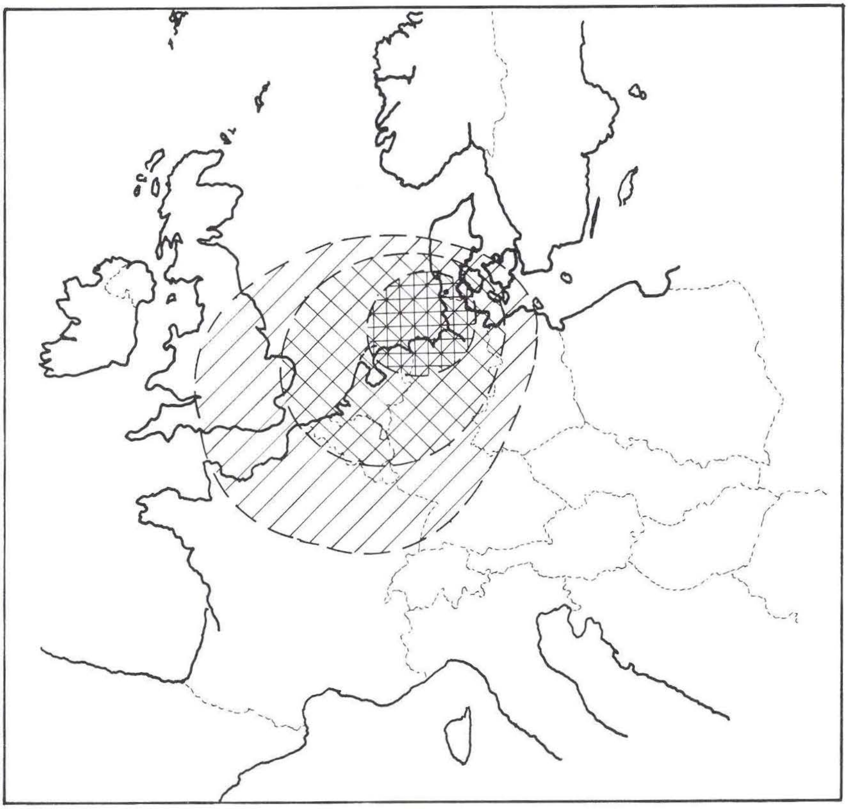


Fig. 10. Emission areas for airborne lead found in Draved Mose. Calculations are based on the seasonal variation of wind direction, wind frequency and lead deposition. Intensity of shading corresponds to the deposition probability in Draved Mose.

The vicinity of Draved Mose has not changed radically during the last centuries except for an intensified farmland use giving an increased deposition of soil dust during the last century. As shown by Aaby and Jacobsen (1979) the annual input of soil dust does not influence the measured lead deposition values markedly. The localization only 20 km from the North Sea and far from main roads and industrial areas means that mainly regional changes in air pollution have affected the development in lead deposition in Draved Mose.

The most frequent wind direction in the area is southwest. Based on seasonal variations of wind direction, wind frequency, and lead deposition (Hovmand 1977), a map of emission areas was calculated (fig. 10). Investigations of airborne transport of mildew conidia (Hermansen et al. 1974; Hermansen and Stix 1974) seem to confirm the calculated emission areas. Western Germany, The Nether-

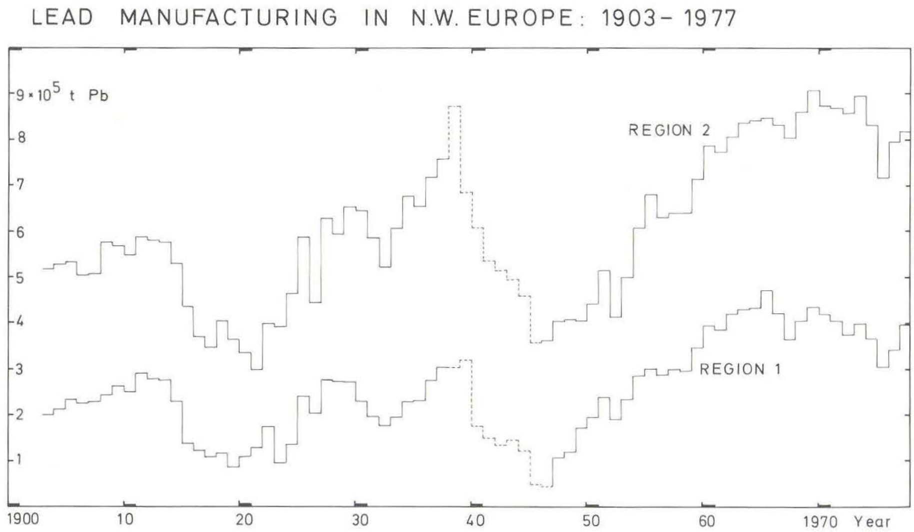


Fig. 11. Lead manufacture in selected areas of N-W Europe. Region I: Germany, Holland and Belgium. Region 2: Germany, Holland, Belgium, France and England.
Levels drawn with dotted line indicate calculated manufacture figures.

lands, Belgium, Northern France and Southwest England thus seem to be the most important source areas for airborne lead deposit at Draved Mose.

Consulting the metal statistics of N-W Europe detailed information on lead production, manufacture, and consumption has been available since the start of the 20th century (fig. 11). Primary and secondary smelters must be potential emittants. The lead manufacture industry has developed since A.D. 1700. During the 19th century the lead manufacturing was concentrated in industrial centres in Germany, Belgium, France and England. Consequently, a long-distance dispersal of air pollution was introduced, and a close relation between lead manufacture and emission must be expected.

As shown in fig. 9 and fig. 11 a nearly synchronous development of lead manufacture in Germany, France, Benelux and England and lead deposition in Draved Mose is found up to A.D. 1950. Even the decline in lead manufacture during the industrial depression during 1915-1925 seems to be reflected in the deposition rate.

Since 1950 the deposition rate increased enormously. This does not correspond to a parallel rise in the activity of lead manufacture, but may be explained by the introduction of tetraethyl-lead as an antiknocking agent in high octane petrol (fig. 12). Based on the curves in figs. 9 and 11 it is supposed that approx 70 % of the lead deposited on Draved Mose derives from alkyl-lead.

It has been pointed out that the use of coal and alkyl-lead petrol contributed by

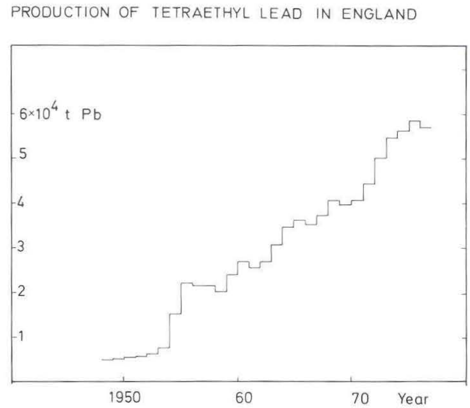


Fig. 12. The production of tetraethyl-lead (antiknocking agent) in England, 1948-1976.

the same amounts to lead emission (Jaworowski 1967). Coal burning contributes to lead emission, but neither statistic correlation between coal consumption and the measured increase in lead emission nor calculation of lead budgets in coal burning processes (Murozumi et al. 1969) would seem to support this suggestion of Jaworowski. Furthermore, airborne lead from coal burning is believed to be associated to »large-particle fractions« and consequently not dispersed over long distances.

An anthropogenic lead increase of 100 times the natural background deposition originating from earth-dust, vulcanic activity, and seaspray seems to agree with the results obtained from the inland ice of Greenland. Murozumi et al. (1969) found an elevation in lead concentration of two orders of magnitude from A.D. 1750 to A.D. 1965.

The absolute annual deposition of lead in Draved Mose is very high compared to measurements on bulk precipitation trapped in rain gauges. Hovmand (1973 and 1976) found values between 7 and 20 mg Pb $m^{-2}y^{-1}$ or 3-8 times lower than results obtained in this investigation (50-60 mg Pb $m^{-2}y^{-1}$).

As mentioned by Hovmand (1976) the rain collectors disregard deposition due to impaction and from aerosols. Flyger et al. (1976) found that lead from petrol engine exhaustion is associated with particles less than 0.5 μm. Consequently, airborne exhaustion particles are non-sedimentary. The most important deposition mechanisms are considered to be rain-out, drop nucleation, and filtration.

Groet (1976) has measured deposition rates as high as 43 mg Pb $m^{-2}y^{-1}$ in woodland areas by analysing the lead content in *Leucobryum* carpets. He found accordingly a very high regional deposition level, corresponding to the present investigation.

Discussion and conclusion

Ombrotrophic peat bogs have obvious advantages as recorders of past and present deposition rates. It is possible to select sites which have had an extremely stable biotic and physical environment during extended periods. Influx of allocthonous organic matter and bioturbation are insignificant. Finally, the deposited material can be dated with high accuracy.

The hollow areas are preferable to hummock areas because of less complexity in the hydrology, the biological structure, and the chemical processes. The water table is generally located close to the hollow surface and the peat is saturated most of the year. Accordingly, the »wash-down« or »rain-down« effect is much smaller than in hummock areas. The structure of the vegetation may influence the deposition efficiency; in hollows the dense structured *Sphagnum* carpet favours the immediate retention of the precipitate.

The hummocks are dominated partly by vascular plants with roots penetrating the aerobic zone to a depth of 20-25 cm and partly by *Sphagnum* species which derive their nutrients from the uppermost 2-3 cm. In contrast, a *Sphagnum* vegetation dominates the hollow areas, and the sparse vascular plants have superficial roots only. Secondary chemical changes caused by selective uptake from peat layers of different ages may be of some importance in hummock peat whereas these changes are negligible in hollow peat because the upper peat layers represent a short time span only.

Small organic particles ($< 1\ \mu m$) may be translocated in peat and function as carriers of chemical compounds. Hollow peat is only moderately disintegrated having a small particulate fraction $<1\ \mu m$, and the »wash-down« effect is supposed to be insignificant. The disintegration and formation of humus particles are more intensive in the hummock peat, and some translocation of elements may appear.

The lead deposition rates obtained from hollow column II have been compared with data from another hollow on the bog (Aaby and Jacobsen 1979). The mean deposition rate in hollow column II (47 mg Pb $m^{-2}y^{-1}$; A.D. 1970-1978) is within the variation found in *Sphagnum magellanicum* patches growing on hummocks in 1973 (41 ± 10 mg Pb $m^{-2}y^{-1}$; n=9). The cumulative lead content (A.D. 1605-1978) from hummock I and hollow II is 2000 mg Pb m^{-2} and 2200 mg Pb m^{-2}, respectively. Aaby and Jacobsen (1979) reported a corresponding lead content (A.D. 1530-1973) of 3200 mg Pb m^{-2} and 2200 mg Pb m^{-2}. These results indicate no general difference in deposition efficiency in hummock and hollow areas.

Thus, it is concluded that the annual deposition values from hollow column II are representative of the bog and may be considered the general background deposition rate in southwest Denmark and Schleswig, at least in areas of similar topo-climatic conditions (e.g. pastures, meadows and moorlands).

It is essential for the interpretation of the lead profile that a time/depth scale is established, and that the concentrations are corrected for changes in bulk density. Sillanpää (1972) concluded based on concentration curves only, cit. »The concentration of trace elements (including Pb) in the surface of the peat soils can be explained as a result of elementlifting activity of the most recent generations of plant«; but the results might as well be explained by the supply of lead from the atmosphere, as pointed out by Pakarinen and Tolonen (1977). These authors in turn claim that a concentration maximum found below the surface is indicative of leaching. This might, however, be a consequence of changes in bulk density and increment rates as demonstrated in this study (see figs. 7 and 9).

The lead profile from a hollow column sampled in Store Mosse, Småland, Sweden (Damman 1978) resembles the lead profile from Draved Mose. Unfortunately, Damman has not dated the material and thus, the two profiles cannot be compared further. Based on the concentration profile and budget considerations, Damman states that the lead has been removed almost completely from the anaerobic zone. However, the data reported might as well be explained by recent increased atmospheric input of lead. In addition, the leaching mechanism claimed to be active seems to be unrealistic.

Based on the lead concentrations in surface moss samples (including *Sphagnum*) from different parts of N-W Eruope, a regional deposition pattern has been established (Rühling and Tyler 1971; Hvatum 1972; Pakarinen and Tolonen 1977). The concentration level in Draved Mose is in accordance with this pattern. In addition, the lead deposition rates obtained from Draved Mose have been compared with Danish data from bulk precipitation, sampled at rural stations in the period 1973-1976 (Hovmand 1977). The reported deposition rates (7.0-21 mg Pb $m^{-2}y^{-1}$) are much smaller than the mean value (47 mg Pb $m^{-2}y^{-1}$) in the same period found in the present study. As the fixation of lead in hollow *Sphagnum* tissue is evidenced, translocation can be neglected, and the high values found in the bog are attributed to natural deposition conditions. In general it is difficult to simulate deposition rates when sampling atmospheric bulk precipitation.

In the neighbouring forest, Draved Skov, Rasmussen (1977) has shown a raise in lead concentration in epiphytic mosses of 65% during the period 1951-75. As indicated by the author a development of the sampling area has taken place and accordingly, the deposition conditions have changed. An increase in lead concentration of an epiphytic moss (*Pterogonium gracile*) from Slotved Skov, N. Jutland, exceeded 150% during the period 1944 to 1976 (Johnsen and Rasmussen 1977), which is in fairly good agreement with the present investigation.

In defiance of very constant sampling areas in epiphytic and epigeic vegetation, differences and changes in exposure and environment make time-dependent comparisons less suitable than an accumulating ombrotrophic system.

Conclusively, ombrotrophic peat bogs must be categorized as optimal recording areas for most airborne depositive materials. Furthermore, the regional deposition of long-distance dispersed lead on natural surfaces has increased by a factor 20-40 due to lead manufacture and by a factor 60-80 due to consumption of alkyllead petrol.

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Dansk sammendrag

En forbedret Pb-210 dateringsmetode er blevet afprøvet på materiale fra Draved Mose i Sønderjylland. Dateringsproceduren bygger på, at et konstant nedfald af Pb-210-bly, der er en af datterradionucliderne fra U-238, har aflejret sig i mosens tørv. Derved er det muligt at bestemme tørvelagenes alder 7-10 halveringstider tilbage (150-200 år). Dette muliggør, at man kan fortsætte en kontinuert tids-dybde-skala ved hjælp af C-14-metoden tilbage til mosens dannelsestidspunkt (ca. 8000 f.Kr.).

En nøjagtig aldersbestemmelse af de yngste aflejringer i et ombrotroft system åbner hidtidig ukendte perspektiver for en beskrivelse af industrialiseringens udvikling op til i dag.

I nærværende arbejde er blynedfaldet over den sydvestlige del af Danmark gennem de sidste 600 år blevet beskrevet i detaljer. Fra 1300 e.Kr. til op i 1700-tallet var det årlige nedfald gennemsnitlig 0,5 mg Pb m^{-2}, hovedsagelig stammende fra jord- og havstøv. Herefter skete der en langsom stigning til starten af det 20. århundrede, hvorefter blynedfladet steg kraftigt, dog med fluktuationer svarende til svingninger i blyforarbejdningen i Nordvesteuropa. Efter 1945 har man målt en ekstrem stigning i det årlige blynedfald med en foreløbig top i 1965-1970 på omkring 55 mg Pb m^{-2}. Denne stigning i efterkrigstiden, som ikke afspejler en større forarbejdning af bly eller anvendelse af kul, må tilskrives anvendelsen af tetraethyl-bly som superbensinadditiv. Skønsmæssigt må benzinblyet udgøre ca. 70% af det totale blynedfald, mens bly kommende direkte fra industri andrager ca. 30%.

Endvidere er den kontinuerte aldersbestemmelse blevet anvendt til en detaljeret beskrivelse af pålejringshastighederne.

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Identification of wild grass and cereal pollen

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Andersen, S.T.: Identification of wild grass and cereal pollen. *Danm. geol. Unders., Årbog 1978*, pp. 69-92. København. 1979.

Annulus diameter and size in pollen of 80 North European Poaceae species were measured. Annulus diameter was considered more reliable for identification of fossil pollen than pollen size because annulus is less modifiable and can be measured on all grains. Surface sculpturing is also useful for identification, and pollen size is useful in cases where preservation is good or moderately good. Pollen of *Glyceria* sp., *Hordeum vulgare* or *Agropyron repens, Secale cereale* and *Avena sativa* were identified in Holocene deposits.

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Due to their uniformity, identification of Poaceae pollen is very difficult and has been considered self-evident only in a few cases *(Secale cereale* and *Zea mays).* Since the publication of Firbas (1937) fossil cereal pollen and wild grass pollen have been distinguished mainly by size criteria; however, this method is not without problems. Other morphological characters mentioned in identification keys are annulus or pore diameter, annulus protrudence and delimitation, and surface sculpturing.

The usefulness of morphological characters for identification of fossil Poaceae pollen

The identification of fossil Poaceae pollen is hampered by the large number of species likely to be represented, by wide overlappings in dimension ranges, and by variability of qualitative characters. Further difficulties arise from size variations due to fossilization and preparation. Bimodality or skewness in size frequency-distribution curves from fossil pollen assemblages may indicate components with different distributions for the dimension measured.

(1) *Pollen size.* Firbas (1937) found that the pollen grains of common cereals are larger than those of the majority of wild grasses occurring in Central Europe,

and showed bimodal size-frequency curves for fossil pollen indicating a mixture of small wild grass pollen and large pollen belonging to cereals or anthropochorous wild grasses. His method has been used i.a. by Troels-Smith (1955) and Beug (1961). Difficulties arise from the fact that fossil Poaceae pollen tend to crumple, and from other modifications of pollen size. The large cereal pollen grains thus crumple more easily than the small wild grass pollen; if only inflated grains are measured in a fossil sample, a size-frequency distribution curve becomes biassed except for cases where preservation is perfect. Troels-Smith (1955) tried to overcome this difficulty by measuring the average diameter rather than the largest diameter in all grains, both inflated and crumpled. Due to the fact that grass pollen grains rarely are spherical, the average diameter of fossil pollen grains must be compared with the same dimension measured in modern grains. The method fails in cases of broken grains (cp. Troels-Smith 1955) or severe crumpling. Accurate measurement is also hampered by variations due to chemical treatment or fossilization conditions, and by swelling if the pollen grains are mounted in glycerol and the slide thickness is smaller than the smallest diameter of the grains (Cushing 1961). Size variations can be eliminated if *Corylus* pollen grains can be measured (Troels-Smith 1955), and swelling of the large cereal pollen grains can be avoided if silicone oil is used as a mounting medium (Andersen 1978b).

(2) *Annulus and pore diameter.* Beug (1961) showed that wild grass and cereal pollen can be distinguished by measurements of annulus width and pore diameter, and Fægri & Iversen (1964) and Leroi-Gourhan (1969) used annulus diameters for the same purpose. Pore diameter and annulus width are difficult to measure, and size-variation curves cannot be produced because a sufficiently small size-class (< 0.5 μm) is unobtainable with a light microscope. Annulus diameters are sufficiently large for measurement with dry-system objectives (size class about 1 μm); they can be measured on all fossil grains and are not modified by pressure from the cover slip.

(3) *Thickness or protrudence and delimitation of annulus.* Beug (1961) and Fægri & Iversen (1964) used these characters as additional criteria for the distinction of pollen of wild grasses and cereals. These characters can only be observed on suitably orientated pollen grains.

(4) *Surface sculpturing.* Grohne (1957) showed that two kinds of sculpturing observable with phase contrast equipment occur in wild grass and cereal pollen, and Beug (1961) distinguished three sculpturing types. Fægri & Iversen (1964) used several terms for description of the surface sculpturing (scabrate, areolate, maculate, verrucate). Electron microscope studies (Rowley 1960, Andersen & Bertelsen 1972, Nilsson et al. 1977) have shown that essentially two types of sculpturing occur: scabrate and verrucate, in the terminology of Iversen & Troels-Smith (1950). The scabrate and verrucate sculpturing can be observed in

phase contrast and can be used for a distinction of certain cereals (Grohne 1957, Beug 1961, Andersen & Bertelsen 1972). Morphological variation and the fact that phase contrast may be difficult to apply to pollen grains that are not well preserved may cause difficulties.

In the present work annulus diameter is considered the most important character for identification of Poaceae pollen, and size and surface sculpturing are considered characters of secondary importance. Measurements of modern pollen and fossil pollen assemblages are shown below.

Material and methods

Modern pollen. Modern pollen from a large number of Poaceae species was prepared and measured under the supervision of Johs. Iversen in connection with the preparation of the pollen key in Fægri & Iversen (1964). Additional material was prepared later. Pollen was collected in nature from flowering specimens and in some cases from herbarium specimens. Each collection usually comprised several individuals. 80 species were examined; in some cases several collections from the same species were prepared.

Dried flowers were mixed with *Corylus avellana* pollen from various sources (see Andersen 1978b), boiled in KOH, sieved, acetolyzed for 1 minute, and transferred to silicone oil via water, ethanol and benzene. Benzene was used as a solvent because it evaporates more quickly than other solvents. Silicone oil was added to the pollen residue transferred to small vials. Surplus benzene was evaporated for one day at room temperature, later in a thermostat cabinet at 50°C. The microscope slides were sealed with cellulose lacquer, later with paraffin (see Andersen 1978b).

Fossil pollen. Fossil Poaceae pollen in sediment and soil samples from Eldrup Forest, Denmark (cp. Andersen 1978a), were measured. The moist or dried samples were boiled in KOH, HF, acetolyzed, and mounted in silicone oil. Benzene was evaporated at 50°C. The pollen grains were measured in unsealed slides.

Measurements. The following parameters (cp. Iversen & Troels-Smith 1950) and statistical expressions were used,

Slide thickness, cp. Andersen (1978b)

M+, largest diameter of a pollen grain

M-, diameter at a right angle to M+

$\frac{M+ + M-}{2}$, average diameter, pollen size

M+/M-, pollen index

anl-D, annulus diameter

n, number of grains measured or samples compared

$\bar{x}$, arithmetic mean or average of groups of means

s, estimated standard deviation
C, coefficient of variation, numerical value of standard deviation in % of the mean
95% confidence interval of normal distributions
sk, third moment-skewness
v.r., variance ratio
r, coefficient of correlation (least squares)
P, probability of a null-hypothesis. A null-hypothesis is rejected if P is less than 0.05 (marked with an asterisk. Two asterisks indicate rejection at the 0.01 level, three at the 0.001 level).

Poaceae pollen tend to orientate themselves with their largest diameter parallel to the surface of the microscope slide. Only inflated grains were measured in modern samples, inflated and crumpled grains in sediment samples. Inflated *Corylus* grains were measured when seen in polar view (M+ = Lt+). Annulus diameters of Poaceae pollen were measured irrespective of orientation. Size class units were 1.125 and 1.15 μm (M+ and M- of modern grains) and 1.20 μm (M+ and M- of fossil grains and anl-D). 100 modern Poaceae and *Corylus* grains were measured; n for sediment samples varied.

Variation in measured dimensions due to chemical treatment and mounting procedure

Andersen (1978b) showed that *Corylus avellana* pollen measured simultaneously with the Poaceae pollen varied in average size even when drawn from the same source. The size of *Corylus* pollen was influenced by the presence of small remnants of solvent and by the mounting procedures. Variation within a *Corylus* source and size differences between the *Corylus* sources were eliminated if benzene was thoroughly removed and the slides sealed with paraffin.

Fægri & Iversen (1964) showed that size differences among various pollen types mounted in silicone oil and in glycerol are similar to the differences in *Corylus* pollen measured in the same slides. Their table 2 includes four Poaceae species from 26.52 to 39.41 μm in mean size in silicone oil. The increase in glycerol slides is correlated with the increase in *Corylus* pollen size (r = 0.996, P = 0.004**).

Annulus diameters measured on pollen of 37 Poaceae species mounted in silicone oil were compared with annulus diameters of the same species on pollen mounted in glycerol (Beug 1961, *Tabelle* 1, anl-D = *Pore-Durchmesser* + *Annulus Breite* × 2). The annulus diameters in glycerol were slightly larger than those measured in silicone oil ($\bar{x}$ = 1.28, C = 12.20, r = 0.905, P <0.001***). It can be concluded that annulus diameter like pollen size is modified by chemical treatment and mounting procedure.

Standardization of measurements according to *Corylus*

One can assume that modern Poaceae pollen varies in the same way as *Corylus* pollen. As changes in Poaceae and *Corylus* pollen size are correlated, and the size of the *Corylus* pollen collections mixed with the Poaceae pollen is uniform, the size measurements of Poaceae pollen could be standardized by means of the *Corylus* measurements. The standardized *Corylus* pollen size was 24.5 μm, which is close to the size of *Corylus* pollen in noncalcareous sediments (treated with KOH, HF, acetolyzed and mounted in silicone oil, Andersen 1978b). The variation of the individual *Corylus* measurements is small (95% confidence interval = 2% of the mean) and was disregarded.

Pollen grains in silicone oil-slides thinner than their smallest diameter are compressed by the cover slip, and their size may increase slightly due to deformation (up to 6%), whereas the size does not increase further at storage (Andersen 1978b). Large Poaceae pollen in thin slides may thus be slightly too large, whereas the small *Corylus* pollen grains have not increased. Slide thickness was measured in all Poaceae collections in which the smallest pollen diameter was larger than 30 μm. Pollen size may change slightly with storage in silicone oil. Size changes in *Corylus* and Poaceae pollen are correlated; hence measurements carried out a long time after the preparation can be compared with other measurements.

Average mean size and variance between *Glyceria* and *Secale* collections before and after standardization are compared in table 1. The *Glyceria* means were not correlated with the *Corylus* means, and the variation did not decrease significantly after standardization; whereas the *Secale* means were correlated with the *Corylus* means, and variation decreased significantly. Original differences among the *Glyceria* collections thus exceeded differences due to treatment, and the *Secale* collections varied more due to treatment than they did originally. Standardization of pollen size thus may reduce differences caused by treatment.

Annulus measurements of *Glyceria* and *Secale* collections are compared in table 2. The annulus diameters were not correlated with the *Corylus* means, and

Table 1. Average pollen size in *Glyceria fluitans* and *Secale cereale* collections before and after standardization (*Corylus* 24.5 μm). $\bar{x}$ = mean, C = coefficient of variation.

		original		standardized			correl. w.	*Corylus* $\bar{x}$
		$\bar{x}$	C	$\bar{x}$	C	v.r.	*Corylus* $\bar{x}$	range
	n	(μm)	(%)	(μm)	(%)	(P)	(P)	(μm)
Glyceria	6	35.00	5.43	34.47	4.58	0.350	0.260	22.84-26.21
Secale	8	39.24	7.18	40.10	3.53	0.046*	0.003**	23.22-26.48

Table 2. Average annulus diameter in *Glyceria fluitans* and *Secale cereale* collections before and after standardization (*Corylus* 24.5 μm)

	n	original $\bar{x}$ (μm)	original C (%)	standardized $\bar{x}$ (μm)	standardized C (%)	v.r. (P)	correl. w. *Corylus* $\bar{x}$ (P)	*Corylus* $\bar{x}$ range (μm)
Glyceria	5	9.70	7.28	9.56	9.30	0.33	0.55	23.69-26.12
Secale	9	8.97	7.08	8.90	6.62	0.42	0.25	23.59-26.48

the variation did not change significantly. It can be concluded that original differences among collections exceeded the variation due to treatment, and that standardization of annulus measurements is unnecessary.

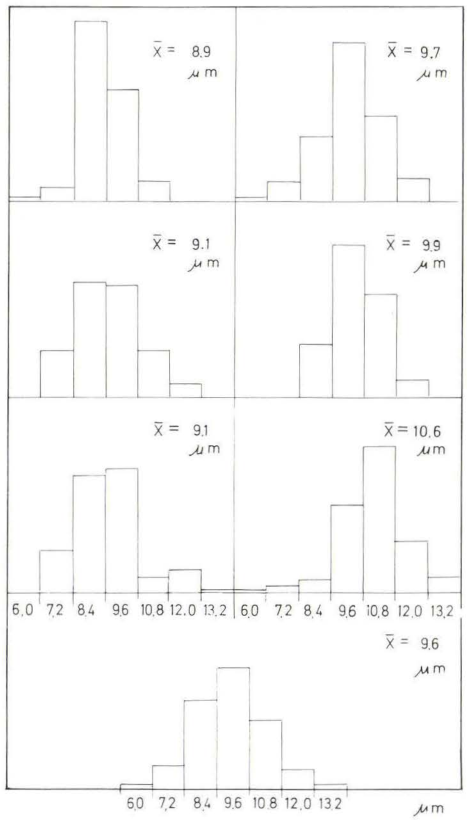

Fig. 1. Glyceria fluitans, annulus diameter. Frequency distribution in 6 collections, and composite population.

Differences among collections. Composite populations

The examples mentioned above show that various collections of a Poaceae species may differ in respect to annulus diameter and pollen size. Each collection represents individuals growing together at one locality. Fossil Poaceae pollen assemblages are likely to derive from an infinite number of individuals in a more or less wide area. The best way to find mean and variance for an infinite population of a species is to measure pollen in surface samples; however, this procedure is impossible for grasses, as the pollen assemblages in surface samples are likely to include many species. Instead, composite populations based on individual collections were calculated for species represented by two or more collections.

The measurements of annulus diameters were performed with the same size class unit. Hence, the number of pollen grains found in identical size classes in the various collections could be added, and size-frequency distribution, mean, and variance of a composite population were calculated (fig. 1). Composite populations were calculated for critical species; it is believed that they express mean size and variation of the species better than the individual collections.

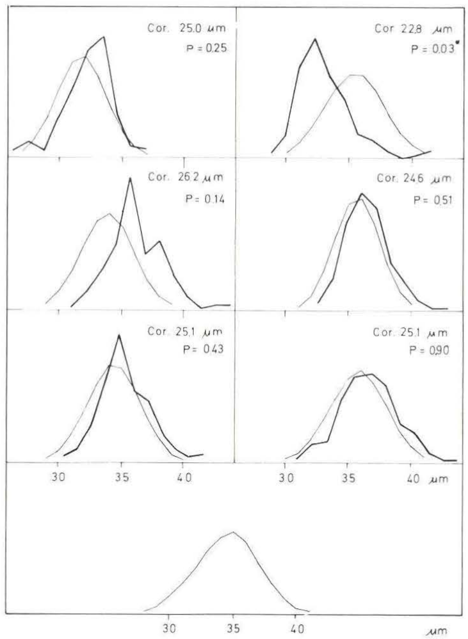

Fig. 2. Glyceria fluitans, pollen size. Measured frequency distributions, standardized (*Corylus* 24.5 µm) and normalized distributions in 6 collections, and composite population. Mean size of *Corylus* pollen and probability of normality (P) for measured distributions are indicated.

Composite populations could not be calculated directly for pollen size because the size class units in individual collections differed. Five out of six size measurements of *Glyceria fluitans* pollen were normally distributed (fig. 2), and it was assumed that the size-frequencies in individual collections generally are normally distributed. A normal distribution based on the standardized mean and variance was calculated for each collection within a species, and the calculated distributions were added to form a composite population as described for the annulus measurements (size class interval 1 μm, fig. 2).

Pollen-morphological characteristics of modern Poaceae species

Data on annulus diameter, standardized pollen size, and pollen index for 80 Poaceae species are shown in table 3 and in fig. 3. Slide thickness is indicated for collections with mean pollen size larger than 30 μm. It was not possible to include all Poaceae species from Northern Europe, and composite populations could only be established in critical cases.

Coefficient of variation (C) reflects homogeneity of individual collections. C for annulus diameter varies from 8.5 to 20.2 and C for pollen size from 3.9 to 9.8. A few collections show a higher C, which might indicate contamination with pollen from another species. *Holcus mollis, Poa compressa, Phleum phleoides* and *Nardus stricta* have high C for annulus diameter (22.5, 21.6, 22.6, 24.7) and *Calamagrostis arundinacea* and *Holcus mollis* high C for pollen size (11.1 and 11.4). The *Holcus mollis* collection may thus contain pollen from another species (with larger pollen), whereas the large variation noticed in only one of the measured dimensions in the other species presumably is accidental.

Slide thickness was considerably smaller than mean pollen size (> 10 μm) in one case *(Secale cereale*, 22 μm); pollen size in this collection was disregarded.

(1) *Annulus diameters*. The species in fig. 3 are arranged according to increasing mean annulus diameter. They were divided into groups and subgroups.

I, mean annulus diameter smaller than 8 μm
- a, no grains with anl-D > 8 μm
- b, 1 - 20% of the grains with anl-D > 8 μm
- c, 20 - 40% of the grains with anl-D > 8 μm

II, mean annulus diameter 8-10 μm, grains with anl-D 8-10 μm predominate.

III, mean annulus diameter larger than 10 μm, grains with anl-D > 10 μm predominate.

Group I comprises only wild grasses, group II wild grasses and cultivated species, and group III cultivated species and one wild grass species.

(2) *Pollen size* (fig. 3). The mean size of pollen grains from cultivated species are larger than 37 μm and only a few wild grasses surpass this limit *(Hordeum*

Table 3. Annulus diameter (anl-D), pollen size (standardized, *Corylus* = 24.5 μm), pollen index and slide thickness (M- > 30 μm) for individual and composite collections of 80 Poaceae species. x̄ = mean, C = coefficient of variation.

	anl-D x̄ (μm)	anl-D C (%)	size x̄ (μm)	size C (%)	index	slide thickn. (μm)
Agropyron caninum L.	6.84	13.7	34.33	9.47	1.07	35
– *junceiforme* A.&D. Löwe	8.89	16.5	39.72	6.92	1.12	32
– *repens* (L.) Beauv.	9.11	14.0	37.33	7.47	1.09	48
– –	8.63	12.3	37.48	8.59	1.11	45
– –	8.68	12.6	38.37	7.63	1.12	45
– – , 3 collections	8.80	13.2	37.72	7.67	1.11	
Agrostis gigantea Roth.	5.72	15.7	22.63	5.62	1.06	
– *spica-venti* L.	6.08	14.0	23.84	5.65	1.06	
– *stolonifera* L.	7.28	12.6	23.57	6.37	1.10	
– *tenuis* Sibth.	6.66	12.8	25.94	7.08	1.05	
Alopecurus geniculatus L.	5.82	20.1	24.91	7.72	1.10	
– *myosuroides* Huds.	6.18	13.8	28.65	9.06	1.14	
– *pratensis* L	6.55	16.0	20.96	6.53	1.08	
Ammophila arenaria (L.) Lk.	8.44	14.9	32.00	7.73	1.13	33
Anthoxanthum odoratum L.	6.66	14.3	29.73	9.81	1.08	
Avena elatior L.	7.51	16.0	31.42	5.46	1.13	33
– *fatua* L.	11.93	10.3	44.24	4.46	1.17	
– *nuda* Höjer	11.60	11.0	40.67	5.26	1.12	34
– *pratensis* L.	7.55	11.5	35.69	8.48	1.14	35
– *sativa* L.	10.91	11.5	38.02	7.11	1.27	50
– –	10.48	16.6	38.99	8.86	1.17	29
– –	11.44	11.8	42.43	5.84	1.26	45
– –	10.07	12.0	44.23	4.74	1.27	38
– – , 4 collections	10.72	13.9	40.92	8.97	1.24	
Baldingera arundinacea (L.) Dum.	7.25	12.4	28.00	7.81	1.09	
Brachypodium pinnatum (L.) Beauv.	6.38	13.0	28.21	4.91	1.09	
– *silvaticum* (Huds.) Beauv.	6.47	15.5	28.32	5.40	1.07	
Briza media L.	5.70	15.3	23.35	7.39	1.08	
Bromus arvensis L.	6.52	13.8	28.05	4.13	1.05	
– *benekeni* (Lge.) Trimen	7.32	11.1	32.33	5.97	1.04	45
– *erectus* Huds.	7.38	11.8	36.54	7.81	1.09	37
– *hordeaceus* L.	7.64	12.3	33.53	4.90	1.04	29
– *racemosus* L.	5.42	16.8	27.32	8.13	1.06	
– *secalinus* L.	7.64	10.6	35.64	5.70	1.06	43
– *sterilis* L.	7.55	10.6	30.14	5.75	1.03	42
– *tectorum* L.	7.48	14.7	30.95	4.88	1.04	50
Calamagrostis arundinacea (L.) Roth.	5.80	15.0	26.47	11.11	1.05	
– *canescens* (Web.) Roth.	5.69	16.5	25.27	6.09	1.07	
– *epigeios* (L.) Roth.	6.34	13.9	30.28	7.45	1.07	
– *villosa* (Chaix.) Mutel.	7.19	14.3	31.34	6.83	1.05	41
Catabrosa aquatica (L.) Beauv.	5.09	15.7	21.77	8.36	1.08	

Corynephorus canescens (L.) Beauv.	4.66	18.0	19.15	7.48	1.07	
Cynosurus cristatus L.	5.26	19.4	26.30	5.56	1.12	
Dactylis glomerata L.	6.40	14.1	29.41	6.87	1.06	
Deschampsia caespitosa (L.) Beauv.	5.83	17.3	23.78	6.92	1.05	
– *flexuosa* (L.) Trin.	5.48	15.5	24.55	6.87	1.07	
Elymus arenarius L.	8.36	14.6	42.57	5.78	1.08	42
– –	8.88	14.1	43.19	5.07	1.09	46
– –	9.40	15.0	45.84	5.57	1.08	41
– – , 3 collections	8.88	15.3	43.86	6.23	1.08	
Eragrostis pooides PB.	5.08	15.9	21.94	9.27	1.04	
Festuca altissima All.	5.84	16.1	23.12	5.80	1.06	
– *arundinacea* Schreb.	6.76	16.4	29.11	6.97	1.10	
– *gigantea* (L.) Vill.	5.62	17.6	31.71	7.70	1.06	37
– *ovina* L.	6.12	15.0	24.03	7.10	1.05	
– *pratensis* Huds.	6.07	17.1	28.89	7.17	1.12	
– *rubra* L.	6.77	13.9	29.56	6.33	1.05	
Glyceria fluitans (L.) R.Br.	8.88	9.6	31.65	6.20	1.07	44
– –	9.70	13.4	33.84	6.09	1.05	34
– –	9.09	13.2	34.44	5.93	1.03	43
– –	9.12	14.1	35.39	6.59	1.05	41
– –	9.94	10.0	35.64	4.87	1.03	30
– –	10.57	11.9	35.86	6.13	1.04	32
– – , 6 collections	9.55	13.6	34.47	7.21	1.05	
– *maxima* (Hartm.) Holmb.	6.73	16.1	28.41	6.53	1.13	
– –	6.56	13.6	29.03	7.84	1.14	
– – , 2 collections	6.64	15.1	28.72	7.22	1.14	
– *plicata* Fr.	9.66	12.4	34.99	7.12	1.03	44
Holcus lanatus L.	4.77	19.1	23.51	4.97	1.07	
– *mollis* L.	5.03	22.5	24.47	11.43	1.04	
Hordeum murinum L.	8.77	16.4	39.10	6.36	1.05	34
– *vulgare* L.	7.99	13.5	36.26	4.77	1.15	
– –	8.63	10.2	37.47	5.34	1.12	42
– –	8.09	11.9	38.14	5.33	1.15	42
– – , 3 collections	8.23	12.3	37.29	5.50	1.14	
Koeleria glauca (Schkuhr.) D.C.	5.16	20.0	23.89	8.81	1.06	
– *gracilis* Pers.	5.05	19.4	25.93	5.20	1.09	
Lolium perenne L.	7.06	15.2	27.84	8.23	1.10	
Melica nutans L.	6.00	18.8	27.86	7.30	1.05	
– *uniflora* Retz.	5.90	19.0	27.84	4.86	1.04	
Milium effusum L.	6.26	18.5	24.71	5.76	1.09	
Molinia coerulea (L.) Moench.	5.93	18.7	24.54	5.11	1.06	
Nardus stricta L.	5.15	24.7	27.30	8.77	1.09	
Phragmites communis L.	5.90	9.0	22.13	6.64	1.04	
– –	5.80	9.9	22.43	3.87	1.09	
– –	5.90	12.9	23.99	5.30	1.07	
– – , 3 collections	5.87	10.7	22.85	6.51	1.07	
Phleum nodosum L.	6.18	18.1	27.86	7.56	1.08	
– *phleoides* (L.) Karst.	5.70	22.6	23.97	6.45	1.08	
– *pratense* L.	5.65	16.8	32.26	5.41	1.08	

Poa annua L.	5.78	18.9	22.78	6.39	1.07	
– *compressa* L.	6.06	21.6	23.79	7.69	1.04	
– *nemoralis* L.	5.89	18.5	26.06	8.40	1.09	
– *pratensis* L.	5.89	20.2	25.74	9.71	1.08	
– *trivialis* L.	5.32	16.4	20.27	5.92	1.06	
Puccinellia distans (L.) Parl.	5.91	18.4	26.95	7.60	1.11	
Secale cereale L.	8.28	10.4	38.17	7.11	1.37	51
– –	8.84	12.0	38.24	5.53	1.41	98
– –	8.69	11.6	39.72	6.37	1.36	39
– –	8.98	9.6	39.97	5.76	1.40	44
– –	8.60	9.3	40.09	5.76	1.41	32
– –	9.71	9.6	41.15	4.84	1.47	40
– –	10.00	16.9	41.49	4.63	1.40	42
– –	8.66	10.1	42.01	5.26	1.39	37
– –	8.65	13.6				22
– – , 9 and 8 collections	8.93	13.2	40.10	6.78	1.40	
Trisetum flavescens (L.) Beauv.	5.58	17.0	24.04	6.35	1.07	
Triticum aestivum L.	11.88	10.8	42.55	5.97	1.13	55
– –	12.22	10.2	45.53	6.34	1.13	47
– –	12.34	8.5	45.88	5.64	1.10	62
– –	10.82	15.4	46.13	4.33	1.13	40
– – , 4 collections	11.81	12.3	45.03	6.33	1.12	
– *dicoccum* Schrank.	13.51	11.5	45.77	5.36	1.10	34
– *compactum* Host.	14.18	12.6	47.19	4.91	1.09	47
– *monococcum* L.	8.26	11.6	36.73	7.17	1.14	39
– –	9.74	12.9	37.22	6.73	1.12	44
– –	9.56	10.9	38.93	7.32	1.13	55
– – , 3 collections	9.19	13.9	37.63	7.34	1.13	
– *polonicum* L.	10.98	11.1	39.57	6.25	1.12	42
– *spelta* L.	12.59	12.2	45.99	4.73	1.11	38

murinum, 65; *Agropyron repens*, 66; *Elymus arenarius*, 67; *Agropyron junceiforme*, 68; and *Avena fatua*, 77; the figures refer to fig. 3).

Pollen size and annulus diameters generally are correlated, with some exceptions. *Festuca gigantea* (14) and *Phleum pratense* (15) have particularly large grains, and *Agrostis stolonifera* (54), *Ammophila arenaria* (64), *Glyceria fluitans* (71) and *G. plicata* (72) have small grains compared with the annulus diameter. The mean sizes of grains with large and small annulus within a species do not differ *(Hordeum vulgare*, table 4).

(3) *Pollen index* varies from 1.03 – 1.15; a higher index occurs in *Avena sativa* (1.24) and *Secale cereale* (1.40, table 3).

(4) *Surface sculpturing*. Pollen grains with scabrate and verrucate sculpturing occur in the wild grasses belonging to group I mentioned above (scabrate, areolate, verrucate or maculate in Fægri & Iversen 1964, Nilsson et al. 1977). The species belonging to group II are scabrate (Andersen and Bertelsen 1972, Nilsson

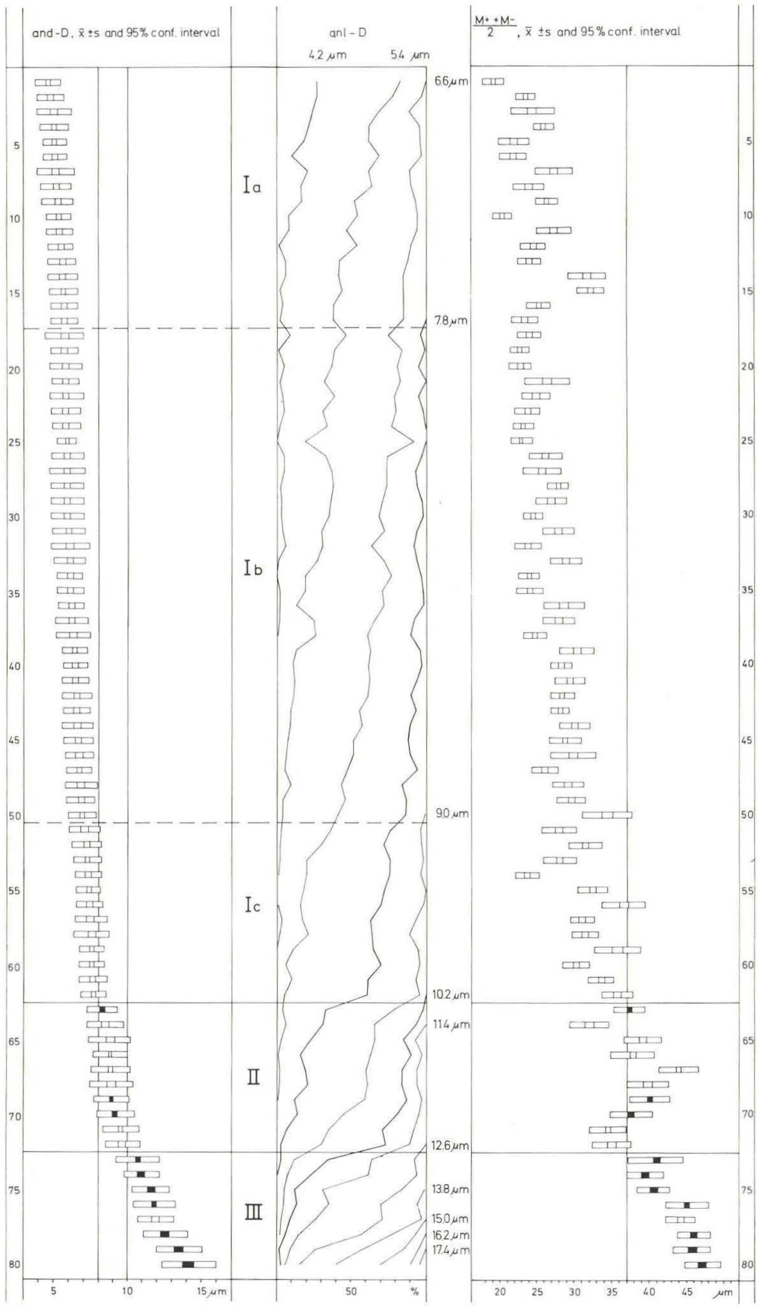
and-D, x̄ ±s and 95% conf. interval
anl-D
4.2 μm
5.4 μm
M+ +M- / 2, x̄ ±s and 95% conf. interval
6.6 μm
7.8 μm
9.0 μm
10.2 μm
11.4 μm
12.6 μm
13.8 μm
15.0 μm
16.2 μm
17.4 μm
Ia
Ib
Ic
II
III
5
10
15 μm
50
%
20
25
30
35
40
45
μm

Fig. 3. Poaceae, annulus diameter (anl-D), mean ($\bar{x}$) and frequency distribution (the lines indicate size class limits), and pollen size($\frac{M+ +M-}{2}$ standardized, *Corylus* = 24.5 μm). Numbers of collections are indicated for composite populations (in brackets). Confidence intervals for cultivated species are black.

Ia	1	Corynephorus canescens		41	Dactylis glomerata
	2	Holcus lanatus		42	Brachypodium silvaticum
	3	– mollis		43	Bromus arvensis
	4	Koeleria gracilis		44	Alopecurus pratensis
	5	Eragrostis pooides		45	Glyceria maxima
	6	Catabrosa aquatica		46	Anthoxanthum odoratum
	7	Nardus stricta		47	Agrostis tenuis
	8	Koeleria glauca		48	Festuca arundinacea
	9	Cynosurus cristatus		49	– rubra
	10	Poa trivialis		50	Agropyron caninum
	11	Bromus racemosus		51	Lolium perenne
	12	Deschampsia flexuosa		52	Calamagrostis villosa
	13	Trisetum flavescens		53	Baldingera arundinacea
	14	Festuca gigantea		54	Agrostis stolonifera
	15	Phleum pratense		55	Bromus benekeni
	16	Calamagrostis canescens		56	– erectus
	17	Briza media		57	– tectorum
Ib	18	Phleum phleoides		58	Avena elatior
	19	Agrostis gigantea		59	– pratensis
	20	Poa annua		60	Bromus sterilis
	21	Calamagrostis arundinacea		61	– hordeaceus
	22	Alopecurus geniculatus		62	– secalinus
	23	Deschampsia caespitosa	II	63	Hordeum vulgare (3)
	24	Festuca altissima		64	Ammophila arenaria
	25	Phragmites communis (3)		65	Hordeum murinum
	25	Poa nemoralis		66	Agropyron repens (3)
	27	– pratensis		67	Elymus arenarius (3)
	28	Melica uniflora		68	Agropyron junceiforme
	29	Puccinellia distans		69	Secale cereale (9,8)
	30	Molinia coerulea		70	Triticum monococcum (3)
	31	Melica nutans		71	Glyceria fluitans (6)
	32	Poa compressa		72	– plicata
	33	Festuca pratensis	III	73	Avena sativa (4)
	34	Agrostis spica-venti		74	Triticum polonicum
	35	Festuca ovina		75	Avena nuda
	36	Alopecurus myosuroides		76	Triticum aestivum (4)
	37	Phleum nodosum		77	Avena fatua
	38	Milium effusum		78	Triticum spelta
	39	Calamagrostis epigeios		79	– dicoccum
	40	Brachypodium pinnatum		80	– compactum

Table 4. Mean size of pollen grains with annulus diameters smaller and larger than 8 μm in three collections of *Hordeum vulgare*. Significance tests by χ^2 -method (differences in means), and student's t (average difference). $\bar{x}$ = mean, C = coefficient of variation.

		anl-D < 8 μm			anl-D > 8 μm		Diff.
coll.		$\bar{x}$	C		$\bar{x}$	C	means
no.	n	(μm)	(%)	n	(μm)	(%)	(P)
1	39	35.91	4.54	32	36.68	4.84	0.92
2	33	37.35	5.75	67	37.53	5.16	0.89
3	30	37.96	5.59	70	38.22	5.24	0.71
average difference = 0.40 μm, P = 0.17							

et al. 1977, *Hordeum-Typ* in Beug 1961). The sculpturing is seen as isolated dark dots with phase contrast equipment (cp. Grohne 1957, Beug 1961). Verrucate sculpturing occurs in the species in group III (Andersen and Bertelsen 1972, Nilsson et al. 1977). The sculpturing is seen as irregular dark spots in phase contrast (Grohne 1957); however, this sculpturing type may not always be distinguishable from the scabrate sculpturing type. Beug (1961) separated an *Avena-Typ* with *Punktklumpen* from a *Triticum-Typ* with *Punktgruppen* seen in phase contrast. These sculpturing types are difficult to distinguish (illustrations in Beug, 1961).

Identification of Poaceae pollen

Based on annulus diameter, pollen size, pollen index and surface sculpturing, Poaceae pollen can be divided into four main groups.

(1) *Wild grass group*; mean annulus diameters smaller than 8 μm, mean pollen size less than 37 μm, scabrate or verrucate. This group comprises the majority of the wild grass species.

(2) *Hordeum group* (fig. 4); mean annulus diameters 8-10 μm, mean pollen size 32-45 μm, scabrate. This group comprises the following wild grasses and cultivated species (for *Secale cereale*, see below),

Ammophila arenaria	*Glyceria fluitans*
Hordeum murinum	*Glyceria plicata*
Agropyron repens	
Agropyron junceiforme	*Hordeum vulgare*
Elymus arenarius	*Triticum monococcum*

In the measurements of 84 Central European species in Beug (1961, *Tabelle* 1), the following North European wild grasses also belong to this group (for recalculation of annulus measurements see p. 72),

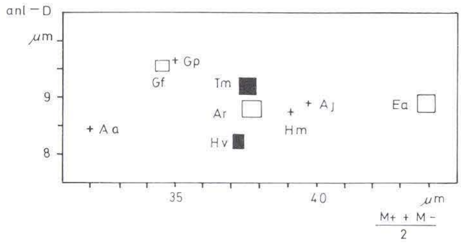

Fig. 4. Hordeum-group, mean pollen size, standardized (*Corylus* 24.5 µm), and annulus diameter. 95 % confidence intervals are indicated for composite populations (cultivated species black). Aa = *Ammophila arenaria*, Gf = *Glyceria fluitans*, Gp = *G. plicata*, Hv = *Hordeum vulgare*, Ar = *Agropyron repens*, Tm = *Triticum monococcum*, Hm = *Hordeum murinum*, Aj = *Agropyron juncoides*, Ea = *Elymus arenarius*.

Bromus inermis (anl-D = 8.8 µm)
Hordeum jubatum (anl-D = 9.6 µm)

(3) *Avena-Triticum group*; mean annulus diameters larger than 10 µm, mean pollen size larger than 40 µm, verrucate. This group comprises one wild grass, *Avena fatua*, and the following cultivated species,

Avena sativa
Avena nuda
Triticum aestivum
Triticum polonicum
Triticum spelta
Triticum dicoccum
Triticum compactum

Triticum durum in Beug's *Tabelle 1* (1961, anl-D = 11.4 µm) also belongs to this group.

Panicum miliaceum has verrucate pollen grains (Beug 1961, *Avena-Typ*). Mean annulus diameter is 8.0 µm and pollen size seems to be small.

(4) *Secale cereale*; *Secale* pollen grains are scabrate (Andersen & Bertelsen 1972). They are distinguished from species within the *Hordeum*-group by a larger pollen index (1.40, table 3). As noticed by Beug (1961), there is considerable overlapping in ranges of pollen index in *Secale* and other species. *Hordeum vulgare* and *Triticum monococcum* pollen grains have the largest pollen index within the *Hordeum* group (1.14 and 1.13). Annulus diameter in these species is similar to *Secale* (8.23, 9.19 and 8.93 µm). Pollen index is higher than 1.26 in only a few *Hordeum* and *Triticum monococcum* grains (4 and 6%) and smaller than 1.26 in 10% of the *Secale* grains. Pollen grains with pollen index higher than 1.26 are thus likely to belong to *Secale*, whereas 10% of the *Secale* grains (index < 1.26) are likely to become confused with *Hordeum* or *Triticum monococcum*, if their pollen occur together. The oblong *Secale* grains tend to fold along the longer axis and may be identified by shape; measurement of pollen index, however, is not possible in these cases.

Pollen grains of Poaceae can thus be grouped by means of morphological characteristics. Due to the wide overlappings of size ranges, it is necessary to produce frequency distribution curves of fossil Poaceae pollen assemblages, for identifications.

Fossil pollen

Poaceae pollen in Holocene gytta and peat samples from a small wet hollow and two soil profiles i Eldrup Forest, Djursland, Denmark, were examined. A pollen diagram from the hollow was shown in Andersen (1973, cp. 1978a); it comprises the Atlantic, Subboreal and Subatlantic. The pollen samples from the soil profiles were from bleached sand and derive from Medieval time (sections C 19 and E 13 in Andersen 1979).

The Poaceae pollen was examined in the following way:

(1) *Secale* pollen was identified by shape,
(2) annulus diameter was measured,
(3) Pollen grains with annulus larger *than 8* μm were separated into *Hordeum* group and *Avena-Triticum* group,
(4) size was measured in all grains with annulus larger than 8 μm if possible.

Most of the pollen grains in the gyttja and peat samples were moderately crumpled. The pollen grains in the soil samples were strongly crumpled and size was not measured. *Corylus* pollen could not be measured. As the sediments are non-calcareous, it can be assumed that the measurements of fossil and modern pollen can be compared directly (p. 73).

Gyttja and peat samples

Annulus diameter (fig. 5). The frequency curves for grass pollen with small and large annulus (excluding *Secale* and *Avena-Triticum*) show that pollen grains with large annulus are frequent (up to 25%) and constitute about 50% of the Poaceae pollen at the middle levels. The annulus diameter-distributions are bimodal at these levels with modes at the 5.4 – 6.6 and 9.0 – 10.2 μm size classes. Two or more species are thus present in the Poaceae pollen assemblages.

Usinger (1975,1978) has shown that coefficient of variation and skewness index are useful for describing pollen assemblages composed of one or more species with different sizes. The coefficient of variation is low in uniform and high in heterogenous assemblages. Skewness may be calculated as Pearson-skewness or third moment-skewness. Pearson-skewness depends on the difference between the

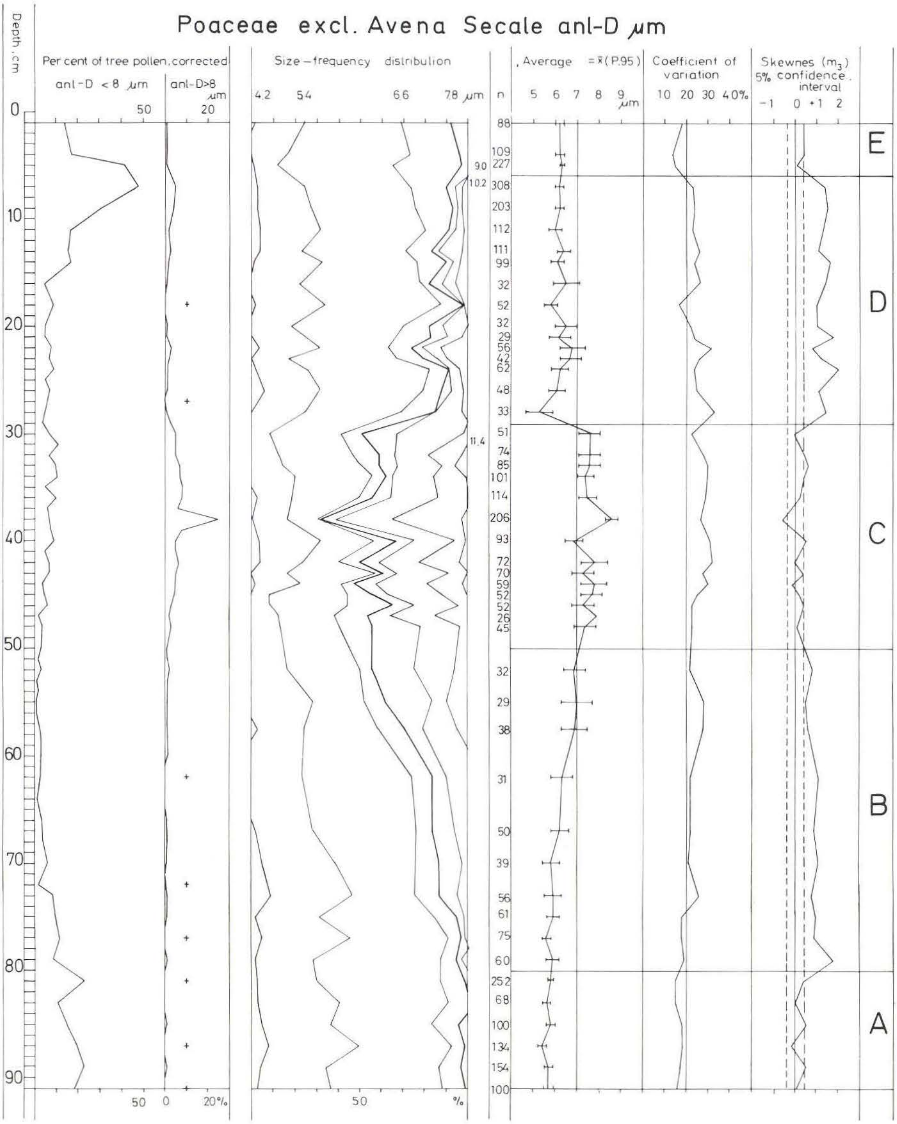

Fig. 5. Poaceae, annulus diameter (anl-D) in Holocene gyttja and peat samples. Frequency (in percent of tree pollen), size-distribution, mean, coefficient of variation and moment-3 skewness.

arithmetic mean and the mode (divided by the standard deviation). Mode could not be calculated accurately in the present distributions because the number of size classes was small. Third moment-skewness was calculated instead. This skewness index is zero in symmetric distributions, positive in distributions skewed to the right-hand side and negative in distributions skewed to the left-hand side. The 0.05 confidence interval for zero skewness varies from ±0.5 (n = 50) to ±0.2 (n = 400, Pearson 1931). Confidence interval for n = 100 is shown in fig. 5.

The annulus size-distributions could be grouped in five main levels according to mean, coefficient of variation and skewness index,

A, low means (5-6 µm), low variances (C = 15%), no skewness; unimodal symmetrical distributions; only grains with small annulus,

B, low means (6-7 µm), intermediate variances (C = 20-30%), high skewness (1.0); unimodal positively skewed distributions, grains with small annulus predominate,

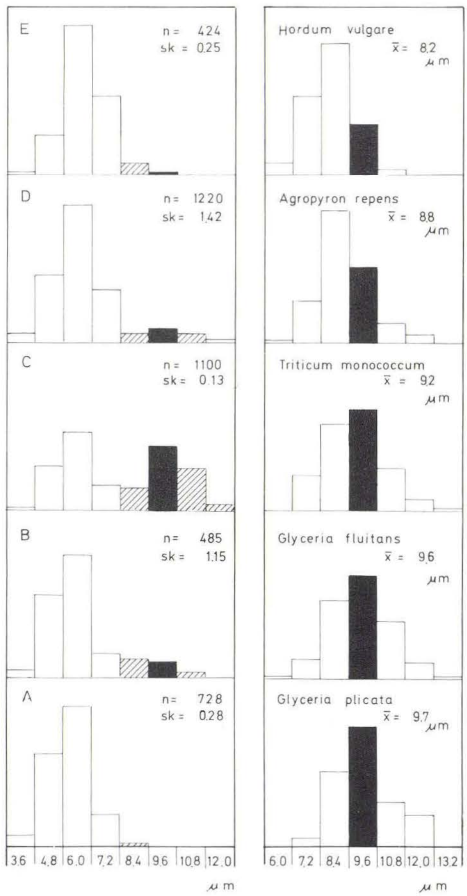

Fig. 6. Poaceae, Holocene samples, annulus diameter. Frequency distributions for levels A-E (see fig. 5) and five modern species. Sk = moment-3 skewness.

C, high means (7-8 μm), high variances (C = 30%), no skewness; bimodal symmetrical distributions, grains with small and large annulus,

D, low means (6 μm), intermediate variances (C = 20-30%), high skewness (1-2); unimodal, positively skewed distributions, grains with small annulus predominate,

E, low means (6 μm), low variances (C = 15%), no skewness; unimodal symmetrical distributions, only grains with small annulus.

The distributions within the levels A-E were summarized into average distributions (fig. 6). The five distributions show a distinctive mode at the 6 μm size class. This mode must be due to one or several wild grass species which have pollen with annulus diameters about 6 μm. These wild grasses were frequent in the lowermost part of the section (fig. 5, 70-90 cm, early Atlantic time) and indicate fair light conditions and abundant local grass populations. They were very rare at 50-70 cm, where strong shade is indicated, and more frequent again above 50 cm. A distinctive wild grass maximum above 10 cm corresponds to a period with grazing (AD 1700-1800, Andersen 1979) and fair light conditions. It is impossible to say which grasses are represented. Species from group Ib in fig. 3 probably contributed a main part of the pollen, and it is not unlikely that *Phragmites* (mean at 5.9 μm) was important.

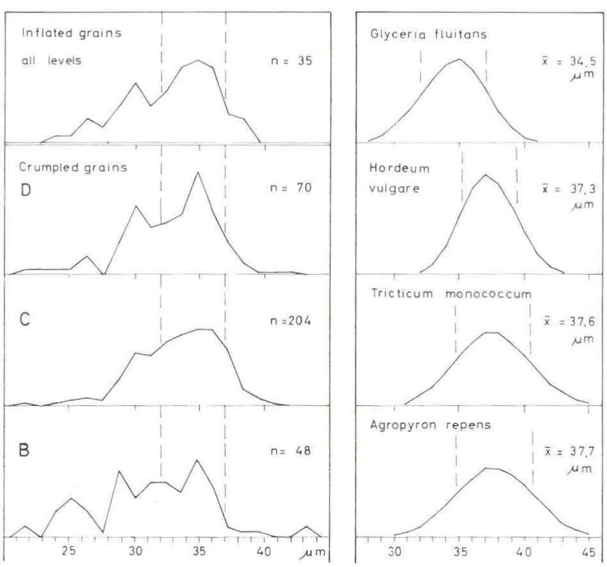

Fig. 7. Poaceae, pollen size. Frequency distributions for grains with annulus diameters larger than 8 μm at the levels B-D ($\bar{x} \pm s$ for *Glyceria fluitans* is indicated) and composite populations of four modern species ($\bar{x} \pm s$ indicated).

The skewed distributions at the levels B and D, and the bimodal distribution from level C indicate the presence of one or more species from the *Hordeum*-group. Pollen grains with annulus diameters 9.6 and 10.8 μm are particularly frequent. Size-frequency distributions in five species, which might have occurred at the site, are shown in fig. 6. *Triticum monococcum* and *Glyceria* resemble the larger mode in the distributions for fossil pollen best; however, it is not possible to say whether *Triticum* or *Glyceria* predominated.

Pollen size. Among the pollen grains with annulus diameter larger than 8 μm, only 35 inflated grains were found (357 measured grains). The size frequency-distribution curve for inflated pollen grains (fig. 7) is negatively skewed with a predominant mode at 35 μm and probably a secondary mode at 30 μm. A similar frequency distribution is repeated in the curves for crumpled grains from levels B, C and D. The average size of the crumpled grains is thus nearly the same as the average size of the inflated grains in this case. The predominant mode is very similar to the mode in the composite population of *Glyceria fluitans* (35 μm), whereas *Hordeum vulgare, Triticum monococcum* and *Agropyron repens* are larger (modes at 37-38 μm). Very few of the fossil pollen grains exceed the maximum size of *Glyceria fluitans* (41 μm); hence, it can be concluded that *Glyceria fluitans* (or *G. plicata*) contributed a major part of the fossil pollen with annulus diameters larger than 8 μm. These species are characteristic of small ponds and apparently occurred abundantly at level C (30-50 cm on fig. 5) at a time when the pond was well illuminated.

The negatively skewed curves in fig. 7 indicate that Poaceae species with pollen grains smaller than 32 μm contributed some of the pollen grains with annulus diameters larger than 8 μm.

The mode at 35 μm is repeated in all the pollen size distributions for individual annulus size classes from levels B – D (fig. 8). Pollen grains with annulus diameters 8.4 μm predominate in *Hordeum vulgare* and *Agropyron repens*; however, no fossil grains with annulus diameters 8.4 μm exceed the size range of *Glyceria* pollen. Hence, no fossil pollen grains of *Hordeum* and *Agropyron* are present. Two fossil grains with annulus diameters 9.6 μm exceed the upper size limit of *Glyceria* pollen (43 and 44 μm). These grains are larger than *Hordeum* and *Triticum monococcum* pollen grains and fall within the size range of *Elymus arenarius* (mean size 43.9 μm). The fossil pollen grains with still larger annulus diameters (10.8 and 12.0 μm) do not exceed the upper size limit of *Glyceria fluitans* pollen. It can thus be shown that hardly any cereals from the *Hordeum*-group occurred.

The distribution curves for grains with annulus diameters 9.6 and 8.4 μm show increasing frequencies of grains smaller than 32 μm, and small pollen grains predominate in the curves from the levels A and E (fig. 8). These pollen grains presumably derive from Poaceae species belonging to group Ic in fig. 3 *(Baldingera arundinacea*?, mean size 28.0 μm).

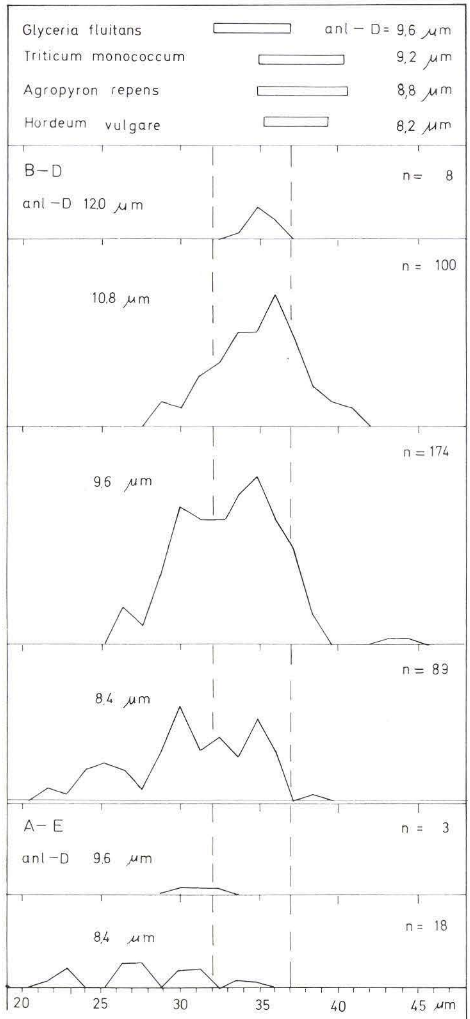

Fig. 8. Poaceae, pollen size. Frequency distributions for grains with various annulus diameters at the levels B-D and A-E, and size ($\bar{x} \pm s$) of four modern species (top).

Several Poaceae species have thus contributed to the fossil Poaceae pollen assemblages measured. The pollen grains with small annulus diameters belong to wild grasses, possibly *Phragmites. Glyceria fluitans* (or *G. plicata*) contributed a major part of the pollen grains with large annulus diameters. Other wild grasses and cereals from the *Hordeum* group are unlikely to be represented except for a few grains, which possibly belong to *Elymus arenarius* and were thus transported from populations at the seashore. A more superficial consideration and inaccu-

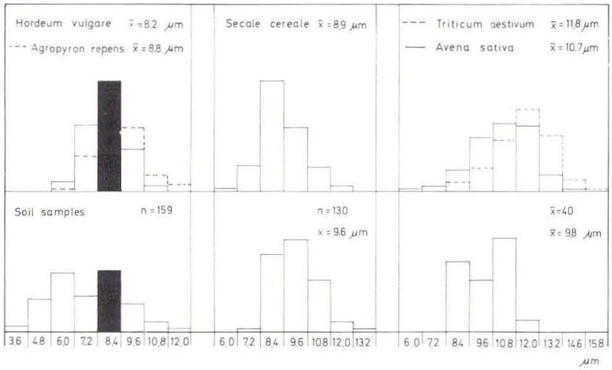

Fig. 9. Poaceae, annulus diameter. Frequency distributions in pollen from soil samples (excluding *Secale* and *Avena – Triticum* group), all *Secale cerale* grains, and all grains referred to the *Avena – Tritucum* group, compared with modern species.

rate measurements might have led to the conclusion that cereals are amply represented.

Soil samples

Annulus diameters of Poaceae pollen from soil samples are shown in fig. 9 (*Secale* and *Avena-Triticum* group ommitted). The frequency distribution curve is bimodal with a mode at 6.0 μm due to wild grasses with small annulus diameters and a mode at 8.4 μm, which coincides with the modes in modern *Hordeum vulgare* and *Agropyron repens* pollen. The samples contain many pollen grains from weeds (i.a. *Centaurea cyanus*), *Secale* and *Fagopyrum* (Andersen 1979) and obviously derive from fields. The *Hordeum* or *Agropyron* pollen grains constitute about 50% of the Poaceae pollen; they could not have been recognized without annulus measurements because pollen size could not be measured.

Secale cereale

Annulus diameters measured on all *Secale* pollen encountered are slightly larger than the mean diameter of modern grains (fig. 9).

Avena – Triticum group

The annulus size-distribution in pollen grains referred to the *Avena – Triticum* group shows a predominant mode at 10.8 μm, and a lower mode at 8.4 μm (fig.

9). The larger mode coincides with *Avena sativa*; no *Triticum* grains thus occur. The smaller mode coincides with *Hordeum*. One suspects that some *Hordeum* grains with intermediate surface sculpturing were erronously refered to the *Avena - Triticum* group; hence, only the pollen grains with annulus diameter larger than 8.4 μm were considered *Avena sativa*.

Conclusion

Poaceae species were divided into groups according to pollen characteristics. The wild grass group (1) is distinguished by small annulus diameter and size (the sculpturing is variable); the *Hordeum* - group (2) by intermediate annulus and size, and by scabrate sculpturing; the *Avena - Triticum* (3) group by large annulus and size, and by verrucate sculpturing, and *Secale* (4) by oblong shape and scabrate sculpturing. The *Hordeum* - group includes cultivated species and some wild grasses, and the *Avena - Triticum* group almost exclusively cultivated species (*Avena sativa* and *Triticum* spp.).

Frequency-distributions for annulus size, and observations of surface sculpturing of Poaceae pollen in Holocene gyttja and peat samples made it possible to detect the presence of a component of wild grasses and a component of species belonging to the *Hordeum* group. Measurements of pollen size indicated that the pollen referred to the *Hordeum* - group derive mainly from *Glyceria (fluitans* or *plicata*). Measurements of annulus diameters in soil samples indicated the presence of wild grass and *Hordum vulgare* or *Agropyron repens* pollen. Pollen grains of *Secale cereale* and *Avena sativa* were also identified.

Acknowledgements. Mr. *C. Vang Nielsen* carefully performed the numerous measurements of modern pollen (since 1960), Mrs. *Vinni Moen* assisted at the statistical work, Mrs. *Doris Blom* revised the English language and typed the manuscript, and Mrs. *Irene Wienberg* performed the drawings.

Dansk sammendrag

Pollen fra græsfamilien er vanskelige at bestemme fordi de er meget ensartede og fordi der er mange arter. I vegetationshistoriske arbejder er det særlig vigtigt at kunne kende og adskille dyrkede kornarters pollen. Forskelle i pollenstørrelse kan være vanskelige at udnytte, hvis mange af pollenkornene er sammenfoldede og det er bedre at benytte diameter af pore-ringen, som altid kan måles. Overfladeskulptur kan også benyttes.

Diameter af pore-ring og pollenstørrelse er blevet målt på 80 græsarter. Græsarterne kan på dette grundlag deles i 3 grupper, hvoraf den første omfatter vildgræsser, den anden dyrkede arter (byg og enkorn) og enkelte vildgræsser og den tredje dyrkede arter (havre og hvede-arter). Rugpollen adskiller sig fra alle andre ved at være aflange. Eksempler på bestemmelse af fossilt pollen ved hjælp af variationskurver er vist.

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Cereal cultivation in Mykines, Faroe Islands AD 600

Jóhannes Jóhansen

Jóhansen, J.: Cereal cultivation in Mykines, Faroe Islands AD 600. *Danm. geol. Unders., Årbog 1978,* pp. 93-103. København 1979.

This paper deals with investigations made by the author on some old, now abandoned fields in Mykines, The Faroe Islands. The results show that corn has grown in these fields – first *oat (Avena)*, later *barley (Hordeum)*. The beginning of the cultivation is radiocarbon dated to about AD 600. It is concluded that it was started by Irish hermits who according to the literature are said to have lived on the Faroes. It is assumed that the later cultivation of *barley* was done by Nordic settlers, but this layer cannot be dated.

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In many remote and more or less inaccessible places in the Faroe Islands are areas which evidently are former cultivated fields. They appear as strips of land separated by low ridges. In some places the ridges consist of rows of stones covered with soil, in other places of soil only. The present author has studied some of them. The results of the investigation of one of them, namely Lambi, Mykines, are presented in the following article.

Description of the locality Lambi and the fields

Most of Lambi is a scree – rocks and stones having fallen down from the mountain to the north of the locality. The eastern area, where the fields in question are situated, is, however, covered by soil – 118 cm at the investigation site – and has a vigorous vegetation. The whole Lambi area is the habitat for a very large colony of puffins *(Fratercula arctica)*. These birds strongly affect the character of the landscape, partly by digging holes in which they live and nest, and partly by manuring the soil. The vegetation is, as mentioned, vigorous but it is poor in the number of species. The most important plants are *Festuca rubra, Stellaria media, Rumex acetosa, Montia rivularis, Poa pratensis, Agrostis stolonifera* and *Tripleurospermum maritimum.*

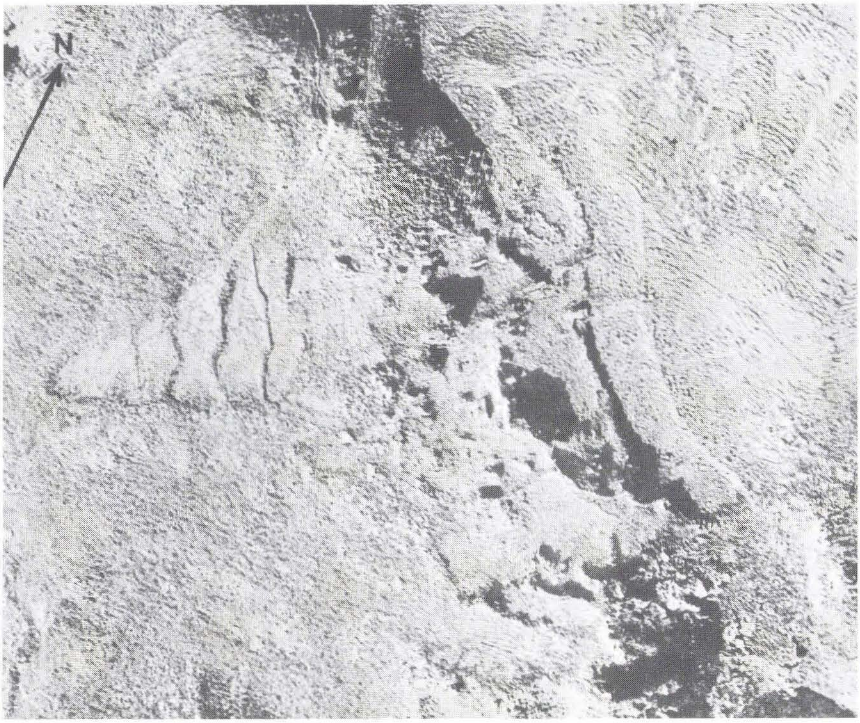

Fig. 1. Aerial photo of the fields. To the right is seen an oblong structure which looks man-made. It has not been investigated as far as I know. Photo Widerøe AS. Reproduced with the permission of Matrikulstovan, Tórshavn.

The fields are situated on a south east facing slope with an average inclination of 50^0, the lowermost part being almost flat. Figs. 1-3.

The ridges consist of rows of stones covered with soil and vegetation. As can be seen from figs. 1 and 2, they are undulating. This is probably due to solifluction. Because of the activity of the puffins, the soil is very loose, and this has caused the stone walls to move irregularly down the slope. The puffins have, however, not been digging in the fields as can be seen in the photograph, fig. 3. There are 5 ridges; the distance between them varies from 1 to 7 m. The longest field is 27 m, the shortest 10 m. This difference in length could be caused by the vigorous plant growth which might conceal some parts of the fields. This can, however, only be known after excavation. The height of the ridges is about 40 cm.

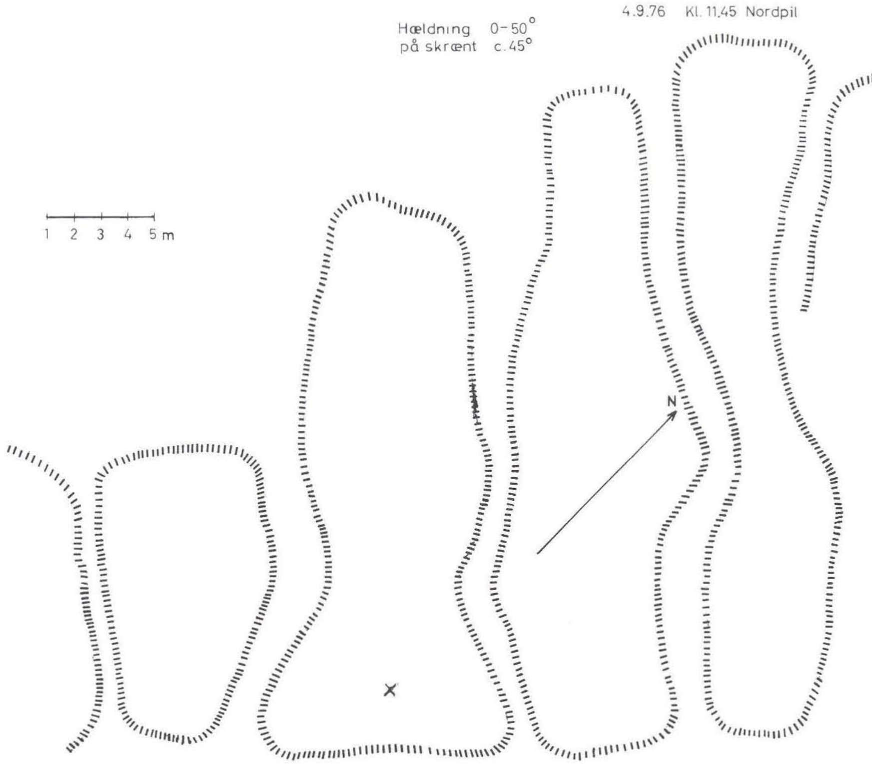

Fig. 2. A sketch plan of the fields. After P.V. Glob.

The profile

The excavation was made at the point marked X in fig. 2. The depth down to solid rock was 118 cm. The material was a homogenous, brown soil containing gravel and small stones without macroscopic plant remains. After treatment with KOH, HF, HC1, and acetolysis, only pollen grains were left – in large quantities, but very poorly preserved. The amount of corroded pollen grains varied between 40 and 100%.

The radiocarbon datings and the pollen diagram

When preparing samples for radiocarbon datings, precautions were taken so as not to dissolve small plant remains but only to remove the humic acids. The samples were treated with cold 5% KOH for one hour and then washed in distil-

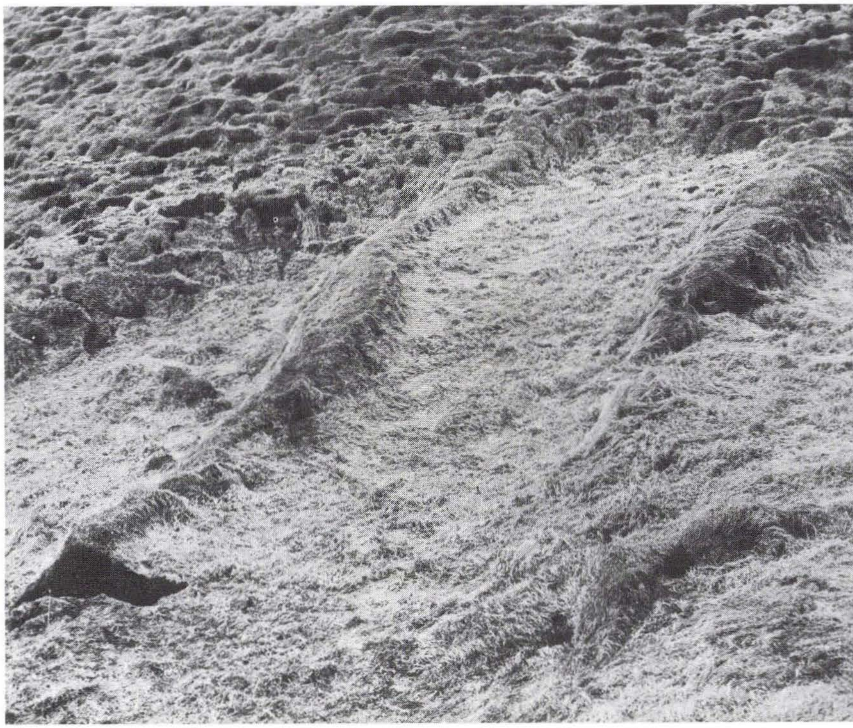

Fig. 3. The upper part of 3 fields. The appearance of the surrounding area is the result of the activity of the puffins. They always dig upwards as they would otherwise get water into their holes. Photo P.V. Glob.

led water until the fluid was clear. The samples were left in 10% HC1 for one night and then dried at 100⁰C.

The datings proved to be highly irregular as seen below. The corrections follow Clark (1975).

K-3046	Depth	20- 30 cm.	$C^{13} = \div 24.5‰$	2720 ± 80 BP Cal. 945 BC
K-3047	Depth	30- 40 cm.	$C^{13} = \div 28.0‰$	1350 ± 70 BP Cal. 640 AD
K-3048	Depth	75- 80 cm.	$C^{13} = \div 25.1‰$	1680 ± 75 BP Cal. 305 AD
K-3049	Depth	95-100 cm.	$C^{13} = \div 27.8‰$	1290 ± 55 BP Cal. 690 AD
K-3050	Depth	100-105 cm.	$C^{13} = \div 26.2‰$	2330 ± 75 BP Cal. 440 BC
K-3051	Depth	105-110 cm.	$C^{13} = \div 24.6‰$	1500 ± 75 BP Cal. 470 AD

K-3052	Depth	110-115 cm.	$C^{13} = \div 26.6‰$	3050 ± 80 BP Cal. 1385 BC

The irregular datings are due to the solifluction referred to above. It is obvious that when the C-14 datings turned out as they did, it is useless to draw any conclusions from the trend of the different curves in the pollen diagram shown in fig. 4. It will, however, be described in brief. As can be seen, there are great fluctuations in the curves as is to be expected in a diagram reflecting a very local vegetation. At the bottom *Poaceae, Rumux acetosa* and *Tubuliflorae (Tripleurospermum?)* each are about 30%. Apart from the next spectrum, where *Poaceae* lie at 50%, *Rumex acetosa* becomes the dominant plant. At a depth of 80 cm there is an abrupt rise of *Poaceae* and a fall of *Rumex acetosa* and *Tubuliflorae*, which were about 30% in 4 spectra. The grasses dominate up to the present day, however, with much *Rumex acetosa* in the three uppermost samples.

LAMBI, MYKINES, FAROE ISLANDS

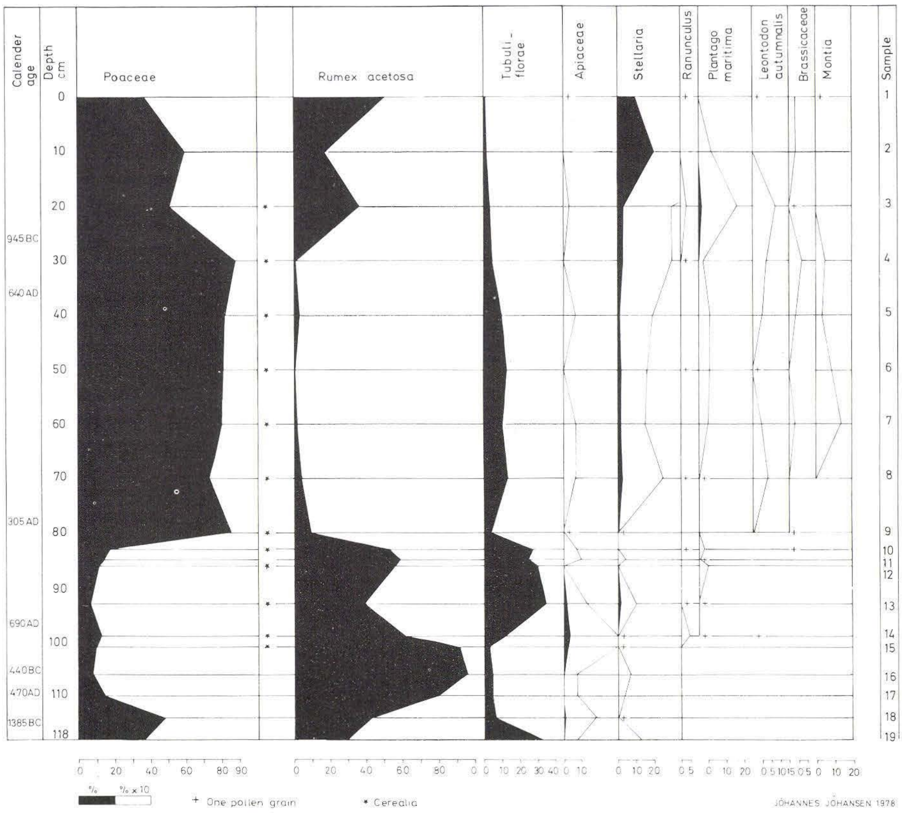

Fig. 4. The pollen diagram from Lambi.

Instead of trying to explain these changes, I shall discuss the curves of Cerealia and *Plantage maritima*.

Cerealia

In pollen analysis, there have been great difficulties in, and discussion about, separating cereals from wild grasses and distinguishing among the different species of cereals. Andersen (1979) has taken up the whole problem and dealt with it very thoroughly. The criteria in question are pollen grain size, annulus diameter, and surface sculpture.

As previously mentioned, the pollen grains from Lambi are very badly preserved, and in the case of the cereals, which are large, they are also very much crumpled. Under such circumstances, measuring the annulus diameter is the most reliable way of separating wild grasses from cereals, as well as the species of cereals from each other. The annulus does not crumple and is highly resistant to corrosion. This means that it can nearly always be measured.

The annulus of 50 pollen grains of *Poaceae* was measured in 9 samples. The size class was 0.98 μm. Size frequency distribution curves are shown in fig. 5.

Using Andersen's results, it is concluded that wild grasses, *Hordeum* and *Avena* are represented in Lambi.

Most wild grasses have an average annulus diameter of 6-7 μm, *Hordeum* 8 μm and *Avena* 10-11 μm (Andersen 1979).

Some wild grasses such as *Glyceria fluitans, Elymus arenarius,* and *Ammophila arenaria*, which are all members of the present Faroese flora, also have large annulus diameters (Andersen l.c.). They can, however, all be excluded here as none of them can grow at or near a place like Lambi.

Out of cereals, *Secale cereale* can be recognized; it has not been observed in the material. *Triticum* can be eliminated for climatic reasons – it has a more southerly distribution (Bacon et al. 1948).

Bearing these facts in mind, I will interpret the size frequency distribution curves in the following way, starting from the bottom. Samples no. 19 and no. 16 contained only wild grasses.

Sample no. 15 also contained wild grasses – as did all the samples, however *Avena sativa* was also present.

Sample no. 13 was similar to no. 15 with probably some *Hordeum* mixed in.

Samples no. 11, 9, 8 (?) and 3; *Hordeum* was the only cereal.

Sample no. 1, which represents the recent surface, only contained wild grasses.

The sizes of the grass pollen grains were also measured but as they were very crumpled, the result is of limited value and is excluded here. An exception is sample no. 1 which had well preserved pollen grains. In that sample 12% of the grass pollen grains had an annulus diameter of 8 μm.

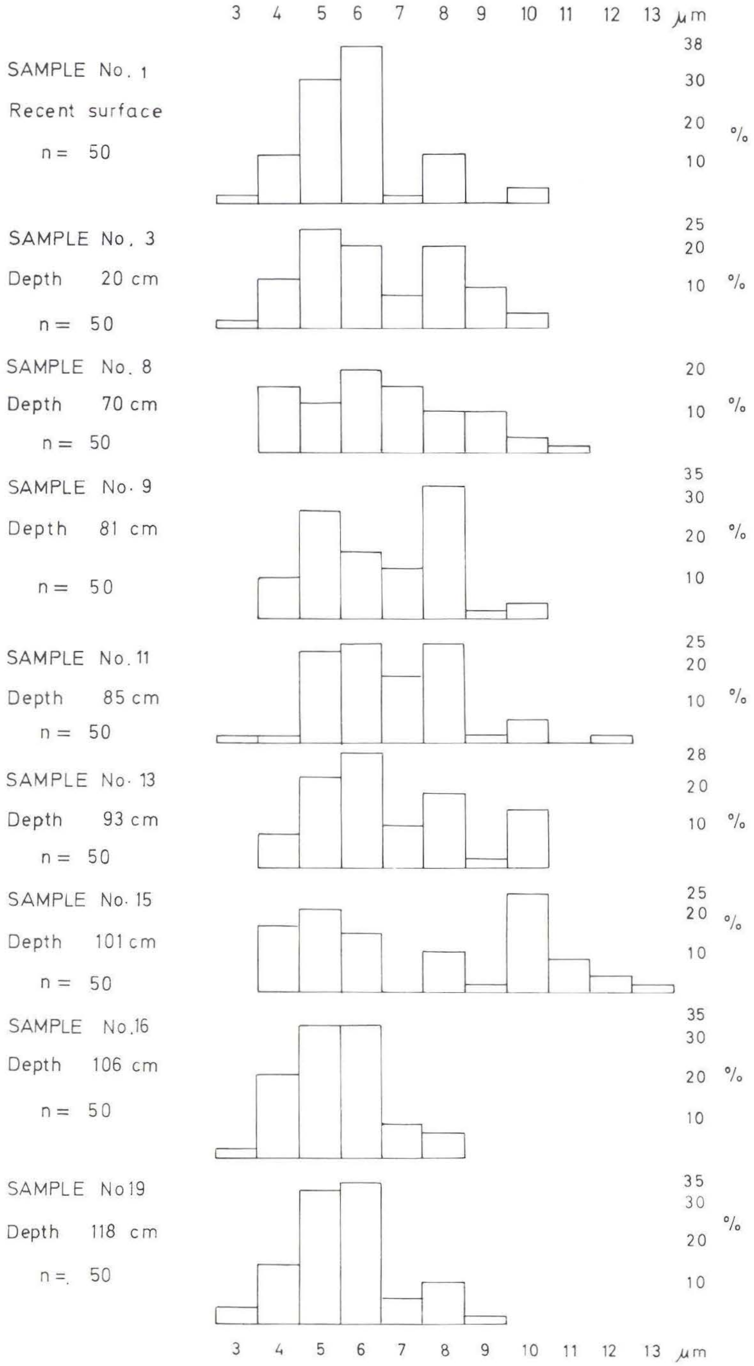

Fig. 5. The size frequency distribution curves of the annulus diameter of grass pollen.

Pollen grains of grass species which are common at Lambi today include pollen with an annulus diameter more than 8 μm (Andersen l.c.). They are *Poa pratensis*, average size 25.7 μm, 7% have an annulus diameter more than 8 μm; *Festuca rubra*, average size 29.6 μm, 13% have an annulus diameter more than 8 μm; and *Agrostis stolonifera*, average size 23.6 μm, 24% have an annulus diameter more than 8 μm.

In sample no. 1, no grass pollen grain had a size exceeding 30 μm. It is, therefore, concluded that the grass pollen in sample 1 with annulus diameter of 8 μm derive from one of the above mentioned species or a mixture of all the three of them.

From sample no. 15 and up to no. 3, it could be observed that many grass pollen grains, even if crumpled, were clearly of cereal size: 38-45 μm. In the samples below, no grass pollen grains exceeded 30 μm. It is, therefore, concluded that the proportion of grass pollen grains in samples no. 19 and no. 16 with an annulus diameter 8 μm are wild grasses, cfr. sample 1.

It should be added that observations of the sculpture of some fairly well preserved exines confirm the above mentioned conclusions.

Finally, the finding of cereals sticking together in clumps proves the strictly local source of them. These fields have been used for growing corn: at first *Avena*, later *Hordeum*, and later again the fields were abandoned.

When the solifluction did not distrub the *Avena-Hordeum* relationship, it is because the slipped down material contained wild grasses only.

Plantago maritima

The question is now when cereal growing at Lambi started. The C-14 datings listed above cannot give the answer. In fact, I expected difficulties with the C-14 datings when taking the nature of the soil and the sloping into consideration. I, therefore, took a continuous series of samples from a flat blanket bog at another place in Mykines, in order to try to find a horizon which could be correlated with the Lambi profile.

In the pollen diagram from Lambi, it can be seen that *Plantago maritima* does not occur until sample no. 14, i.e. 2 cm above the first occurrence of cereals. *P. maritima* has immigrated to the Faroes in the Preboreal (Jóhansen 1975) but it did not come to Mykines until the cereal growing had started. Pollen slides containing thousands of pollen grains were examined, and not a single pollen grain of *Plantago maritima* was observed until sample no. 14. The purpose was then to get a reliable date for the first occurrence of *P. maritima*, and I shall describe the result of this work briefly.

The locality North of Uldalíð, the profile, pollen diagram and radiocarbon datings

North of a place called Uldalíð, there is a flat area which is covered with blanket peat. From an open section in this bog, I took a series of samples for pollen analysis and radiocarbon datings. The profile was 121 cm consisting of uniform brown peat. There was much gravel in the uppermost 85 cm. The pollen diagram in fig. 6 shows the local vegetation with the usual dominance of *Poaceae* and *Cyperaceae*. The curve of the greatest interest is the *Plantago maritima*. I could be ascertained that *Plantago maritima* did not occur below a depth of 83 cm. The radiocarbon datings are listed below, and the depth of 83 cm lies between the ages AD 740 and AD 460. From this we must conclude that *Plantago maritima* was introduced to Mykines at about AD 600. This ought to be the approximate age of the first appearance of cereals at Lambi because there can be no doubt that *Plantage maritima* spread over this little island (10 km^2) in a very short time, when first introduced.

K-2935	Depth	11- 14 cm.	$C^{13} = \div 25.4‰$	180 ± 65 BP Cal. 1660 AD
K-2936	Depth	39- 42 cm.	$C^{13} = \div 25.8‰$	480 ± 70 BP Cal. 1430 AD
K-2937	Depth	79- 82 cm.	$C^{13} = \div 26.3‰$	1230 ± 70 BP Cal. 740 AD
K-3066	Depth	83- 86 cm.	$C^{13} = \div 25.4‰$	1510 ± 70 BP Cal. 460 AD
K-2938	Depth	100-103 cm.	$C^{13} = \div 25.9‰$	2430 ± 75 BP Cal. 560 BC
K-2939	Depth	116-119 cm.	$C^{13} = \div 26.2‰$	3550 ± 85 BP Cal. 1975 BC

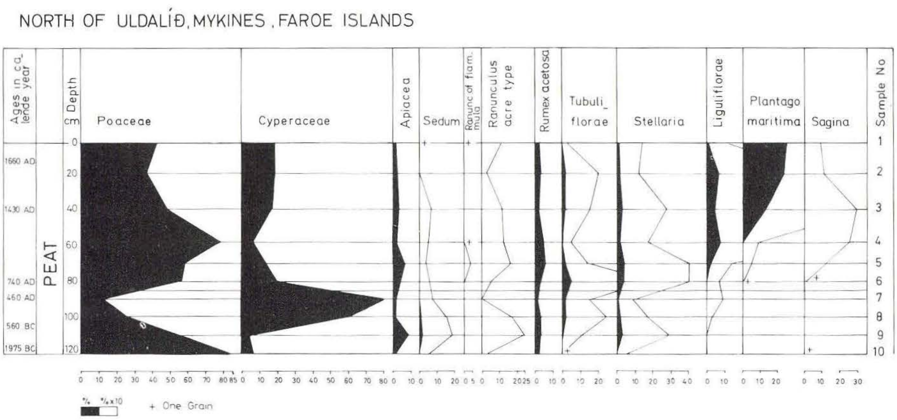

Fig. 6. The pollen diagram from North of Uldalíð.

Archaeological Aspects

In the year AD 825, an Irish clergyman named Dicuil wrote a book called DE MENSURIS ORBIS TERRAE, which means »The dimensions of the earth.« In that book he writes (in translation):

».... There are many other islands in the north British sea. They can be reached from the northern islands of Britain by sailing for two days and two nights on a straight course under full sail if the wind is favourable the whole time. A devout priest has related to me that he navigated this route in two summer days and the intervening night, in a small boat with two thwarts, and landed on one of the islands. These islands are for the most part small, and there are mostly narrow sounds between them, and in these islands hermits, come from our Scotland (i.e. Ireland) by boat, have lived for almost a hundred years. But as they have always been uninhabited from the beginning of the world, so have Norwegian vikings caused them to be devoid of monks, but sheep are abundant and there are different kinds of sea birds. I have never seen these islands mentioned in the books of other authors.«

Researchers (e.g. Brøgger 1937) agree that these islands must be the Faroe Islands. The problem until now has been that no traces of these men have been found.

In 1971, I studied a peat bog in Tjørnuvik, Streymoy, where I found a layer which clearly reflected human influence (Jóhansen 1971). Three C-14 datings were made of the layer, and they were of the age AD 650 $\pm$ 100, AD 620 $\pm$ 100, and AD 600 $\pm$ 100. No old fields were observed.

In Mykines, we have definite evidence of cornfields. I find it important that we can say that these fields were made by the monks. This must be the case when the age is taken into consideration, and it means that for the first time in the Faroes we have a definite proof of these men who were previously known from the book of Dicuil only.

Summary and Conclusion

The facts mentioned in this paper can be summarized as follows:

1. The areas in question at Lambi, Mykines are former corn fields.
2. The cereal growing started about AD 600.
3. The cereals grown were, first *Avena*, then *Hordeum*, and later the fields were abandoned.
4. It is concluded that Irish hermits started the growing of *Avena*.
5. It is assumed that the growing of *Hordeum* was made by the Nordic settlers but this layer can not be dated.

Acknowledgements. The first to recognize these old cornfields was Dr. *Sverri Dahl,* antiquarian in Tórshavn. He found them so much resembling fields he had seen in Ireland that he connected them with the Irish hermits, who the above mentioned Dicuil had written about. Dahl's first observation was in 1947. *Dahl* has written about his theories (1968 and 1970). He later asked me to make a botanical and pollen analytical investigation of these localities and the present paper deals with one of them. I wish to thank *Sverri Dahl* for directing my attention to this problem, for encouragement and many inspiring discussions, on this subject.

I wish to thank Professor *P. V. Glob* for permission to use his material. The C-14 datings were made by Dr. *H. Tauber.*

Dansk sammendrag

Artiklen omhandler en undersøgelse forfatteren har gjort på Mykines, Færøerne. Det drejer sig om nogle arealer, der tilsyneladende engang har været dyrket. Ved hjælp af pollenanalyse blev det konstateret, at felterne er gamle kornmarker. Målinger af annulus diameteren på et antal græspollen i profilet viste, at der først har været dyrket havre, senere byg og senere igen er al dyrkning ophørt. Alderen på korndyrkningens begyndelse er C-14 dateret til ca 600 e.Kr., hvilket er før nordboernes bosættelse. Det konkluderes derfor, at markerne er anlagt af irske munke, som ifølge en irsk præst, Dicuil, skal have holdt til på øerne, indtil de blev fordrevet af vikinger. Den senere dyrkning af byg formodes at være foretaget af nordboerne, men dette lag kan ikke dateres.

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Om den geologiske kortlægning af Fjendsområdet i 1978

L. Aabo Rasmussen, H. Bahnson, N. Mikkelsen, A.V. Nielsen, K. Strand Petersen

Rasmussen, L. Aabo, H. Bahnson, N. Mikkelsen, A. V. Nielsen og K. Strand Petersen: Om den geologiske kortlægning af Fjendsområdet i 1978. *Danm. geol. Unders., Årbog 1978,* pp. 105-118. København 1979.

Preliminary results from the geological mapping of the Fjends area between Skive Fjord and Hjarbæk Fjord are presented. Cliff sections and cored sections were studied in order to obtain kineto-stratigraphic drift units for the area. Other studies included morphogenetic analysis of the landscape and investigations of marine deposits which were characterized by their molluscan and microfossil assemblages.

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På grundlag af de opstillede retningslinier for den geologiske kortlægning (Sørensen & Nielsen 1978) begyndte DGU's almengeologiske afdeling i foråret 1978 planlægningen af årets feltarbejde. Kortbladet (1:50.000) 1215 IV Viborg udvalgtes som område for de første undersøgelser. Området frembød et bredt spektrum af geologiske forekomster og havde tidligere indtaget en central plads i overvejelser vedr. afsmeltningsforløbet (Milthers 1935). Det udvalgte område var endvidere dækket af kort fremstillet i forbindelse med den amtskommunale hydrogeologiske kortlægning (geologisk basisdatakort, grundvandskemisk basisdatakort, kort over grundvandspotentiale og kort over prækvartæroverfladens højdeforhold; Rasmussen et al. 1978). Indledningsvis samledes tilgængelige data fra litteratur, arkiver, luftfotos, m.v.

Feltarbejdet begyndte med en rekognoscering i april og afsluttedes i november, efter at fem geologer havde været i felten i ialt 225 dage, assisteret af fem studenter i ialt 88 dage. DGU's borehold udførte i samme periode otte boringer på udvalgte lokaliteter. Karteringsarbejdet blev yderligere suppleret med geoelektriske undersøgelser og jordbundsanalyser.

Kortet 1215 IV NV Skive blev færdigkarteret, og tilstødende arealer på kortene 1215 IV NØ Skals, 1216 III SV Hvalpsund og 1216 III SØ Gedsted blev ligeledes dækket (fig. 1& 4).

Karteringen af kortbladet 1215 IV Viborg vil fortsætte, og efterhånden som delkortene (1:25.000) bliver færdigkarterede, vil Foreløbige Kort (Sørensen & Heller 1978) blive fremstillet. Kortlægningen vil blive afsluttet med udgivelse af et geologisk kort i målforholdet 1:50.000 med tilhørende kortbladsbeskrivelse. Resultaterne af detaljerede videnskabelige undersøgelser publiceres i separate afhandlinger.

De efterfølgende afsnit giver en kortfattet oversigt over nogle af resultaterne fra årets feltarbejde.

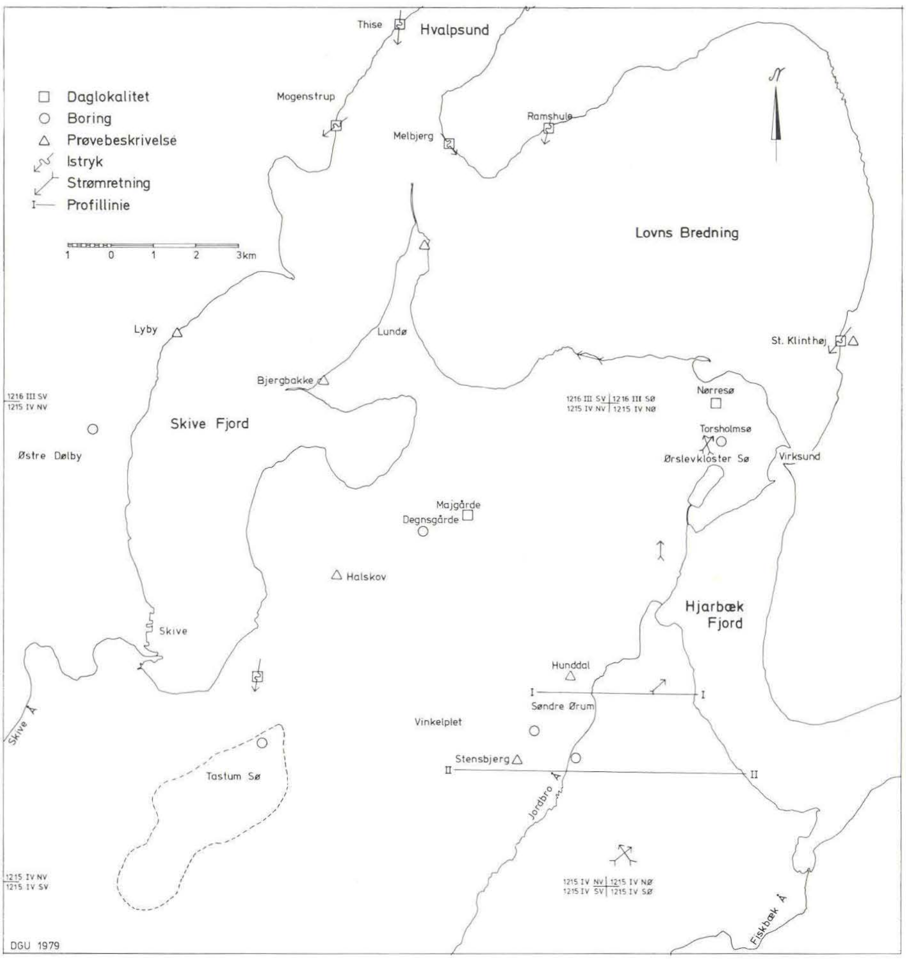


Fig. 1. Oversigtskort.
Index map.

Glacial Stratigrafi

Den geologiske kortlægning tilstræber en tredimensional fremstilling af de overfladenære, geologiske formationer. Dette medfører, at indgående studier af geologiske profiler får en fremtrædende rolle i kortlægningsarbejdet. Disse studier gør det muligt at udrede de enkelte formationers aldersmæssige relationer.

Det udvalgte kortblad, 1215 IV Viborg, viste sig at være sparsomt forsynet med dybere snit gennem områdets glaciale aflejringer, men i umiddelbar tilknytning til det kortlagte område fandtes en række kystklinter ved Hvalpsund på østkysten af Salling, på Lovns halvøen og nord for Virksund (fig. 1). Disse blotninger blev opmålt, og foreløbige korrelationer mellem de enkelte lokaliteters lithologiske enheder opstillet. Korrelationerne bygger på glacialtektoniske istryksbestemmelser, stentællinger, studier af glacialdynamiske strukturer, stenoriente-

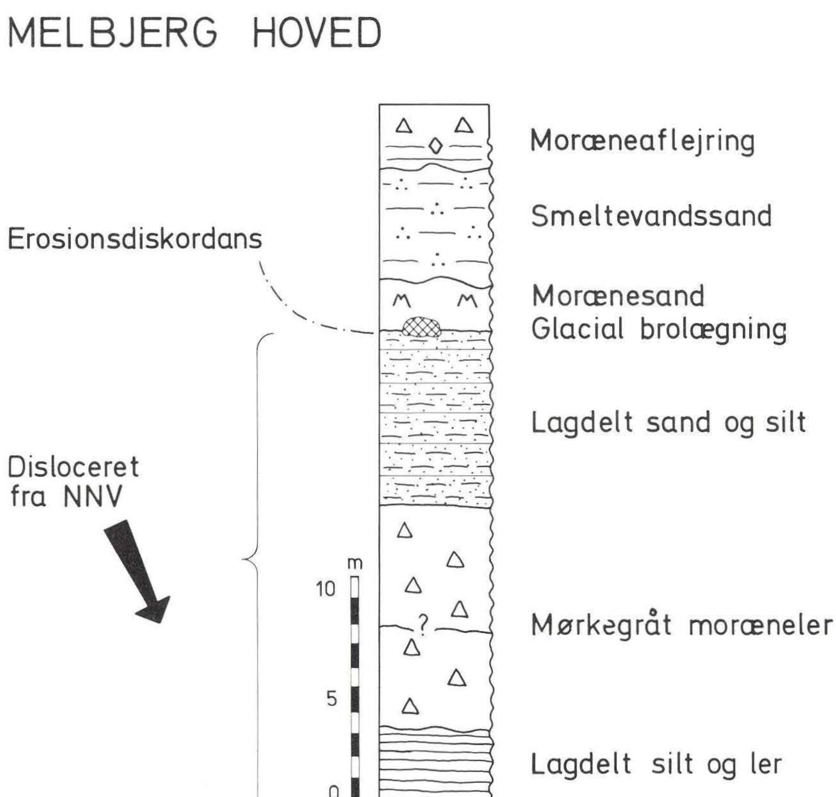


Fig. 2. Tentativ stratigrafi for kystprofil ved Melbjerg Hoved.
Tentative stratigraphy of the cliff section at Melbjerg Hoved.

ringsmålinger (delvis mikrofabric-analyser), strømretningsbestemmelser, lermineralanalyser og studier af mikrofossiler. Disse metoder bruges til opstilling af kinetostratigrafiske enheder (cf. Berthelsen 1973, 1978; Rasmussen 1975; Sjørring 1978).

Ved klintopmålinger viste det sig rationelt at studere klinterne fra vandet og fotografere klintafsnittet med en passende overlapning. Samtidigt skitseredes profilets enheder og strukturer. Dette observationsmateriale dannede grundlag for en detaljeret opmåling af klinterne med efterfølgende prøvetagning. Efter tolkning af glacialtektoniske strukturer var det herefter muligt at opstille en stratigrafisk lagsøjle.

Et eksempel på en konstrueret geologisk lagsøjle fra Melbjerg Hoved på Lovns ses på fig. 2. Nederst findes lagdelt silt og ler, og ifølge boringer i området er denne aflejring af betydelig mægtighed. Denne enhed overlejres af fedt, mørkegråt moræneler, som tilsyneladende indeholder mange kalkstensfragmenter. Morænen er endvidere karakteriseret af xenolither af grønligt sand med velbevarede primære sedimentstrukturer. Den samlede tykkelse af morænekomplekset overstiger 10 m. Herover følger en mindst 8 m tyk serie af lyst, rytmisk lejret, lagdelt silt og sand. Morænekomplekset og sand-siltserien er opfoldet og forkastet fra NNV og er skarpt afskåret af en vandret, markant erosionsdiskordans. Over diskordansen følger en op til 2 m tyk morænesandsbænk med en sporadisk udformet glacial brolægning ved basis. Morænesandet overlejres af en ca. 5 m tyk serie af smeltevandssand. Øverst i profilet findes en moræneformation, der bl.a. er karakteriseret ved et indhold af Eocænt materiale. Formationen er i den basale del grovklastisk med nogen lagdeling.

Omlejrede coccolither optræder i de fleste morænebænke. Der forekommer to distinkte grupper: 1) Kretasiske former og 2) former fra ældre Tertiær (overvejende Eocæn og Oligocæn). De fleste moræner i kystklinterne langs Lovns Bredning kan indbyrdes differentieres på grundlag af forholdet mellem mængden af tilstedeværende Kretasiske og Tertiære arter. Den stratigrafisk laveste moræneenhed erkendt i Melbjerg Hoved er således karakteriseret af en omlejret Tertiær flora.

Den omtalte stratigrafi ved Melbjerg Hoved kan genkendes i andre kystlokaliteter og samstemmer i vid udstrækning med den succession, der er fundet i boringer foretaget i det glaciale landskab inden for det kortlagte område.

Som supplement til sommerens overfladekartering udførte DGU's borehold i september måned ialt fem undersøgelsesboringer med 6" Pilconboregrej. Tre af disse boringer fandt sted i glaciallandskabet. På laboratoriet foretages omfattende analyser af det indsamlede prøvemateriale, f.eks. bestemmes kornstørrelse, rundingsgrad, glødetab, kalkindhold, stenselskab samt indhold af makro- og mikrofossiler.

I materialet fra en ca. 20 m dyb boring i glaciallandskabet ved Sdr. Ørum er kornstørrelsesforholdene undersøgt (fig. 3). Tilsyneladende svarer materialet og

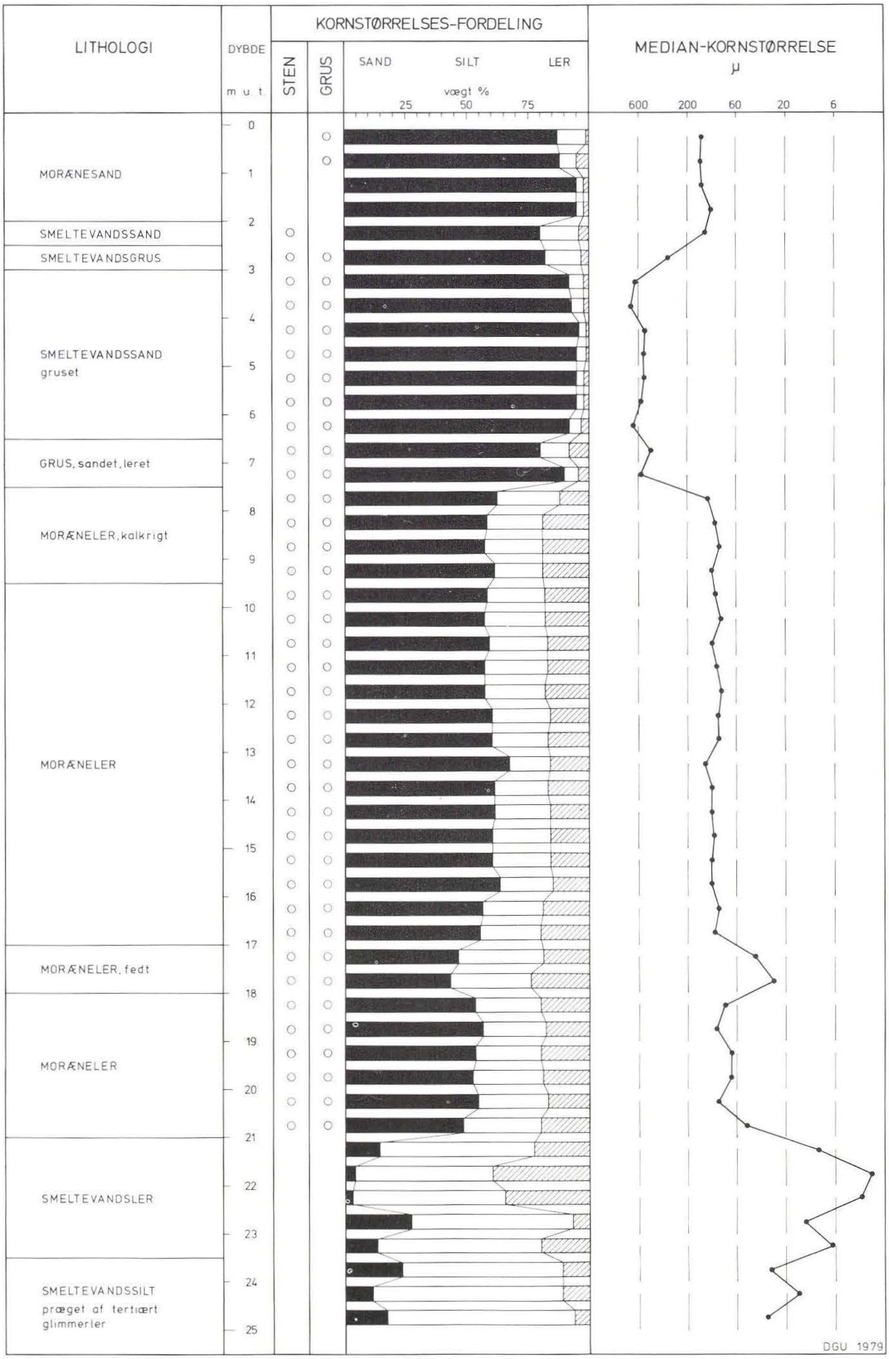


Fig. 3. Boreprofil fra Sdr. Ørum.
Well profile at Sdr. Ørum.

lagfølgen i denne boring i store træk til de forhold, som er iagttaget i kystklinterne ud mod Hvalpsund og Lovns Bredning. Moræneşand underlejres af groft, gruset smeltevandssand, som hviler på en ca. 14 m tyk morænelersaflejring, der ved beskrivelsen kunne opdeles i fire bænke. Under moræneleret finder man siltrigt smeltevandsler, som nedefter bliver mere og mere præget af opblanding med Tertiært materiale.

I Ørumboringen kan mindst 4 stratigrafiske enheder adskilles på grundlag af coccolithindholdet. I de øverste 7,5 meter mangler mikrofossilerne som følge af sedimentets beskaffenhed (smeltevandssand). I afsnittet fra 7,5 m - 21 m dominerer Kretasiske coccolither med en stadig stigende artsrigdom nedover. Der er et markant indslag af Tertiære former mellem 21 m og 22 m, hvilket afløses af overvejende Kretasiske arter i afsnittet 22 - 23,5 m. Et Tertiært selskab optræder igen fra 23,5 m og til boringens totale dybde af 25 m. I boringens dybere del er der således en Tertiær dominans ligesom i klinten ved Melbjerg Hoved.

I Salling, hvor såvel morfologi som jordarter afviger stærkt fra forholdene i de kortlagte landskaber på Fjends, nåede en boring ved Resen gennem glaciale aflejringer af fedt moræneler til Oligocænt glimmerler i få meters dybde. Der boredes til ca. 20 m uden at nå gennem glimmerleret.

I flere niveauer i det glaciale landskab på Fjends træffes stenfrit, siltrigt ler, som muligvis er vinduer af en større sammenhængende lerforekomst. For at få et overblik over udbredelsen af dette ler vil det være nødvendigt at supplere med en del undersøgelsesboringer i området. En enkelt boring blev udført ved Degnsgårde og er fulgt op af en geoelektrisk undersøgelse, som i første fase omfattede tre linieprofiler og syv punktprofiler. Undersøgelserne tyder på, at forekomsten har en anselig størrelse, og at dens udstrækning, såvel horisontalt som vertikalt, vil kunne fastlægges ved supplerende geoelektriske målinger. Endvidere konstateredes i såvel boringen som i en større lergrav ved Majgårde, at det fede ler er overlejret af glaciale aflejringer. Leret ved Majgårde er dislocERET fra NNV.

Overfladekortlægning

Et simplificeret geologisk overfladekort, fremstillet på grundlag af den geologiske kortlægning i 1978, er vist på fig. 4.

Det glaciale landskab

Som det fremgår af kortet, optræder de glaciale aflejringer i den sydlige del af området som større eller mindre enklaver omgivet af sand- og grusterrasser afsat af smeltevandsfloder ved slutningen af sidste istid. I områdets nordlige del træffes

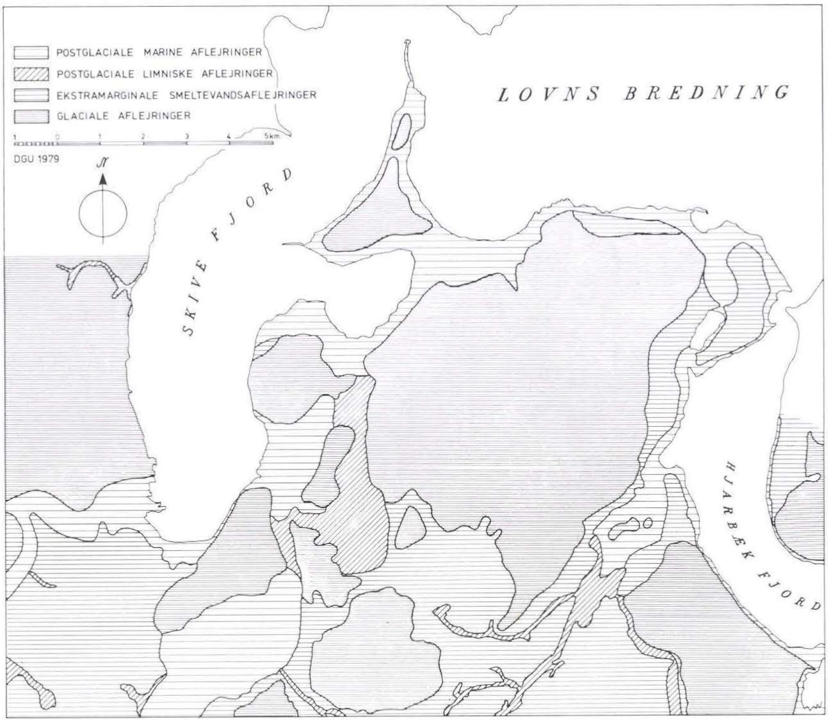


Fig. 4. Generaliseret kort over fordelingen af jordarter i 1 meters dybde. Vinkelplet-området er på dette kort udtegnet som ekstramarginale aflejringer.
Generalized map of the distribution of soils in a depth of one meter. The area around Vinkelplet is designated as an area covered with outwash sediments.

et sammenhængende glaciallandskab af mere kuperet natur, omsluttet af limniske og marine, postglaciale aflejringer.

Den dominerende aflejring i det glaciale landskab er let leret sand med et varierende indhold af grus og sten. Af profiler i grave og klinter fremgår, at jordarten har karakter af morænesand. I felten adskiller aflejringen sig kun i ringe grad fra smeltevandssandet, men kornkurverne viser en forskel i sorteringsgraden (fig. 5).

Mange steder optræder enklaver af smeltevandssand og -grus, der dels er vinduer af underliggende, ældre smeltevandsdannelser, og dels er aflejringer fra den sidste afsmeltningsfase. I sidste tilfælde er aflejringen ofte afsat som rækker af kame-bakker, hvis form tydeligt adskiller sig fra det øvrige glaciallandskabs morfologi.

Moræneler er kun truffet enkelte steder i Fjends, og da ofte hvor terrængradienten betinger blotninger af dybe lag i det glaciale landskab. I kortlagte områder af Salling og Himmerland findes moræneler derimod mere udbredt som overfladenære forekomster.

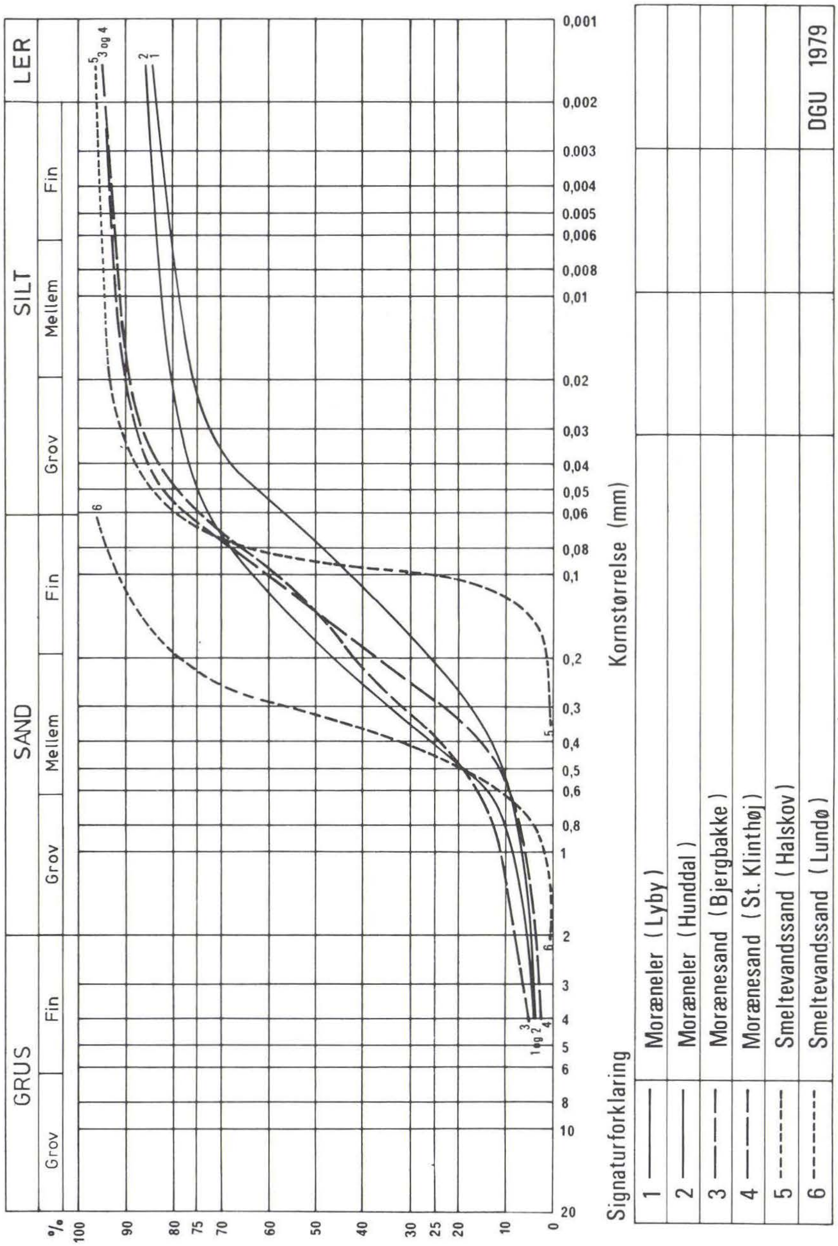


Fig. 5. Kornstørrelsesfordelinger i udvalgte prøver fra Fjends-området.
Grain-size distribution in selected samples from the Fjends area.

De ekstramarginale dale

En stor del af det karterede område er jordartsmæssigt karakteriseret som ekstramarginale smeltevandsaflejringer, dvs. overvejende grus og sand, afsat af vandstrømme foran isranden. Disse aflejringer fremtræder i dag som store flader eller terrasser i de brede dalstrøg, der gennemskærer området fra syd til nord. Afvandingen af disse dale sker gennem vandløbene Skive Å til Skive Fjord og Jordbro Å og Fiskbæk Å til Hjarbæk Fjord. Dalenes morfologiske udvikling er tidligere behandlet (Ussing 1903, 1904, 1907; Jessen 1920; Milthers 1935; Milthers 1948).

Topografiske snit over Jordbro Å-dal fra vest til øst (fig. 6) giver, sammenholdt med karteringsresultaterne, et indtryk af landskabselementernes hovedtræk. Det glaciale bakkeland i den vestlige del af snit I og II og tillige den østlige del af snit II er opbygget af moræne- og smeltevandsaflejringer og gennemfuret af markante erosionsdale. Jordbro Å-dal følger et nord-syd gående dalstrøg, hvis konturer er svage, da dalen blev delvis opfyldt med grus og sand under smeltevandsafløbets Falborgstadium (Milthers 1935).

Efterhånden som erosionsbasis sænkedes i takt med isafsmeltningen i Limfjorden, blev flodsletten gennemskåret af nye dalsystemer, således at kun terrasser langs bakkefoden står tilbage.

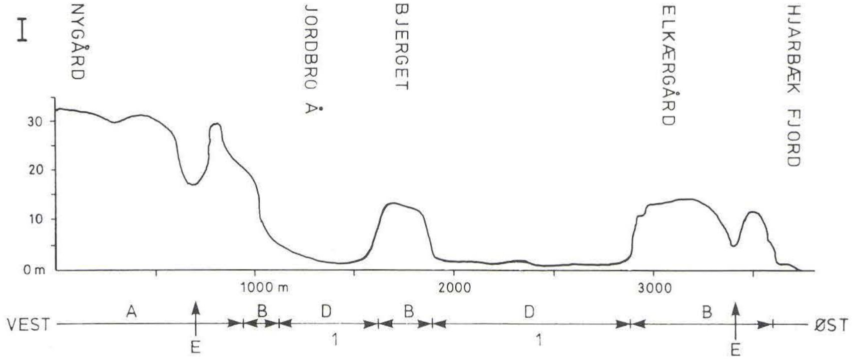
Løsningen af en række spørgsmål, som f.eks. lagseriernes mægtighed, smeltevandsdalenes glaciale relief og eventuelle præglaciale afhængighed, afventer resultater fra nye boringer, geoelektriske undersøgelser m.v. . En enkelt boring i Jordbro Å-dal viste, at ca. 15 m marine sedimenter overlejrer glaciale aflejringer. Hvorvidt der her er tale om et udfyldt dødishul i den ekstramarginale dal, eller om de marine sedimenter generelt når denne mægtighed, må fortsatte undersøgelser give svar på.

De mange profiler i tilgængelige grave gav et godt indblik i variationsbredden hvad angår sammensætning og struktur af de store smeltevandsaflejringer, såvel vertikalt som horisontalt. Enkelte profiler viste, at morfologisk sammenhørende flader dels kunne være akkumulationsflader, opbygget af lagserier af velsorteret smeltevandsmateriale, dels udformet som erosionsflader i mere uensartet materiale af glacial karakter.

1978-karteringen berørte kun de nordligste dele af det store system af ekstramarginale dale, der fortsætter langt sydover. Rekognoscering gav dog indtryk af, at der under den videre kortlægning kan findes væsentlige elementer til en mere detaljeret tolkning af landskabsudviklingen.

Det postglaciale, marine landskab

Hjarbæk Fjord og Skive Fjord danner sydlige udløbere i Limfjordens forgrenede system. Ved kortlægningen er postglaciale, marine aflejringer registreret un-



Terrænformer

A - glacialt bakkeland
B - ekstramarginal smeltevandsslette
C - mosedækket dal (efter dødis)
D - erosionsdal i smeltevandsslette (B)
1 - dækket af postglaciale marine aflejringer
2 - dækket af postglaciale limniske aflejringer
E - erosionskløft

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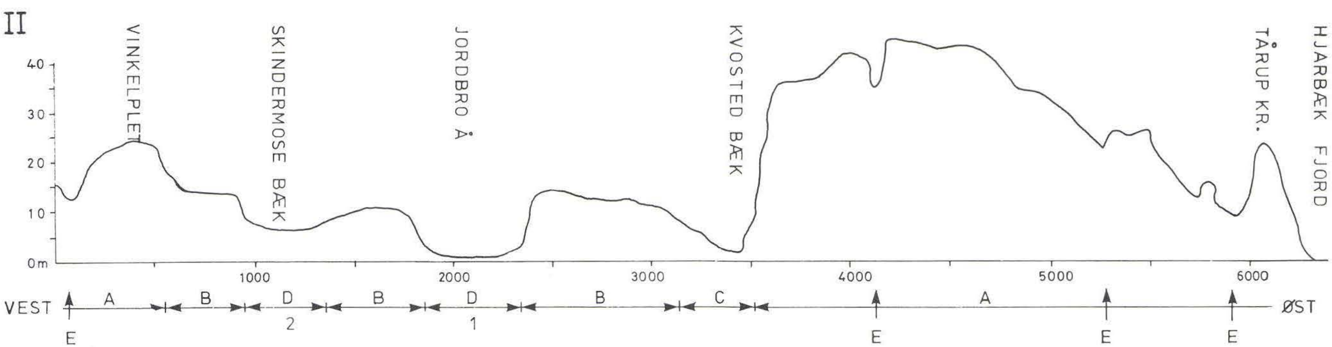

I - Profillinie fra vest for Sdr. Ørum til Hjarbæk Fjord nord for Borup i øst
II - Profillinie fra Vinkelplet i vest til Hjarbæk Fjord nord for Tårup Kr. i øst

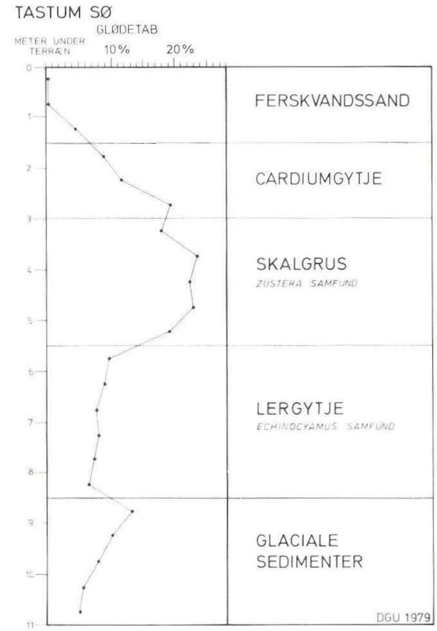

*Fig. 7.*Glødetabsanalyser, lithologi og faunistiske forhold i Tastum Sø boringen. Glødetabsanalyserne er ikke reducerede for kalk. De store værdier mellem 5,5-3,5 m u.t. skyldes antagelig biomassens kalk.

Analyses of loss-on-ignition, lithology and fauna composition in the Tastum Sø well. The analyses of loss-on-ignition are not reduced for carbonate. The high values between 5.5 and 3.5 m below surface may result from biogenic carbonate.

der et dække af yngre ferskvandsdannelser i Skive Å-dal, Tastum Sø og Jordbro Å-dal. Boringer i disse lavninger (bl.a. Jordbro Å, Tastum Sø, se fig. 1) har givet et indtryk af den marine udvikling samt mægtighederne af disse aflejringer i Fjendsområdet.

I Tastum Sø fandtes 7 m marine sedimenter, og i Jordbro Å-boringen 15 m let sandet gytje, hvilende på glaciale aflejringer. Den marine udvikling i Tastum Sø kan på baggrund af molluskfaunaen i boringen inddeles i 3 stadier (fig. 7). Den største artsrigdom (36 arter) findes i den nedre del af det marine indslag fra 8-5 m

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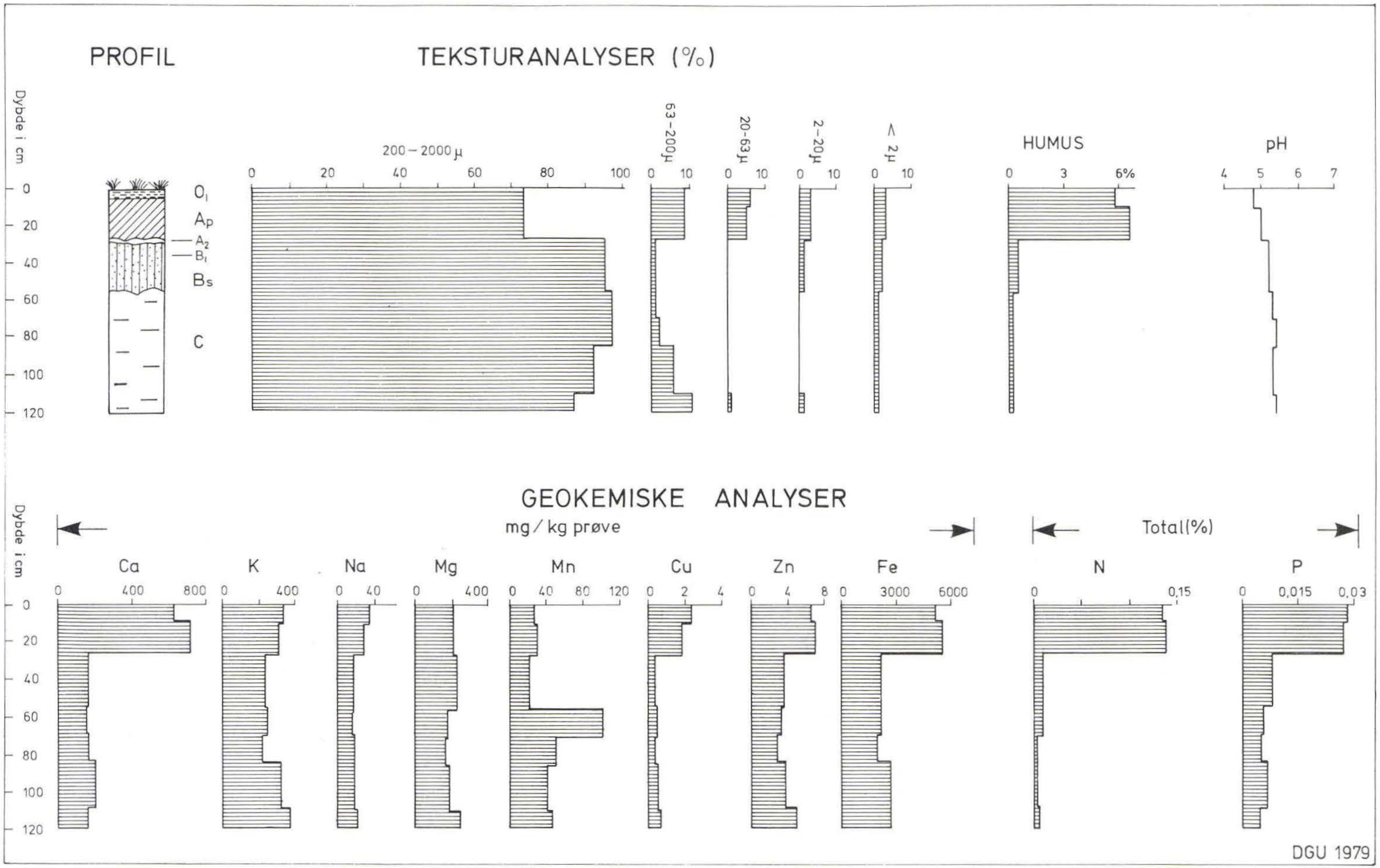
Fig. 6. Topografiske profiler over Jordbro Å-dal (jfr. fig. 1) tegnet på grundlag af GI 4 cm kort (1:25.000) med hovedtrækkene af de morfologiske og jordartsmæssige enheder fra karteringen (jfr. fig. 4).

Topographic profiles across the Jordbro Å valley (see fig. 1). The profiles are based on the GI 4 cm maps (1:25.000) and illustrate the main features of the morphological and lithological units (compare with fig. 4).


PROFIL
TEKSTURANALYSER (%)
Dybde i cm
O1
Ap
A2
B1
Bs
C
200 – 2000 μ
63 – 200 μ
20 - 63 μ
2 – 20 μ
< 2 μ
HUMUS
pH
GEOKEMISKE ANALYSER
mg / kg prøve
Total (%)
Ca
K
Na
Mg
Mn
Cu
Zn
Fe
N
P
DGU 1979

under terræn. De marine sedimenter er karakteriseret af *Echinocyamus pusillus*, der giver navn til bundsamfundet mellem *Abra* og *Zostera* samfundene i den recente Limfjord (Spärck og Lieberkind 1921). Fra 5-3 m under terræn er der udviklet et skalgruslag med arter karakteristiske for *Zostera* samfundet. Fra 3-1,5 m under terræn findes *Cardium*-gytje med kun få arter, men med stor individrigdom. For sneglenes vedkommende er der dominans af *Littorina saxatilis tenebrosa* og *Hydrobia stagnorum*, som er karakteristiske for et slutstadium af en marin fase.

Mikrofossilerne underbygger ovennævnte zonering, idet *Echinocyamus* samfundet er domineret af coccolither, medens diatoméer optræder i *Cardium*-gytjen og opefter udvikles til en artsrig brak- til ferskvandsflora.

Sammenholdes ovennævnte succession med glødetabsanalyserne (fig. 7) findes her en jordartsmæssig parallel.

Den sidste fase af den marine udvikling kan også fastlægges ved mollusker i det tidligere sund vest for Virksund, hvor nu Nørresø, Torsholmsø (udtørrede) og Ørslevkloster Sø er beliggende. Tilstedeværelsen i disse aflejringers yngste dele af *Venerupis aurea*, der traditionelt betragtes som en af ledeformerne fra Stenalderhavet, udelukker ikke, at lukningen af sundet kan være sket så sent som i Subatlantikum (Petersen 1976).

Køkkenmøddingerne, som under karteringen er fundet i samme område, afspejler ligeledes den rige fauna, som tidligere fandtes i denne del af Limfjorden.

Den marine forlandsdannelse i Fjendsområdet er, som andre steder i den nordvestlige del af landet, stabiliseret ved den postglaciale landhævning. I Fjendsområdet andrager hævningen ca. 2,5 m (Mertz 1924), og som karteringen har vist (fig. 4), indgår derfor flere tidligere øer nu som en del af Fjendshalvøen. Tidspunktet for udviklingen af højeste marine grænse må ifølge undersøgelser nord for området (Petersen 1976) antages at være sket i løbet af Subboreal.

Jordbundsudvikling i Fjendsområdet

For at udvide kendskabet til jordbundsudviklingen i det karterede område blev jordbundsprofiler undersøgt i 3 forskellige karteringsenheder (morænesand og smeltevandsler i glaciallandskabet samt ekstramarginalt sand). Undersøgelserne omfattede en jordbundsbeskrivelse og teksturanalyse af de tilstedeværende horisonter samt en række geokemiske analyser. De indsamlede data kan anvendes til karakterisering og adskillelse af de enkelte karteringsenheder og muliggør dermed en sammenligning med andre områder i Danmark.

Fig. 8. Jordbundsprofil i den ekstramarginale flade ved Stensbjerg i Jordbro Å-dalen. Podzolprofilets horisont af blegesand (A_2) er kun svagt repræsenteret på grund af oppløjning.
Soil profile in the outwash plain at Stensbjerg in the Jordbro Å valley. The bleached horizon (A_2) of podzolized soils is weak due to ploughing.

Det illustrerede profil (fig. 8) er baseret på undersøgelser af en podzoleret ekstramarginal aflejring ved Stensbjerg i Jordbro Å-dalen. Podzoleringen genfindes i de fleste ekstramarginale aflejringer i Fjendsområdet, men er udviklet med varierende intensitet. Profilets teksturelle og geokemiske data er iøvrigt karakteristisk for ekstramarginale dannelser i Danmark.

I feltarbejdet deltog som karteringsassistenter *Lars Nydahl Jørgensen, Jørn Bo Jensen, Arne Mogensen* og *Hans Martin Friis Møller* fra Københavns Universitet og *Erling Fuglsang Nielsen* fra Århus Universitet. Den geoelektriske kortlægning blev udført af *Niels Viggo Jessen* og *Torben Jensen* fra DGU. Jordbundsanalyserne blev foretaget af Sekretariatet for Jordbundsklassificering i Vejle.

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Eksempel på kort over prækvartæroverfladens højdeforhold

Knud Binzer og Claus Andersen

Binzer, K. og Andersen, C.: Eksempel på kort over prækvartæroverfladens højdeforhold. *Danm. geol. Unders. Årbog 1978*, pp. 119 – 129, 1 kortbilag. København 1979.

The topography of the contact between Quaternary sediments and underlying pre-Quaternary sediments within the map sheet 1215 Viborg (1:100.000) is constructed from geological data from more than 2000 wells.

It is concluded that fluvial erosion previous to the Quaternary glaciations is the main factor influenced on the topography. Halokinesis of Permian evaporites seems to have influenced locally.

The topography of the Quaternary sedimentary cover generally conforms to the topography of the pre-Quaternary top surface.

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I miljøstyrelsens vejledning vedrørende den hydrogeologiske kortlægning (vejledning nr. 2/1975), står der bl.a., at områder, hvor undergrundsaflejringerne spiller en væsentlig rolle for vandforsyningen, vil det være rimeligt at fremstille kort over prækvartæroverfladen.

Et ønske fra miljøstyrelsen om et kort til brug som bilag i »Vejledning vedrørende planlægning af grundvandsindvinding 1. delrapport/1978", hvori brugen af det hydrogeologiske kortværk omtales medførte, at DGU's planlægningsafdeling påtog sig opgaven at udarbejde kortet. Da både kemikort og PT-kort (potential- og transmissivitet) over kortbladet 1215 Viborg indgår som kortbilag i »Vejledningen«, og da man allerede har påbegyndt udarbejdelsen af prækvartærkort over Viborg amtskommune i forbindelse med den hydrogeologiske kortlægning (Rasmussen et al., 1978), blev det bestemt, at kortbladet 1215 Viborg skulle fremstilles specielt til brug for »Vejledningen«.

I forbindelse med revisionen af kortet er der fremkommet værdifuld og konstruktiv kritik fra amtsgeolog, cand. scient. *Richard Thomsen*, Århus amtskommune og fra lektor, lic. scient. *Ivan Madirazza*, Laboratoriet for Geofysik Århus universitet. Endvidere har geologerne *Peter Claudi Rasmussen* og *Peter Gravesen*, begge DGU, ydet værdifuld bestand med revisionsarbejdet.

Materialer og metoder

Grundlaget for udarbejdelsen af kortet over prækvartæroverfladen er oplysninger om boringer, som ligger i DGU's EDB-database samt cirkeldiagramkort (geologiske basisdatakort, 2 cm kortene 1215 I, II, III og IV). Desuden er medtaget oplysninger fra lokaliteter, hvor prækvartære aflejringer er eksponeret, i det omfang disse oplysninger findes i DGU's arkiver eller i publikationer (se f.eks. Ødum, 1926). Endvidere er DGU's arkiver over geofysiske undersøgelser af den dybere undergrund blevet benyttet. Geodætisk Instituts orohydrografiske planer indeholdende højdekurver og vandområder i målforholdet 1:50.000 er anvendt ved udarbejdelsen af kortet. Kortet er trykt i målforholdet 1:100.000.

Udvælgelse af boringer blev foretaget ved hjælp af basisdatakortene 1215 I, II, III og IV og EDB-udskrifter af boringsoplysninger. Følgende oplysninger har dannet grundlaget for udvælgelsen og er afbildet på kortet:

1) boringsnummer
2) borestedssymbol
3) kote for prækvartæroverfladen eller bundkote for dybere boring, som ikke når prækvartæroverfladen
4) kote, som angiver bund af boring, men hvor prækvartæroverfladen ligger højere end bundkoten, på et ukendt niveau
5) samt bjergartsbetegnelse for den undergrundsaflejring, boringen eventuelt har nået.

Kun få boringer er blevet udeladt uden relevante oplysninger om prækvartæroverfladens beliggenhed samt enkelte dybdeboringer, som ikke er indført i DGU's database.

Kurverne over prækvartæroverfladens højdeforhold er tegnet med en ækvidistance på 10 m. Den udarbejdede kurveplan blev korrigeret med hensyn til den topografiske overflade ved hjælp af en oro-hydrografisk plan.

Prækvartæroverfladens morfologi

Prækvartæroverfladens højdeforhold er vist med sorte stiplede eller heloptrukne kurver, således som den tager sig ud ved basis af kvartærlagene.

Områder med ensartet lithologisk sammensætning i prækvartærets overflade er afgrænset med samme farve, og omridset af større strukturer og forkastninger i den dybe undergrund er vist med gråtonede tykke streger. Disse oplysninger er blevet trykt sammen med et topografisk kortgrundlag indeholdende højdekurver over den nuværende landoverflade trykt med brun farve og vandløb, søer og vådområder med blå farve (den orohydrografiske plan) samt navne og stregplan (bygninger, veje m.v.) trykt med lysegrå farve.

Dalstrækninger i prækvartæroverfladen

Prækvartæroverfladen virker mere udjævnet end den aktuelle landoverflade, fordi kurverne er draget på grundlag af færre oplysninger (koter), og fordi, den valgte ækvidistance er 10 m og ikke 5 m, som på det topografiske kortgrundlag. Det er imidlertid mest sandsynligt, at prækvartæroverfladen faktisk er mere udjævnet end den nuværende landoverflade, f.eks. som følge af glacialerosion.

På kortet (se bilag) ses, at der i prækvartæroverfladen findes langstrakte mere eller mindre slyngede, lavt liggende områder, der f.eks. kan opfattes som fluviatile erosionsdale. Et særlig tydeligt eksempel er en dal, der har udgangspunkt sydvest for Hald Sø og som løber i nordøstlig retning indtil Viborg, hvor den drejer mod nord, og som lidt nord for Viborg svinger mod nordvest og breder sig ud under Hjarbæk Fjord. På kortet er dalen angivet at have sit højeste punkt omkring kote$\pm$ 0 m syd for Hald Sø, og i den nordlige ende, nord for Hjarbæk Fjord, er prækvartæroverfladen truffet i kote -121 m (boringsnr. 56.438). På en strækning af 30 km er der et fald på 3-4 promille. Selv en så relativt velmarkeret dal har altså i sin længderetning et ganske svagt fald. Dalens sider er derimod langs visse strækninger betydelig stejlere. Det stejleste sted findes på en kort strækning i Viborg på vestsiden af dalen, hvor Søndersø og Nørresø støder op til hinanden. Her falder dalsiden ca. 80 m over en strækning på ca. 800 m, altså et fald på 10%. Andre steder, hvor kurverne beskriver stejle dalsider eller skrænter, er syd for Skive Fjord, ved nordenden af Tjele Langsø og ved Bjerringbro, hvor dalsiden ligeledes falder ca. 10%, hvilket svarer til en hældningsvinkel på 5-6^0. Flere sådanne knap så tydelige skrænter kan ses andre steder på kortet, men selvom kurvebilledet angiver sådanne terrænskrænter, er det dog ikke terrænforskelle, som afviger fra det nuværende terræns.

Andre dale i prækvartæroverfladen, foruden Hald Sø-Hjarbæk Fjord dalen, er dalen, som falder sammen med Gudenådalens nuværende forløb og med fald i samme retning og dalkomplekset omkring Nørreådalen, som deler sig i to grene, en nordlig og sydlig gren, vest for Viskum. De to sidstnævnte dalstrækninger støder op til Hald Sø-Hjarbæk Fjord dalen, henholdsvis syd og nord for Viborg og har begge et fald i vestlig retning.

I det sydøstlige hjørne af kortet findes en dal, som falder sammen med Gjernå og Granslev ådalen og med fald mod nordøst.

I den sydvestlige del af kortet findes en knap så tydelig dal, der har et sydøst-nordvestligt forløb og som falder sammen med Karupdalens længderetning og med fald mod nordvest.

Foruden disse dale er der flere andre mindre tydelige eller kortere dalstrækninger i prækvartæroverfladen. F.eks. er der antydet et dalstrøg, som følger Faldborgdalens forløb fra Rødkærsbro mod nordvest til Rindsholm med fald ligeledes mod nordvest.

Foruden dalene er der sænkninger i prækvartæroverfladen, som har karakter af lavninger. Sådanne bassinlignende lavninger findes omkring Skive Fjord og Hjarbæk Fjord. En tredie lavning kan ses i kortets nordøstlige del fra omkring den strækning af Skalsådalen, som forløber fra sydøst mod nordvest og videre i nordlig retning til omkring Øls (Skalså-Øls lavningen). I alle de nævnte lavninger er prækvartæroverfladen truffet i koter, der er lavere end -80 m.

Højdeområder i prækvartæroverfladen

Mellem de ovenfor skildrede dale eller dalstrøg hæver der sig større og mindre arealer, som må antages at have dannet en mere sammenhængende overflade i det landskab, hvori dalene er blevet nedeproderet.

De højeste koter, hvori prækvartæroverfladen er truffet, findes i kortets sydlig-

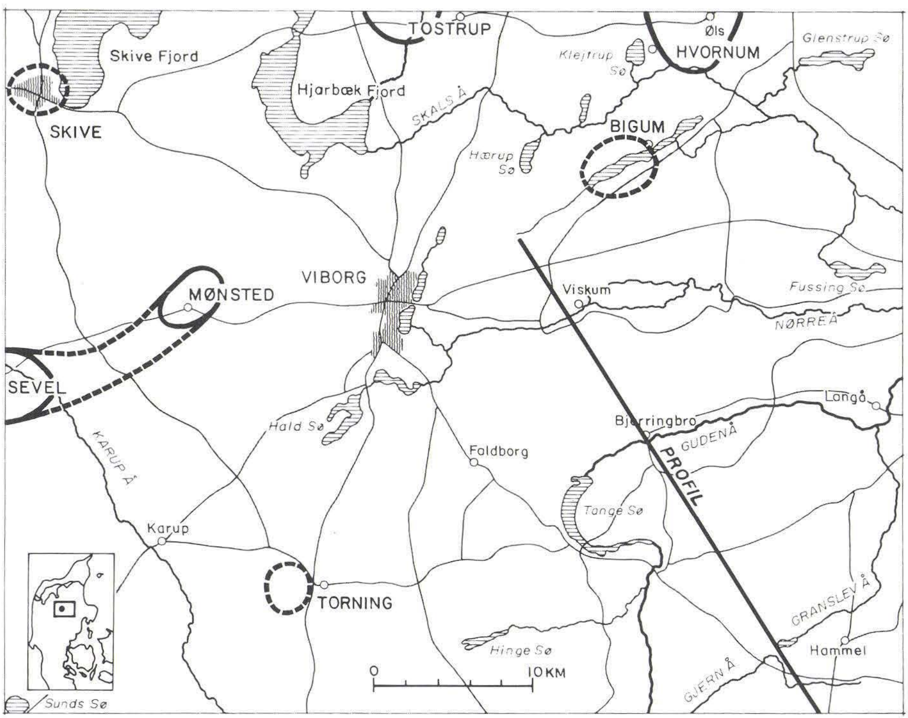

Fig. 1. Oversigt over beliggenheden af saltstrukturer og deres navne og nogle stednavne og større terrænelementer nævnt i teksten samt beliggenheden af profilet vist i fig. 2.

Fig. 1. *Sketch map showing the location of salt structures and their names, some locality names and morphological features used in the text and the profile line shown in fig. 2.*

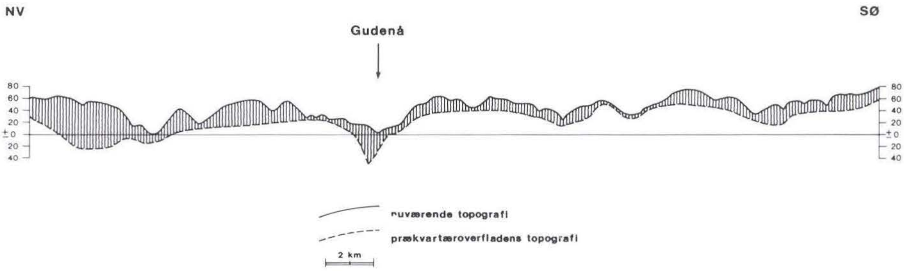

Fig. 2. Profil gennem kortets østlige del (se fig. 1), som viser sammenfaldet i det store træk mellem prækvartæroverfladens topografi og det nuværende landskabs topografi.
Fig 2. *Profile through the eastern part of the map (see fig. 1) showing the coinsidence between the topography of the contact Quaternary – Prequaternary and present surface topography.*

ste del lidt syd for Serup og Gjern Bakker, hvor koterne er over 70 m (boring 77.42 når kote 83 m og 77.829 når kote 85,5 m). Højdeområderne når i det hele taget de højeste koter syd og sydøst for en linie fra Karup over Hald Sø og langs Nørreådalen. Her når prækvartæroverfladen flere steder kote 40, og sydøst herfor nås koter over 50 og 60 m.

Vest og nord for denne linie når prækvartæroverfladen ikke op over kote 30 bortset fra Daubjerg, Mønsted og Velds, hvor prækvartæroverfladen er truffet i over kote 40 m.

Mellem Skive Fjord og Hjarbæk Fjord og øst herfor når prækvartæroverfladen kun nogle få steder over kote 10 m. Der er således en klar tendens til at topkoterne for højdeområderne generelt beskriver en flade med hældning mod nord og nordvest (se fig. 2).

Strukturer under prækvartæroverfladen

På kortet (se bilag) er afbildet flere strukturer, som findes i undergrunden under prækvartæroverfladen (se fig. 1). Disse hidrører fra bevægelse af stensaltaflejringer (halokinese) fra zechstein perioden (øvre perm).

Kortområdet ligger placeret nær den centrale del af det Dansk-Norske Bassin, hvor der er aflejret 500-1200 m stensalt ved inddampning af havvand. I de efterfølgende tidsperioder: trias, jura, kridt og tertiær er stensaltet blevet overlejret af sedimenter med en tykkelse på 4000-5000 m.

Som følge af stensalts relativt lavere massefylde og høje plasticitet kan denne bjergart starte horisontale og vertikale bevægelser udelukkende som følge af massefyldeforskelle. Første stadium i saltbevægelsen vil være dannelse af bløde opbulninger (saltpuder) og ved fortsat bevægelse vil der dannes stejltstillede saltdiapirer, som bryder igennem de overliggende lag. I Nordjylland formodes saltbevægelsen at være påbegyndt i keuper (øvre trias) og er fortsat op i nutiden (Madirazza, 1968a).

Blandt de afbildede strukturer er »Mønsted salthorsten« den mest kendte (Ødum, 1960, Madirazza, 1966a, b, 1968a, b og Baartmann, 1973). I nærværende sammenhæng er det kun saltstrukturernes betydning for prækvartæroverfladens geologi og højdeforhold, der vil blive omtalt.

Prækvartæroverfladens kurvebillede og de anvendte farver afspejler flere steder tilstedeværelsen af saltstrukturer i undergrunden. Mønsted strukturen viser sig ved, at ældre lag forekommer uden dække af yngre prækvartære lag i en uregelmæssig ringformet figur. På kortet er dette vist ved at danien's grønne farve fremtræder omgivet af nedre tertiærs mørkeblå farve. Kurveforløbet viser, at der findes et højdedrag i prækvartæroverfladen, som når op i kote 40 m. Endvidere er der langs den sydøstlige rand af strukturen en trugformet fordybning, som når ned under kote -20 m mellem Mønsted strukturen i nordvest og et plateau sydvest herfor beliggende i over kote 20 m. Denne depression kan opfattes som en indsynkning af prækvartæroverfladen som følge af saltmigration i undergrunden i retning mod saltdiapiren, hvilket har medført en assymmetrisk udvikling af en ung randsynklinal (Trusheim, 1960).

Ved Skive og Tostrup strukturerne er prækvartæroverfladen hævet noget over omgivelserne og antyder dermed, at saltet i undergrunden har presset de ovenliggende lag op. Ved Skive er ældre tertiær omgivet af yngre tertiær og ved Tostrup findes danien omgivet af yngre tertiær. Skive strukturen er en saltpude, og Tostrup strukturen er en saltdiapir med stejle, måske endda lokalt overhængende flanker. Ved Bigum strukturen, som er meget dårligt kendt, er der også lokalt en forhøjning af prækvartæroverfladen, uden at der dog er blevet konstateret lag der er ældre end yngre tertiær.

I modsætning til de ovenfor omtalte strukturer falder Hvornum strukturen sammen med en markant lavning, tidligere omtalt som Skalså-Øls lavningen. Det er dog vanskeligt, p.g.a. manglende data, at afgøre, hvorledes dette står i forbindelse med Mariager Fjord-systemet udenfor kortets nordøstlige hjørne. Data, som ikke er medtaget på kortet fra Dansk Salt I/S's produktionsboringer placeret nær den centrale del af strukturen, angiver kvartære till- og smeltevandsaflejringer opblandet med tertiært materiale direkte ovenpå gips-anhydrit caprock, hvis koter veksler mellem -170 m og -220 m indenfor afstande på få hundrede m. Den meget markante depression i prækvartæroverfladen kan tænkes forklaret som en kombination af karstdannelse i caprock'en samt en opløsning af underliggende salt der er sket hurtigere end saltets opskydningshastighed, hvilket kan have medført kraftig indsynkning og forsætninger.

Som nævnt viser farverne på kortet en vis sammenhæng med tilstedeværelsen af saltstrukturer i undergrunden som beskrevet ovenfor i Mønsted, Skive og Tostrup strukturerne. I kortets østligste kant er der imidlertid også ældre lag som mod vest er afgrænset af yngre lag. Dette forhold skal formodentlig søges forklaret med de strukturelle forhold i undergrunden, som ikke er vist på kortet. Det nordlige område, hvor danien og kridt danner prækvartæroverfladen, hænger sammen med Gassum strukturen (saltpude) umiddelbart uden for kortranden. Med hensyn til det sydlige område med ældre tertiær kan et andet forhold spille en væsentlig rolle, nemlig beliggenheden af randen af det sedimentations bassin, hvori de yngre sedimenter er aflejret. Her er der muligvis tale om en pålejringskontakt.

Kvartærlandskabets og prækvartæroverfladens højdeforhold

Ved en sammenligning mellem den kvartære morfologi og den prækvartære morfologi, fremgår det, at der på kortet findes en tydelig og påfaldende overensstemmelse mellem det nuværende landskabs topografi og prækvartæroverfladens topografi (se fig. 1 og 2). Der, hvor der er dale og bakker i kvartærlandskabet, er der som regel også dale og bakker i prækvartæroverfladen. Undtagelser fra denne regel findes. Således genfindes den prækvartære dal, »Hald Sø-Hjarbæk Fjord« i kvartærlandskabet på strækningen fra Hald Sø til Viborg, hvorimod prækvartærdalen på strækningen fra Viborg til Hjarbæk Fjord bliver fyldt op med kvartære sedimenter og derfor ikke kan ses i det kvartære landskab. Fra Hjarbæk Fjord er dalene atter sammenfaldende. Et lignende forhold kan ses i det tidligere omtalte Nørreådal kompleks, hvor den nordlige dalforgrening i prækvartæroverfladen vest for Viskum er blevet »begravet« eller fyldt med kvartære sedimenter (se fig 2).

Man har tidligere antaget, at de store dale i det kvartære landskab var dannet enten under isen som tunneldale eller foran isen som smeltevandsfloddale under weichsel glaciationen (se f.eks. S. Hansen 1965, V. Milthers 1948, K. Milthers 1935). Flere forfattere har rejst tvivl, om man kan fastholde smeltevandsfloderosion som generel dannelsesmåde (K. Hansen, 1971, H. Lykke Andersen 1973, I. Marcussen 1976). Woldstedt (1952) og Berthelsen (1972) foreslår en alternativ dannelsesmåde, som er en kombination mellem smeltevandsfloderosion og glacialerosion af en avancerende gletscher.

Glacial erosion og glaciofluviatil erosion har således været betragtet som væsentlige erosive kræfter ved prækvartæroverfladens udformning. Et af problemerne med denne hypotese er, at man ikke kan vise, hvornår glacial erosion har fundet sted. Hvis det antages, at der ved hver glaciation er sket en væsentlig ændring af udformningen både af prækvartæroverfladen og det glaciale landskab, indebærer det, at prækvartæroverfladen hovedsagelig må være udformet under weichsel glaciationen. Dette er ikke troligt, da man flere steder i de østjyske dale har fundet moser af eem-alder (Hartz 1909, Jessen og Milthers 1928, Bull et al. 1976, I. Marcussen, 1977). Disse dale må altså have eksisteret i eem-interglacialtid og må med andre ord være ældre end weichsel. Derimod kan man ikke afvise, at udformningen af prækvartæroverfladen er sket ved glacial erosion under en ældre istid og mest oprindeligt ved den første kvartære glaciation. Men det må erindres, at den morfologi, som antagelig har eksisteret forud for den første glaciation, sandsynligvis i et vist omfang påvirkede en evt. glacial erosion og antagelig derfor har præget det glaciale landskab, som dannedes efter den første glaciation. Konklusionen af disse overvejelser må blive, at prækvartæroverfladens større morfologiske træk (bl.a. de store dale) primært er anlagt forud for de kvartære glaciationer og har præget de senere glaciale landskaber, men at glacial erosion under den første glaciation i det mindste har modificeret eller evt. bidraget med nye træk til prækvartæroverfladens morfologi.

Den dokumentation, der er indeholdt i kortet, har ikke vist meget om de glacialtektoniske forhold på kortet. Der har dog kunnet konstateres glacialflager af ældre sedimenter blandt det bearbejdede dokumentationsmateriale i kortbladets nordvestlige del. Glacialflager vil højst sandsynligt også kunne findes flere steder, som f.eks. i Juelsminde området (uden for kortet) (Stockmarr, 1976), i områder, hvor følgevirkninger af f.eks. salttektonik kan lades ude af betragtning. Glacialtektoniske fænomener er beskrevet i områderne nord for det her undersøgte område (Gry, 1940, 1979).

Overensstemmelse mellem kvartærlandskabets og prækvartæroverfladens højdeforhold er tidligere blevet beskrevet fra området (Andersen, 1972). Dette blandt andet har ført til spekulationer over, om andre geologiske begivenheder end den sedimentologiske proceskreds, halokinese, glacialerosion og/eller glacialtektonik kan have medvirket ved landskabsmorfogenesen, f.eks. unge tektoniske bevægelser i prækvartærlagene og i kvartærlagene (Madirazza, 1966a, b, 1968a, b, Bull et al., 1976, Kronborg et al., 1978, Bondesen og Andersen, 1978, Andersen, 1979). Hermed er man kommet ind på tektoniske processer forbundet med »neo-tektonik«, som også bl.a. i Sverige (Lundqvist och Lagerbäck, 1976, Lagerlund, 1977 a og b) har været diskuteret.

Ved tolkningen af kortets informationer synes således hypotesen om prækvartæroverfladens landskabsmorfogenese, hovedsagelig som resultat af et eroderende dræneringssystem på en gammel landoverflade, at være den mest nærliggende mulighed. Hvis denne hypotese kan verificeres, må man antage, at det kvartære landskabs udseende i en vis udstrækning har været afhængig af det ældre landskabs topografi under landskabsmorfogenesen.

Kronologiske implikationer

Prækvartæroverfladen må være udformet som resultatet af processer, der har virket gennem det lange tidsrum fra tertiærtiden og frem til nutiden. Dog ser det ud til, at erosionsprocesser forud for de kvartære glaciationer har været de betydeligste ved prækvartæroverfladens landskabsmorfogenese. Udformningen af mange af de større træk i det kvartære landskab, først og fremmest dalene, har, som allerede nævnt været påvirket af prækvartæroverfladens morfologi. Men glaciologiske og sedimentologiske processer under glaciationer og deglaciationer må naturligvis have spillet en væsentlig rolle ved den detaljerede udformning af det kvartære landskab.

Den praktiske anvendelse af kortet

Den praktiske anvendelighed af kortet beror bl.a. på muligheden af, at man ret nemt kan aflæse tykkelsen af de kvartære lag, som dækker prækvartæroverfladen. Ved at sammenholde koterne for prækvartæroverfladekurverne med koterne for det aktuelle landskabs overfladekurver fås en størrelsesorden for tykkelsen af de kvartære lag. Herved kan kortet bruges som udgangspunkt ved konstruktion af isopakytkort over de kvartære lag.

Kendskab til de kvartære lags tykkelse har betydning for vurderingen af tykkelsen og evt. udbredelsen af de vandførende lag i de kvartære sedimenter. Kortet har også betydning for vurderingen af råstofforekomsters tykkelse og udbredelse i kvartærlagene. Dokumentationsindholdet i prækvartæroverfladekortet gør det ligeledes muligt at anvende det ved bedømmelse af vandindvindings- og råstofindvindingsmuligheder i prækvartærlagene.

Sammenfatning

Udarbejdelsen af kort over prækvartæroverfladens højdeforhold bidrager til at rette opmærksomheden mod de geologiske processer, som eventuelt har haft betydning for udformningen af både prækvartæroverfladens morfologi og det kvartære landskabs morfologi og medvirker dermed til en bedre forståelse af landskabsmorfogenesen. Kortet og den informationsmængde, der er nedlagt i det, gør det anvendeligt i mange sammenhænge, både af ren geologisk art, og i forbindelse med løsningen af mere praktisk betonede undersøgelser, f.eks. vandindvinding eller råstofefterforskning.

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A new dinoflagellate zone at the Maastrichtian/Danian boundary in Denmark

Jens Morten Hansen

Hansen, J.M.: A new dinoflagellate zone at the Maastrichtian/Danian boundary in Denmark. *Danm. geol. Unders., Årbog 1978*, pp. 131-140. København 1979.

A new dinoflagellate zone, the *Chiropteridium inornatum-Palynodinium grallator* Concurrent Range Zone, is added to a previously established biozonation. The zone is restricted to the uppermost c. 0.5 m of the Maastrichtian chalk in northwestern Denmark. The biostratigraphical events at the Maastrichtian/Danian boundary is discussed and documented with examples from the sections at Kjølby Gård, Nye Kløv, Bjerre, Eerslev and Dania.

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In 1977 a dinoflagellate stratigraphy for the Upper Maastrichtian and Danian of Danmark was proposed. This zonation includes 3 Upper Maastrichtian and 4 Danian biostratigraphical units (Hansen 1977). The possibility to establish one further zone immediately below the boundary was mentioned, since at Kjølby Gård (fig. 1) *Chiropteridium inornatum* Drugg 1970 was found to occur already below the Maastrichtian/Danian boundary whereas at other localities investigated (Stevns Klint, Copenhagen core TUBA 13) *C. inornatum* occurred only above the boundary together with other characteristical dinoflagellate species such as *Danea mutabilis* Morgenroth 1968, *Carpatella cornuta* Grigorovitch 1969, *Membranilarnacia tenella* Morgenroth 1968, and *Hafniasphaera hyalospinosa* Hansen 1977. This biostratigraphical differential development of the Maastrichtian/Danian boundary in Denmark was believed to reflect a more complete development of the boundary in northwestern Denmark compared to the type area of the Danian in eastern Denmark.

Since much interest is attributed to the biostratigraphy of the Mesozoic/Cainozoic boundary and therefore especially to the Maastrichtian/Danian boundary in Denmark, the level of first occurrence of *Chiropteridium inornatum* has been further investigated at various localities in northwestern Denmark. Thus close sampling of the Maastrichtian/Danian boundary sections at Nye Kløv, Kjølby Gård, Bjerre, Eerslev and Dania (fig. 1) has been done. All of these sections showed that *Chiropteridium inornatum* occur below the first occurrence of *Car-*

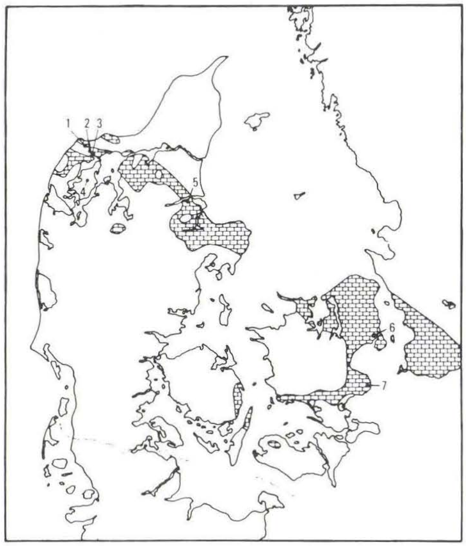

Fig. 1 Geological map of the Danian showing position of localities. 1: Bjerre. 2: Kjølby Gård. 3: Nye Kløv. 4: Eerslev. 5: Dania. 6: Copenhagen TUBA 13. 7: Stevns Klint.

patella cornuta, Danea mutabilis, and *Membranilarnacia tenella* and below the disappearance of *Palynodinium grallator* Gocht 1970 and *Spiniferites ramosus cavispinosus* Hansen 1977.

In fig. 2 the stratigraphical occurrence of biostratigraphically diagnostic dinoflagellates is presented. It is seen that some diagnostic Danian species occur at all localities, whereas *Hafniasphaera hyalospinosa* is only found at the easternmost localities. On the basis of these observations 5 biostratigraphical events may be defined to establish a basis for a discussion of the chronostratigraphical value of these events:

1). First occurrence of *Palynodinium grallator.*
2). First occurrence of *Thalassiphora pelagica.*
3). First occurrence of *Chriropteridium inornatum.*
4). First occurrence of *Membranilarnacia tenella, Carpatella cornuta, Danea mutabilis* and disappearance of *Palynodinium grallator* and *Spiniferites ramosus cavispinosus.*
5). First occurrence of *Xenicodinium rugulatum.*

At the localities Kjølby Gård, Nye Kløv, Bjerre, Dania and Eerslev these events take place in the same order whereas at Stevns Klint and in Copenhaven core TUBA 13 events 3) and 4) are confluent. This differential development of the biostratigraphy can be explained in two basically different ways: sediments con-

	KJØLBY GÅRD	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	EERSLEV	DANIA	STEVNS KLINT	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	EERSLEV	DANIA	STEVNS KLINT	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	EERSLEV	DANIA	BJERRE	KJØLBY GÅRD	NYE KLØV	DANIA	STEVNS KLINT	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	DANIA	STEVNS KLINT	TUBA 13
S RAM CAVISPINOSUS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		(•)		(•)	(•)							
P GRALLATOR			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		(•)	(•)	(•)	(•)			(•)				
T PELAGICA										•	•	•	•	•	•	•	•	•		•	•	•	•	•	•		•	•		•			•
C INORNATUM																	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
D MUTABILIS																						•	•	•	•	•	•	•	•	•	•	•	•
H HYALOSPINOSA																										•	•					•	•
M TENELLA																						•	•	•	•	•	•	•	•	•			•
C CORNUTA																						•	•	•	•	•	•	•	•	•			•
H SEPTATA																													•	•		•	•
X RETICULATUM																													•			•	•
X RUGULATUM																												•	•	•	•	•	•
	V a (WILSON 1974)		TANYOSPHAERIDIUM MAGDALIUM SUBZONE							THALASSIPHORA PELAGICA SUBZONE							CHIROPTERIDIUM INORNATUM - PALYNODINIUM C.R. ZONE NOV					CARPATELLA CORNUTA ZONULE						XENICODINIUM RUGULATUM ZONULE					
																						CHIROPTERIDIUM INORNATIUM SUBZONE											
			PALYNODINIUM GRALLATOR ZONE																			DANEA MUTABILIS ZONE											

Fig. 2 Scheme showing the occurrences of some stratigraphycally significant species at different localities and at different stratigraphical levels. Brackets indicate occurrences of specimens, that are belived to be reworked.

taining event 3) may be missing at the easternmost localities, or event 4) could be palaeoenvironmentally controlled.

The fact that event 4) including not less than 3 first occurrences and 2 disappearances at most localities take place at the base of a marl layer containing clasts of Upper Maastrichtian age indicates that a part of the section is missing. However, in Stevns Klint the clasts are rounded giving the marl layer a conglomeratic appearance whereas at Kjølby Gård and Dania the clasts are angular giving the marl layer as well as the superposing sediment in Kjølby Gård a brecciated appearance. Furthermore, the clasts in Kjølby Gård are derived from both sediments older than event 4) and younger than event 5) whereas in Stevns Klint all clasts are older than event 4). The section at Kjølby Gård as well as the section at Eerslev, where the marl layer is missing, are situated above halokinetically induced structures elevating Mesozoic and Tertiary strata (cf. Rasmussen 1978). This deformation of the strata combined with the different competance of the flint-poor Maastrichtian chalk and of the flint-rich Danian chalk and bryozoan limestones could easily explain the brecciation of the Maastrichtian/Danian boundary strata at Kjølby Gård whereas at Stevns Klint the clasts more likely have been formed during the long durated (cf. Hansen 1977 for discussion) accumulation of the marl layer. Therefore, it may be concluded that the sedimentological development of the boundary strata indicates a hiatus at Stevns Klint and Eerslev whereas incomplete preservation of the boundary strata at other localities could partly be explained by post-sedimentary deformation and solution. In addition to this point of view hardgrounds in contact with the Maastrichtian/Danian boundary are clearly developed only at Stevns Klint and Eerslev.

On the other hand, if the differential biostratigraphical development of the Maastrichtian/Danian boundary is only palaeoenvironmentally controlled, the first occurrence of all diagnostic species should be related to lithological changes. However, *Chiropteridium inornatum* occurs below the marl layer in northwestern Denmark but in the marl layer in eastern Denmark together with diagnostic Danian species. This confluence of two biostratigraphical events in eastern Denmark could easily be explained by a small hiatus below the Maastrichtian/Danian boundary. Palaeoenvironmentally controlled differences are more likely to be reflected in the relative abundance of certain species. Thus *Hafniasphaera hyalospinosa* has not been found at all in northwestern Denmark whereas it is abundant in eastern Denmark. A similar pattern is observed with respect to the species *Carpatella cornuta* and *Membranilarnacia tenella* which are most frequent in northwestern Denmark.

Systematic biostratigraphy

Chiropteridium inornatum – Palynodinium grallator Concurrent Range Zone nov.
Definition: Sediments containing both *Chiropteridium inornatum* Drugg 1970 or *Spiniferites ramousus cavispinosus* Hansen 1977 but excluding sediments containing *Carpatella cornuta* Grigorovitch 1969, *Danea mutabilis* Morgenroth 1968, or *Membranilarnacia tenella* Morgenroth 1968.

Stratigraphical range: Upper part of the Upper Maastrichtian *Thalassiphora pelagica* Subzone which constitutes the upper part of the Upper Maastrichtian *Palynodinium grallator* Zone (Hansen 1977).

Reference section: Kjølby Gård; upper c. 0.5 of the Withe Chalk until the base of marl layer (cf. fig. 3).

Correlations: This zone is equivalent with the youngest ammonite-bearing strata in Denmark, since *Baculites* sp. has been found up to the top of the zone and never above.

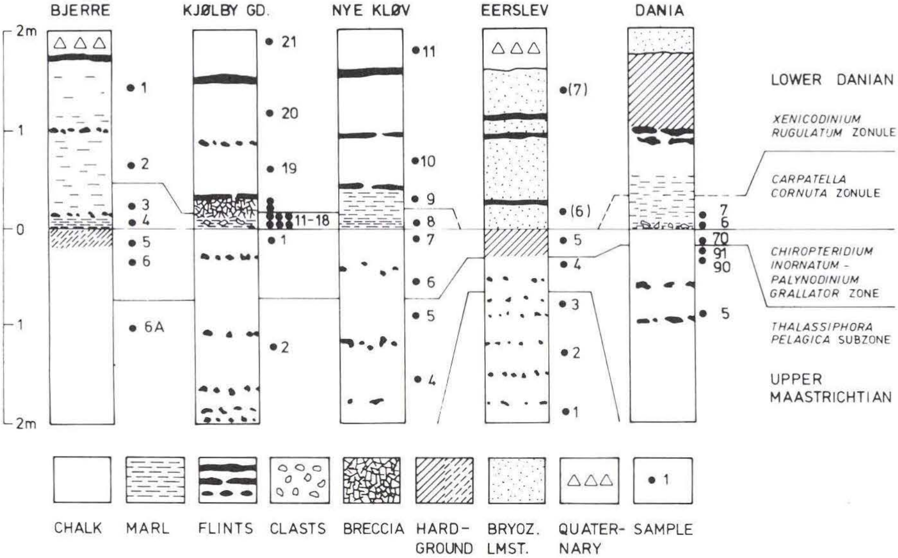

Fig. 3 Lithological sections of the upper 2 m of the Maastrichtian and the lower 2 m of the Danian in northwestern Denmark. Dinoflagellate zonation and position of samples indicated. Brackets indicate samples without dinoflagellates.

Remarks: This zone comprises c. 0.5 m at Kjølby Gård, c. 0.7 m at Nye Kløv, c. 0.28 m at Dania c. 0.7 m at Bjerre and 0.2 m at Eerslev. I tseems to be absent in Stevns Klint and Copenhagen core TUBA 13.

Conclusions

The dinoflagellate stratigraphy established across the Maastrichtian/Danian boundary in Denmark yields a very detailed biostratigraphical resolution of the boundary strata (fig. 3). Furthermore, several diagnostic dinoflagellates including *Carpatella cornuta, Danea mutabilis* and *Chiropteridiun inornatum* have been reported from especially North America (Drugg 1967 and 1970, Evitt 1973) and Europe (Grigorovitch 1969, Jan du Chêne 1977). Consequently, the stratigraphical scheme presented here may prove to be an effective tool in the paleontological dissection of the Cretaceous/Tertiary boundary.

Although it is not the objective of the present study to carry out a revision of the taxa involved, it should be mentioned that some taxonomical problems remain unsolved corcerning the species *Carpatella cornuta, Danea mutabilis* and *Chiropteridium inornatum*. In the concept of the present author *Carpatella cornuta* Grigorovitch 1969 compares well with parts of the type material of

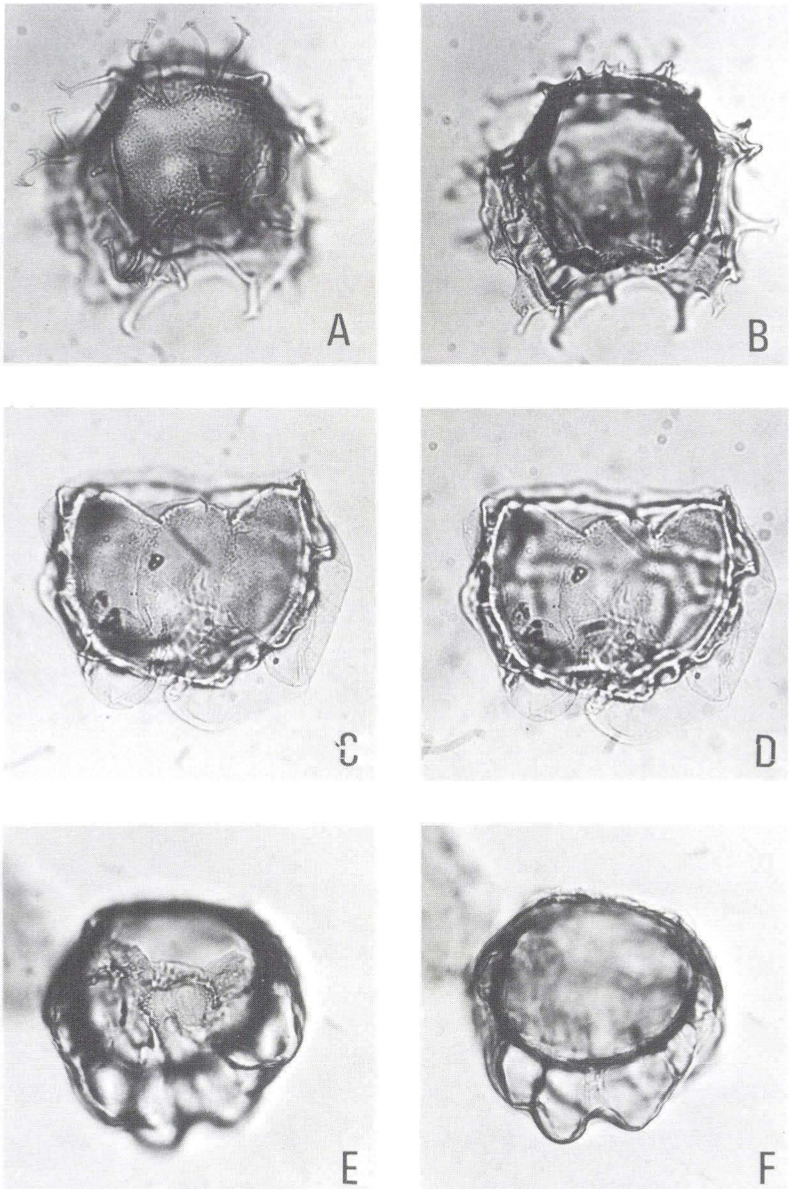

Fig. 4 All figures 500 X. A: *Palynodonium grallator*, high focus, Dania 70, 2:26.1-106.6. B: *Palynodinium grallator*, low focus, same as A. C: *Chiropteridium inornatum*, high focus, Nye Kløv 10, 1:23,0-104.4 D: *Chiropteridium inornatum*, low focus, same as C. E: *Chiropteridium inornatum*, high focus, Dania 70,2:46.2-103.9. F: *Chiropteridium inornatum*, low focus, same as E.

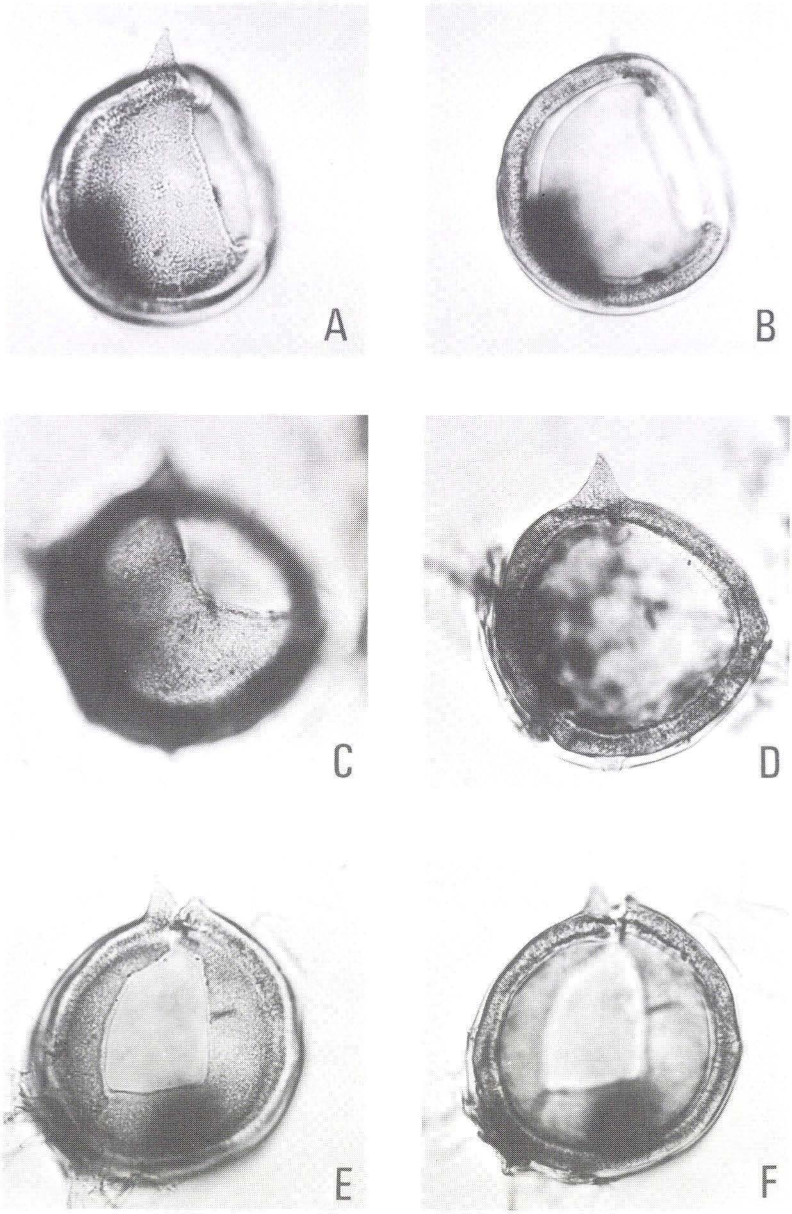

Fig. 5 All figures 500 X. A: *Carpatella cornuta*, high focus, Bjerre 2,3:22.2-101.5 B: Carpatella cornuta, low focus, same as A. C: *Carpatella cornuta,* high focus, Bjerre 2,3:51.9-107.2 D: *Carpatella cornuta,* low focus, same as C. E: *Carpatella cornuta,* high focus, Bjerre 2,2:44.5-97.2 F: *Carpatella cornuta*, low focus, same as E.

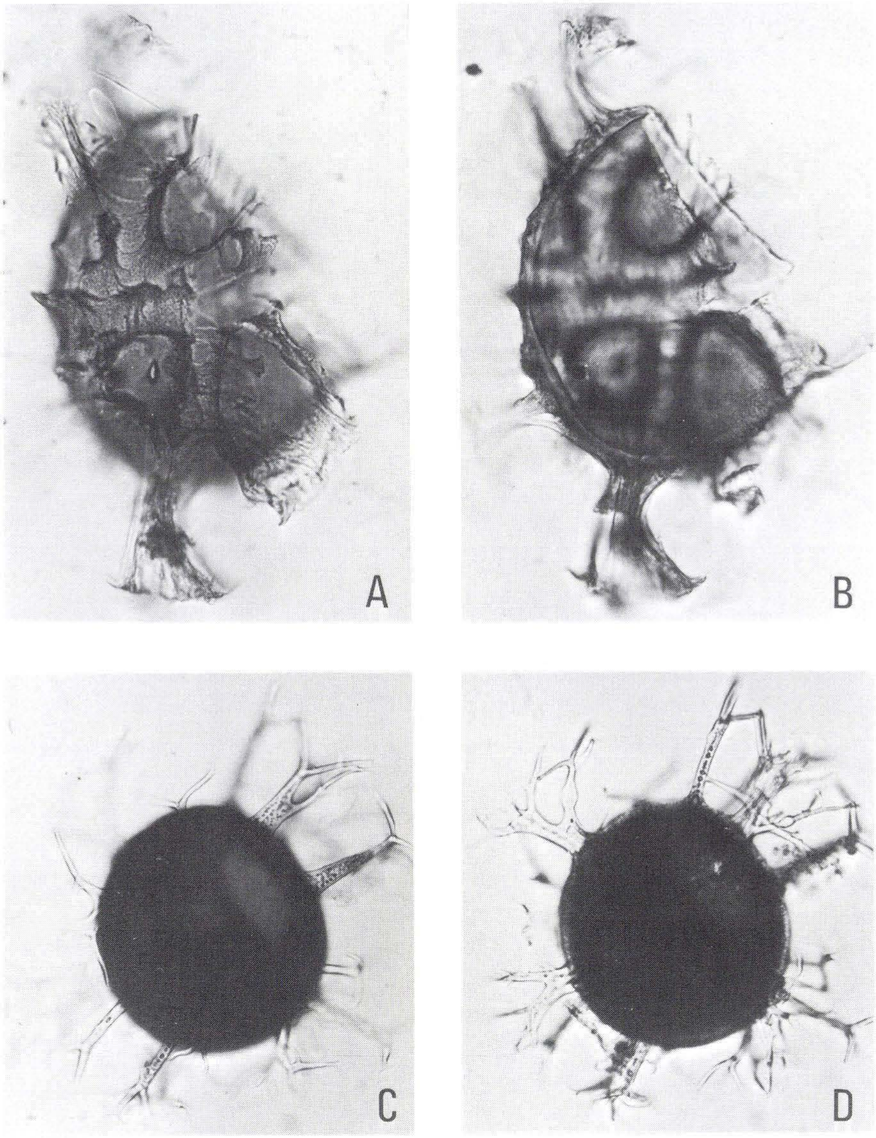

Fig. 6 All figures 500 X. A: *Danea mutabilis*, high focus, Copenhagen TUBA 13, MGUH 13966. B: *Danea mutabilis*, low focus, same as A. C: *Hafniasphaera hyalospinosa*, high focus, Copenhagen TUBA 13, A1:13093. D: *Hafniasphaera hyalospinosa*, low focus, same as C.

Danea mutabilis Morgenroth 1968 (pl. 44, fig. 1-3, *non* pl. 43, figs. 5-9). *Danea mutabilis* (Morgenroth 1968, pl. 43, figs. 5-9) on the other hand compares well with *Palmnickia californica* Drugg 1967, which thus seems to be a *senior synonym* of *Danea mutabilis*. Drugg (pers. comm. 1974) agrees with this point of view. *Chiropteridium inornatum* Drugg 1970 compares well with parts of the type material of *Rhenidinium membraniferum* Morgenroth 1968 (pl. 47, fig. 2, *non* pl. 47, fig. 1). However, to prevent stratigraphical confusion, and revision of the stratigraphical names, the well-known names are maintained provisionally.

Dinoflagellate list

The 40 most abundant dinoflagellates from the Maastrichtian/Danian boundary sections at Bjerre, Kjølby Gård, Nye Kløv and Eerslev are listed below. The letters 'M' and 'D' indicate that the species has been found in Maastrichtian and Danian sediments, respectively.

Achomosphaera ramulifera, M+D.
Achomosphaera sagena, M.
Amphidiadema rectangularis, M.
Cannosphaeropsis utinensis, D.
Carpatella cornuta, D.
Areoligera spp., M+D.
Catillopsis sp., D.
Cordosphaeridium inodes, M+D.
Chiropteridium inornatum, M+D.
Cyclonephelium spp., M+D.
Danea mutabilis, D.
Deflandrea diebeli, M.
Deflandrea galeata, M.
Eisenackia circumtabulata, D.
Fibradinium annetorpense, D.
Gonyaulacysta wetzeli, M+D.
Hafniasphaera septata, D.
Hafniasphaera sp., M.
Hexagonifera chlamydata, M.
Hystrichokolpoma bulbosa, M+D.
Hystrichokolpoma fimbriata, D.
Hystrichosphaeridium recurvatum, M+D.
Hystrichosphaeridium tubiferum, M+D.
Lanternosphaeridium axiale, M+D.
Lanternosphaeridium ovale, M+D.
Membranilarnacia tenella, D.
Palaeocystodinium sp., M.
Palaeoperidinium pyrophorum, M+D.
Palynodinium grallator, M.
Pyxidiella sp., D.
Rhenidinium membraniferum, D.
Spiniferites ramosus cavispinosus, M.
Spiniferites ramosus granosus, M+D.
Spiniferites ramosus ramosus, M+D.
Spiniferites cf. cornutus, M+D.
Spongodinium delitiense, D.
Tanyosphaeridium magdalium, M+D.
Thalassiphora pelagica, M+D.
Trithyrodinium sp., M.
Xenicodinium rugulatum, D.

Acknowledgements. The present study was partly supported by grants from the Danish Natural Science Research Foundation. Photographs were prepared by *Irma Torres* and drawings by *Bjarne Jespersen* and *Danuta Kestenbaum*. Sections were measured in co-operation with *Eckart Håkansson*.

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Report on the Jurassic of the Hobro No. 1 and Voldum No. 1 borings, Denmark

Olaf Michelsen

A contribution to PROJECT TORNQUIST (IGCP Accession Number 86)

Michelsen, O. : Report on the Jurassic of the Hobro No. 1 and Voldum No. 1 borings, Denmark. *Danm. geol. Unders., Årbog 1978*, pp. 141-149, pl. 4-6.

The lithostratigraphy and biostratigraphy in the Jurassic series of the Hobro No. 1 and Voldum No. 1 borings are described briefly. The lithology and the facies indicated by the petrophysical measurements for certain parts of the series, a part of the Lower Jurassic, the Middle Jurassic, and the uppermost part of the Upper Jurassic, show a transitional position of the series in the Danish Subbasin.

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The present report is published to inform about the borings in the Jurassic sequence most recently released for publication. The borings are situated in the Danish Subbasin (fig. 1).

The interpretations included in the report mainly derive from internal reports. The palynology has been studied by *Finn Bertelsen*, the Upper Jurassic ostracod faunas by *Ole Bruun Christensen,* and the Lower Jurassic ostracod faunas as well as the lithostratigraphy have been studied and worked out by the present author.

The *Voldum No. 1* boring was drilled in the period 4th March to 15th April 1974 south of Randers at the location 56^0 23’ 02” N and 10^0 16’ 01” E. The elevation of ground level is 30 m above MSL and of kelly bushing 35 m above MSL. The following series were drilled (depth measured from ground level):

0–21 m:	Danian limestone
21–1242 m:	Upper Cretaceous limestone
1242–1752 m:	Lower Cretaceous and Jurassic claystone and sandstone
1752–2307 m:	Triassic claystone, sandstone, limestone, and evaporites

The *Hobro No. 1* boring was drilled in the period 1st June to 10th July 1974 west of Hobro at the location 56^0 36’ 30” N and 09^0 38’ 04” E. The elevation of ground level is 27 m above MSL and of kelly bushing 32 m above MSL. The following series were drilled (depth measured below ground level):

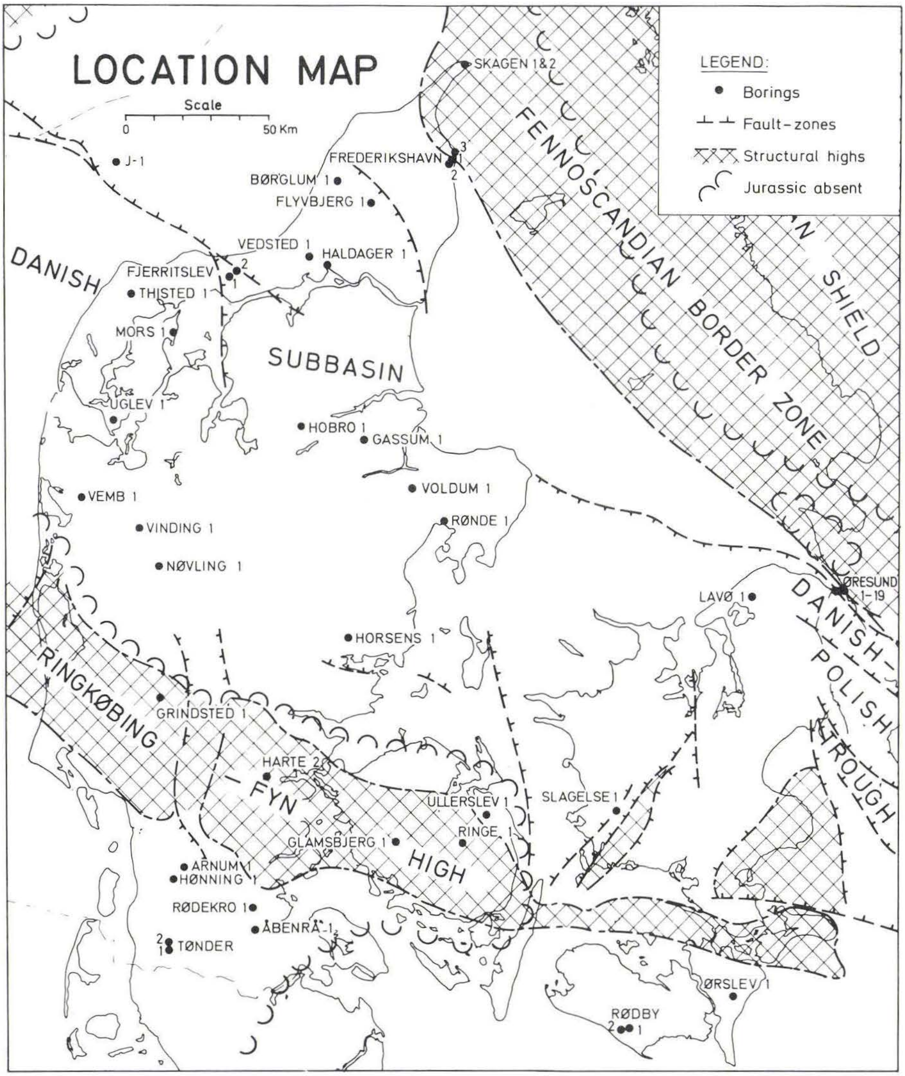

Fig. 1. Location map.

0–20 m: Quaternary
20–154 m: Tertiary, including Danian limestone
154–1610 m: Upper Cretaceous limestone
1610–2371 m: Lower Cretaceous and Jurassic claystone and sandstone
2371–2592 m: Triassic claystone, sandstone, and limestone.

Lithostratigraphy

The lithostratigraphy has been worked out and given in the table below in accordance with the definitions in Michelsen (1978). All depth figures are measured in metres below MSL.

	Hobro No. 1	Voldum No. 1
Bream Formation	1741–1823	1278–1358
Frederikshavn Member	1741–1806	1278–1344
Børglum Member	1806–1823	1344–1358
Haldager Formation	1823–1891	1358–1388
Flyvbjerg Member	1823–1852	absent
Haldager Sand	1852–1891	1358–1388
Fjerritslev Formation	1891–2343	1388–1722
Member F-IV	1891–1923	absent
Member F-III	1923–2077	1388–1497
Member F-II	2077–2108	1497–1527
Member F-I	2108–2343	1527–1722

Fjerritslev Formation

The formation characters are as known from the main part of the basin, and the formation can easily be correlated to the series known from the Rønde No. 1 (pl. 4) and the Gassum No. 1 borings (Michelsen 1978, fig. 14).

The character of the Member F-I is as known from all borings south of Vendsyssel. It is divided into the two subunits, F-Ia and F-Ib, which represent the Jurassic transgression and the deepening of the basin respectively.

In relation to the reference section, Dansk Nordsø J-1, and to the general features, the Member F-II is rather thin and untypical. It cannot be subdivided into the three subunits as known elsewhere in the basin. In both borings the gamma ray curve is insignificant with relatively low values as in the Gassum No. 1 boring. The acoustic measurements in the Hobro No. 1 boring distinctly separate the member as it can be done in the sections to the west and northwest. In the Voldum No. 1 boring the acoustic measurements are only slightly differentiated as in the Rønde section to the southeast.

The Members F-III and F-IV in the Hobro boring and the Member F-III in the Voldum boring have been developed as typical for the central part of the basin, and the series can easily be correlated to other borings.

Haldager Formation

Apart from the Horsens No. 1 boring, these sections are the most southeasterly ones comprising the formation (cf. Michelsen 1978, fig. 15).

In the Hobro No. 1 boring both the Haldager Sand and the Flyvbjerg Member are present but the latter member in a more clayey facies than usual. It does not comprise limestone beds in the top of the series but instead a solid sand bed.

In the Voldum No. 1 boring the Flyvbjerg Member is absent, and the Haldager Sand is more silty than in the type section.

Bream Formation

In both borings the formation appears in a rather typical way. The Børglum Member is thinner than normally but of comparable thickness with the series in the Gassum No. 1 boring.

In general, the Frederikshavn Member has the typical characteristics. In the Hobro No. 1 boring it can be dicided into the three cycles A, B, and C (see pl. 4). The lower part of the cycle C does not comprise a claystone series as known from the Haldager No. 1 and Børglum No. 1 borings (cf. Michelsen 1978, fig. 16). In the Voldum No. 1 boring the member is a massive sandstone series with a few thin claystone layers as it can be seen in the Rønde No. 1 boring. The Hobro boring may be regarded as transitional between the area to the north and the area to the south comprising the Voldum No. 1, Rønde No. 1, and Horsens No. 1 borings.

Conclusions

The two Jurassic series are of transitional character between the facies known from the central and northern part of the Danish Subbasin and the facies known from the southern and southeastern part. The lithostratigraphical units in question are the Member F-II, the Haldager Formation, and the Frederikshavn Member, which are the units representing shallow water condition (?) and two regressive periods respectively.

Generally the Hobro section shows affinities to the central and northern parts of the basin, but the Member F-II and the Frederikshavn Member of the section resemble Gassum section too.

The Voldum section shows affinities to the southern part of the basin comprising the Rønde No. 1 and Horsens No. 1 borings.

Biostratigraphy

The biostratigraphical subdivision of the two sections is given in pl. 4 in chronostratigraphical terms and with signatures indicating when ostracods, foraminifera, or palynology have been used. The biostratigraphy based on ostracods is as described in Christensen & Kilenyi (1970), Christensen (1974a), and Michelsen (1975b). The palynological investigations are described by Bertelsen (1974, and in the appendix). The chronostratigraphical conclusions are based on lithostratigraphy and biostratigraphy as defined by Michelsen (1978).

The stratigraphical subdivision of the two sections is in accordance with the subdivision known from sections in the central part of the basin (cf. Michelsen 1978). Therefore, the biostratigraphical data will be presented only briefly.

The *Lower Jurassic* ostracod faunas found in the two sections are rather equal. A distribution chart from the Hobro No. 1 boring is given in pl. 5 to demonstrate the fauna composition and the basis for the stratigraphical determination. The review of the faunal seccession is given below referring to Michelsen (1974).

Hettangian and Lower Sinemurian comprises the *C. betzi – C. crassireticulata* and *O. aspinata* Zones. The *O. aspinata* Zone is the lower one of the two zones; it is characterized by *Ogmoconchella aspinata* (Drexler 1958), *Ogmoconcha hagenowi* Drexler 1958, *Klinglerella (Klinglerella) medioreticulata* (Michelsen 1970), *Pseudomacrocypris subtriangularis* Michelsen 1975, *Nanacythere (Goniocythere) elegans* (Drexler 1958), *N. (G.) paracostata* Michelsen 1975, and *N. (G.) circumcostata* Michelsen 1975. The two first-named species are the most dominating species, and *K. (K.) medioreticulata* a common and characteristical species. The group *Nanacythere (Goniocythere)* is common and characteristic in the upper part of the zone which can be referred to Lower Sinemurian. The *C. betzi – C. crassireticulata* Zone is poor in species and in specimens. It is determined on the uppermost occurrence of *Cristacythere betzi* (Klingler & Neuweiler 1959) and *O. hagenowi.*

Upper Sinemurian comprises the lower part of the *O. danica* Zone. The fauna is dominated and characterized by *Ogmoconchella danica* Michelsen 1975. The fauna is furthermore characterized by a successive occurrence of *Progonoidea reticulata* (Klingler & Neuweiler 1959), *Klinglerella (Klinglerella) laqueata* (Klingler & Neuweiler 1959), *K.(K.) multicostata* (Klingler & Neuweiler 1959), *K. (K.) vulgaris* (Klingler & Neuweiler 1959), *K. (K.) triebeli* (Klingler & Neuweiler 1959), and *K. (K.) variabilis* (Klingler & Neuweiler 1959).

The lower part comprises the *P. reticulata* Subzone.

Lower Pliensbachian comprises the upper part of the *O. danica* Zone (the *G. apostolescui – K. (K.) foveolata* Subzone). The fauna is characterized by *Klinglerella (Klinglerella) foveolata* Michelsen 1975, *Pleurifera harpa* (Klingler & Neuweiler 1959), *Ogmoconcha amalthei form A* Michelsen 1975, *Ogmoconchella danica* Michelsen 1975, and *Ogmoconchella transversa* (Gründel 1970). The fauna is rich in species and in specimens, a typical feature in the Danish Subbasin. The three first-named species are not known outside this subzone; *O. danica* is usually rare above the subzone (however, in Rønde No. 1 it has range corresponding to its range in the present boring). *O. transversa* is a species typical for the subzone and for the lower part of the superjacent *O. adenticulata – N. (N.) simplex* Zone.

Upper Pliensbachian comprises the *O. adenticulata – N. (N.) simplex* Zone. The fauna is rich in species and specimens and is characterized by *Ogmoconchella adenticulata* (Pietrzenuk 1961), *Ogmoconchella aequalis* (Herrig 1969), *Ogmoconchella pseudospina* (Herrig 1969), and *Nanacythere (Nanacythere) simplex* Herrig 1969.

The zone can be subdivided into two subzones. The lower subzone is characterized by *Ogmoconchella transversa* (Gründel 1970) and *Acrocythere tricostata* Michelsen 1975, and the upper subzone by *Nanacythere (Domeria) firma* Herrig 1969 and *Nanacythere (Domeria) fissicosta* Herrig 1969.

The boundary Lower-Upper Sinemurian is found lowermost in the Member F-Ib. The Lower-Upper Pliensbachian boundary is found at the transition between the Members F-I and F-II, which is deeper in the series than usual. It may be due to a reduction of the Member F-II which elsewhere in the basin is thicker and comprises three subunits. The top of the Upper Pliensbachian is found in the upper part of the Member F-III, which indicates that the upper part of this member has been reduced or condensed (cf. Michelsen 1975b and 1978).

The Middle Jurassic age is only indicated in one sample within the Haldager Sand in each of the borings (for further information see the appendix).

The boundary Jurassic-Cretaceous has not been defined biostratigraphically but is based on correlation and determined to the transition cycles B-C (see Michelsen 1978, p. 23). Only a few ostracod specimens are found in the upper part of the Frederikshavn Member indicating a probable Upper Jurassic age. Lowermost in the member and in the Børglum Member is found a fauna belonging to the *G. dissimilis* and *G. elongata* Zones referring the series to Lower Kimmeridgian. The fauna comprises species as *Galliaecytheridea postrotunda, G. elongata, G. dissimilis, G. wolburgi, Macrodentina (Polydentina) gallica,* and *Monoceratina* cf. *vulsa* (Christensen 1974 b).

Appendix

The appendix is an extract of the unpublished report:

Bertelsen, F. 1974: Palynological investigations of the Triassic-Jurassic section of the Hobro No. 1 borehole. – Danm. geol. Unders.

This is done with the permission of the author due to the rather insufficient knowledge of the distribution of the various taxa within the Danish Subbasin. It has not been feasible to divide the studied section strictly into stages. Instead certain assemblage units are recognized (see also pl. 6).

The assemblage units

Unit A

The assemblages dominated by pollen of the Circumpollis group: *Granuloperculatipollis rudis* Venkatachala & Góczan 1964, *Corollina meyeriana* (Klaus) Venkatachala & Góczan 1964, and *Classopollis torosus* (Reissinger) Balme 1957. *Ovalipollis ovalis* Krutzsch 1955, *Ricciisporites tuberculatus* Lundblad 1954 a.o. seem to occur due to caving. Probably all of the miospores present in the lowermost sample are contaminants.

Unit B

The characterising element of this unit is *Ricciisporites tuberculatus* Lundblad 1954, which is extremely abundant in sample 2449 m (70.5%). Important accessory species are *Rhaetipollis germanicus* Schulz 1967, *Limbosporites lundbladii* Nilsson 1958, and *Ovalipollis ovalis*. Also bisaccate pollen grains *(Alisporites, Pityosporites)* are common.

An assemblage of the above type was found in sidewall core 1857 m in the Voldum 1 borehole (Bertelsen int. report April 1974).

Unit C_1

Deltoidispora spp. ocur with high percentages. *Perinopollenites elatoides* Couper 1958, *Classopollis torosus, Chasmatosporites* spp. and bisaccate pollen are common. *R. tuberculatus* is sporadically present whereas other 'Rhaetic types' have disappeared. A number of long ranging taxa are introduced among which is *Cerebropollenites thiergartii* Schulz 1967.

Microplankton in the form of Tasmanitids and Acritarchs are present indicating marine influence. Important is the presence of *Leiofusa jurassica* Cookson & Eisenack 1958.

The megaspore species *Nathorstisporites hopliticus* 1958 found in the ditch sample 2376-2382 m is probably also to be included in assemblage unit C_1.

Unit C_2

The assemblages consist of a majority of bisaccate pollen grains (gymnosperms) and other airborn pollen types as *Perinopollenites elatoides* whereas microspores are infrequent compared with the C_1 assemblages. Younger Liassic elements are not present but the occurrence of *Cerebropollenites mesozoicus* may indicate an age younger than Lower Sinemurian.

The occurrence of Tasmanitids, *Michrystidium* spp., Dinoflagellate cysts, especially in sample 2210 m, the high frequency of gymnosperms, and the generally poor state of preservation indicate increased marine influence compared with the C_1 unit.

Unit C_3

The bisaccate gymnospermpollen are dominant as in the C_2 unit but *Quadraeculina anellaeformis* Maljavkina sensu Schulz 1967 are probably not present. Osmundacean pollen (*Osmundacidites, Baculatisporites, Todisp.*) show increasing numbers. Occurrence of *Ceratosporites spinosus* Schulz 1967 and *Neoraistrickia truncata* (Cookson 1953) Schulz 1967.

The microplankton shows increasing diversity. Among the new forms are *Nannoceratopsis gracilis* (Alberti 1961) Evitt 1962 and several acritarchs.

Two megaspore species occur in ditch sample 2028-2034 m: *Horstisporites planatus* Marcinkiewicz 1971 and *Hughesisporites pustulatus* Marcinkiewicz 1962.

Unit C_4

There is a distinctive decrease in the percentage of bisaccate pollen in comparison with the units C_1 - C_3 indicating an important change of the environments to more shallow conditions. In the lower sample *Deltoidispora* spp., *Chasmatosporites* spp. and *Cerebropollenites mesozoicus* show high frequencies whereas *Sphaeripollenites* spp. are extremely abundant in the upper sample. Stratigraphically important is the regular presence of *Isochyosporites variegatus* (Couper 1958) Schulz 1967 and of *Converrucosisporites rariverrucatus* (Danze-Corsin & Laveine 1963) = *Trilites minutus* Mai in Schulz (1967).

The microplankton is made up by Tasmanitids and *Nannoceratopsis gracilis,* the latter being common in the lower sample.

Unit D

The assemblage is composed of numerous *Perinopollenites elatoides,* a moderate number of bisaccate pollen grains, and in comparison with the C_4 unit a number of new important species. These are *Foveosporites multifoveolatus* Döring 1965, *Matonisporites crassiangulatus* (Balme 1957) Levet-Carette 1964, *Neoraistrickia gristhorpensis* (Couper 1958) Tralau 1968, *Staplinispora* cf. *caminus* (Balme 1957) Pocock 1962, *Leptolepidites major* Couper 1958, *Callialasporites trilobatus* (Balme 1957) Dev 1961, *C. turbatus* (Balme 1957) Schulz 1967, a.o.

No microplankton is present.

In the Danish Subbasin similar assemblages have been found by the author in part of the Haldager Formation in the Haldager No. 1 borehole. They indicate shallow, probably deltaic conditions and seem to derive from the lignite-bearing sandy member at ca. 1920 m below KB.

Unit E

Cicatricosisporites spp. are present but not common, thus indicating that the assamblages are not older than the uppermost Upper Jurassic. Microplankton is represented by a rather variated assemblage especially in the uppermost sample.

Conclusions

The biostratigraphical results of the investigation can be summarized as below:

Unit E	1810–1840 m	Upper Jurassic/Lower Cretaceous
Unit D	1896–1902 m	Middle Jurassic
Unit C_4	1951–1970 m	Lower Jurassic, Toarcian
Unit C_3	2005–2060 m	Lower Jurassic, Pliensbachian
Unit C_2	2150–2270 m	Lower Jurassic
Unit C_1	2325–2352.5 m	Lower Jurassic, Hettangian/L. Sinemurian
Unit B	2445.5–2460 m	Upper Triassic, Middle Rhaetian
Unit A	2556–?2610 m	Upper Triassic, Upper Norian/Lower Rhaetian

Dansk sammendrag

Nærværende rapport giver en kortfattet oversigt over den litho- og biostratigrafiske inddeling af jura lagserien i de to boringer Hobro nr. 1 og Voldum nr. 1. Boringerne blev udført i henholdsvis juni-juli og marts-april 1974 og er dermed fem år gamle og nu frigivne for publikation.

Der gives en kort beskrivelse af de lithostratigrafiske karakterer i de to serier i relation til definition og beskrivelse givet i Michelsen (1978). Den lithostratigrafiske inddeling findes i tabellen p. 143, og den er sammen med lithologisk karakteristik og biostratigrafisk inddeling gengivet i pl. 4.

Lagserien i de to boringer er i store træk udviklet typisk i forhold til den centrale del af Det danske Subbassin. Member F-II (Fjerritslev Formationen), der formodes at være marin lavtvandsdannelse, og Haldager Formationen og Frederikshavn Member, der repræsenterer regressive faser, afviger på karakteristisk måde fra deres udformning centralt og nordligt i bassinet og danner dermed overgangstyper til karaktererne i den sydlige og sydøstlige del.

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Geotermiske reservoirformationer i den danske lagserie

Olaf Michelsen og Finn Bertelsen

Michelsen, O. og Bertelsen, F.: Geotermiske reservoirformationer i den danske lagserie. *Danm. geol. Unders., Årbog 1978*, pp. 151-163. København, 1979.

The report deals with the Triassic, Jurassic, and Lower Cretaceous sequences which comprise the most important reservoirs for the geothermal exploitation started in 1978. The Lower Buntsandstein, the Gassum Formation (Upper Triassic - Lower Jurassic), the Haldager Formation (Middle Jurassic), and the Frederikshavn Member (Upper Jurassic - Lower Cretaceous) are regarded as potential reservoir formations.

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Inden for de senere år er alternative energiformer kommet til at spille en stadig større rolle i debatten om energiforsyningen. I den forbindelse nedsatte Handelsministeriet i november 1976 en arbejdsgruppe med den opgave at vurdere mulighederne for forekomst af varmt vand i Danmarks undergrund med henblik på en udnyttelse af geotermisk energi. På baggrund af den af udvalget udarbejdede rapport, »Udnyttelse af geotermisk energi i Danmark«, København 1977, fik Dansk Olie og Naturgas A/S i 1978 eneretsbevilling til at udføre efterforskning og indvinding i Danmark. I den forbindelse har det været en af Danmarks Geologiske Undersøgelses (DGU's) opgaver at foretage studier af undergrundsformationerne. DGU deltager såvel i efterforskningsarbejde i Aars (Nordjylland) som i de »Landsdækkende Geotermiske Undersøgelser«, der financieres af Dansk Olie & Naturgas A/S.

Som et resultat af disse opgaver samt af DGU's generelle bearbejdning af data fra undergrunden, er der udarbejdet en lang række interne rapporter og enkelte publikationer. Nærværende artikel er en sammenfattende beskrivelse af lagserien mellem stensaltaflejringerne fra øvre perm og kalkstenserien fra øvre kridt, idet denne del af lagserien indeholder i reservoirformationer, der antagelig vil spille en hovedrolle i de kommende års efterforskningsarbejde. Det er hensigten, som et afsluttende led i projektet »Landsdækkende Geotermiske Undersøgelser« at publicere en indgående beskrivelse af reservoirformationerne og deres karakteristika.

Definition og beskrivelse af en del af de omtalte formationer er publiceret af Bertelsen (1978) og Michelsen (1978).

Bassinudvikling

Gennem perioderne perm, trias og jura var det danske område opdelt i to aflejringsbassiner, Det danske Delbassin mod nord og den nordlige del af Det nordtyske Bassin mod syd. Indsynkningen i bassinernes midte har været betydelig, idet seismiske målinger kan afsløre sedimentmægtigheder fra de nævnte perioder på mere end 5-6000 m (fig. 1). Den øst-vestlige tærskel mellem bassinerne, der kaldes Ringkøbing - Fyn Højderyggen, har en kerne af højtliggende grundfjeld, der flere steder er adskilt af nord-sydlige gravsænkninger.

Under perm tiden og den ældste del af trias er det sandsynligt, at dele af Ringkøbing - Fyn Højderyggens grundfjeldskerne har ligget blottet som »øer« og de to bassiner har da været forbundne via de ovenfor nævnte gravsænkninger. Men i

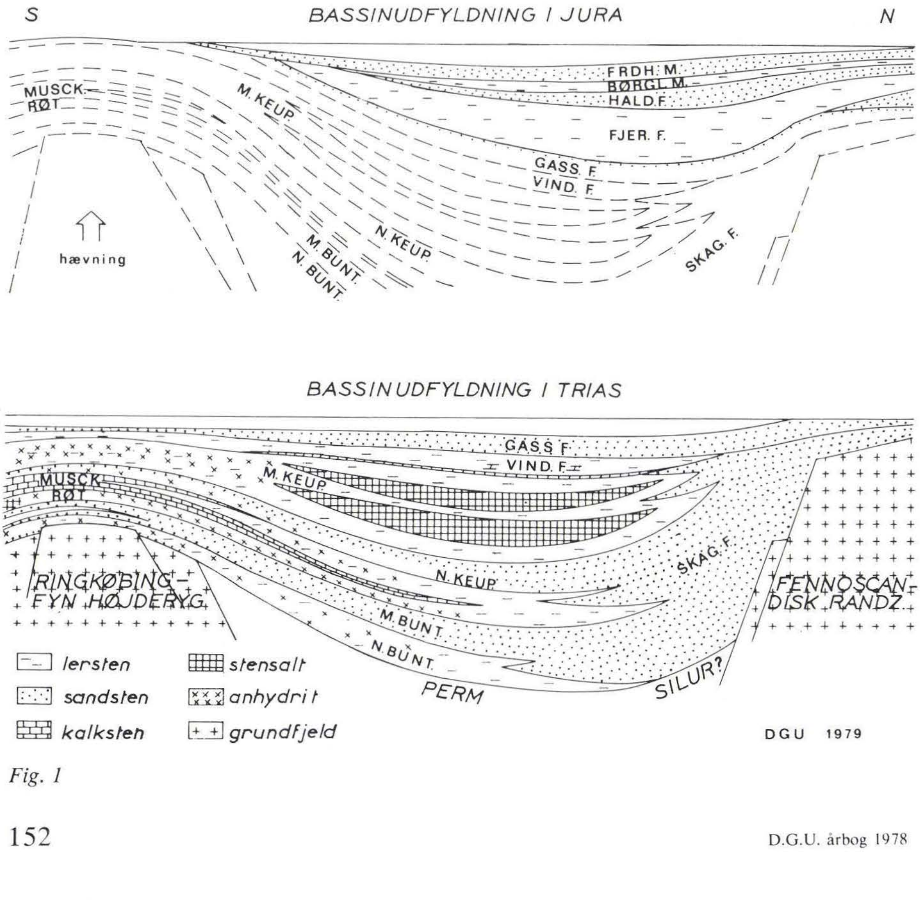

Fig. 1

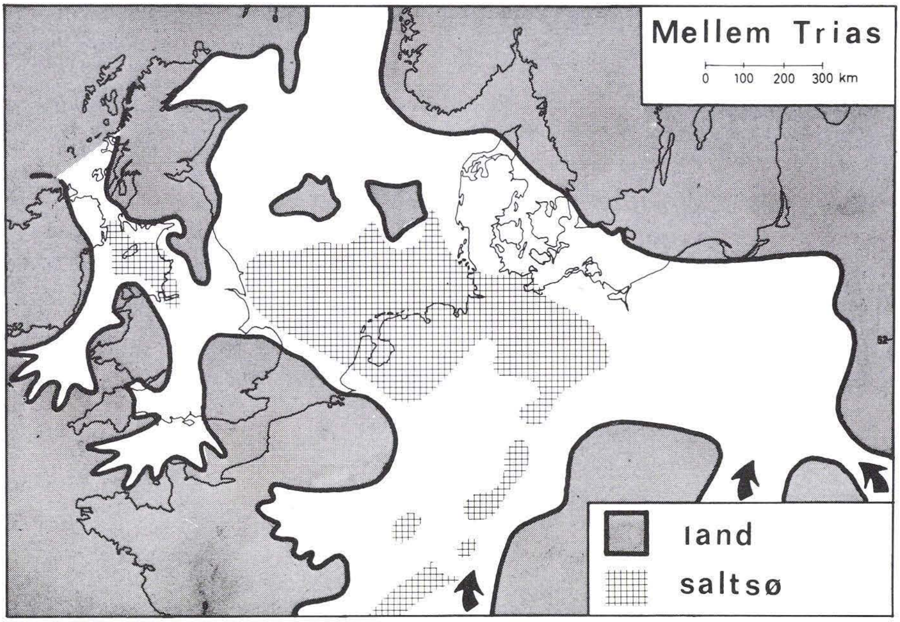

Fig. 2. Det nordvesteuropæiske sedimentationsbassin i mellemste trias-tid. De sorte pile viser de stræder havet benyttede ved sin indtrængen fra det sydligt beliggende Tethys hav.

løbet af mellem trias synker også Højderyggen og der opstår ét sammenhængende aflejringsområde (fig. 2). Indsynkningen af Højderyggen har dog været beskeden sammenlignet med indsynkningen af de egentlige bassiner, idet sedimenterne tynder stærkt ud over denne. Denne udvikling varer ved til udgangen af nedre jura, hvor der sker en større regional hævning af det danske område. I den efterfølgende fase, mellem – øvre jura, hæves Højderyggen og der finder en intensiv erosion sted over dens centrale dele. Således findes i Glamsbjerg 1 boringen lag fra mellem trias direkte under lag fra nedre kridt. I bassinerne fortsætter indsynkningen. Ved udgangen af øvre jura finder endnu en regional hævning sted og efter denne fortsætter indsynkningen indbefattende Ringkøbing – Fyn Højderyggen, der således også dækkes af aflejringer fra yngste del af nedre kridt, øvre kridt og tertiær.

Det danske Delbassin har antagelig i øvre perm og nedre-mellem trias været afgrænset mod nord og øst af forkastninger i Den fennoskandiske Randzone. I løbet af øvre trias og jura udvides aflejringsområdet som følge af bassinets opfyldning til større dele af Skagerrak, Kattegat og Sydsverige – hvor langt vides dog ikke, idet senere erosion, blandt andet i forbindelse med de kvartære nedisninger, har slettet sporene.

STRATIGRAFISK STANDARDINDDELING AF DET DANSKE SUBBASSIN (Ø.PERM - Ø.KRIDT)

DGU 1979 — *Finn Bertelsen*

SYSTEM	SERIE	ETAGE	FORMATION	MEMBER
KRIDT			Ø.Kridt Kalksten	
KRIDT	Nedre	Albien	Rødby Formation	
KRIDT	Nedre	Autien Barremien Hauterivien Valanginien	Vedsted Formation	
KRIDT	Nedre	Berriasien	Vedsted Formation	
JURA	Øvre	Portlandien	Bream Formation	Frederikshavn Member
JURA	Øvre	Kimmeridgien	Bream Formation	Børglum Member
JURA	Øvre	Oxfordien	Haldager Formation	Flyvbjerg Member
JURA	Mellem	Callovien Bathonien Bajocien	Haldager Formation	Haldager Sand
JURA	Nedre	Aalenien	Fjerritslev Formation	Member F-IV
JURA	Nedre	Toarcien	Fjerritslev Formation	Member F-III
JURA	Nedre	Ø. Pliensbachien	Fjerritslev Formation	Member F-II
JURA	Nedre	N. Pliensbachien	Fjerritslev Formation	Member F-II
JURA	Nedre	Ø. Sinemurien	Fjerritslev Formation	Member F-I
JURA	Nedre	N.Sin.-Hettangien	Fjerritslev Formation	Member F-I
TRIAS	Øvre	Rhaetien	Gassum Formation	Member G_0-G_4
TRIAS	Øvre	Norien	Skagerrak Formation / Vinding Form.	
TRIAS	Øvre	Carnien	Skagerrak Formation / Oddesund Formation	Member O_3 O_2: Evaporit / Evaporit Member O_1
TRIAS	Mellem	Ladinien	Skagerrak Formation / Tønder Form.	
TRIAS	Mellem	Anisien	Skagerrak Formation / Muschelkalk	
TRIAS	Nedre	Olenikien	Skagerrak Formation / Röt	
TRIAS	Nedre	Jakutien	Skagerrak Formation / Bunter Sandsten	
TRIAS	Nedre	Brahmanien	Bunter Lersten	
PERM	Øvre		Stensalt	

Fig. 3

Hovedparten af de sedimenter, der i trias-jura tid er aflejret i den danske del af Det nordtyske Bassin og Det danske Delbassin, består af ler, silt og sand, der ensidigt er tilført bassinerne fra nord og øst af skiftende floder og vandløb. Dette indebærer at de mest grovkornede aflejringer generelt skal søges i et bælte langs Det danske Delbassins nord- og østrand. I begge bassiner er trias sedimenterne aflejret oven på stensalt fra perm perioden. I slutningen af trias og i jura perioden har stensalt-lagene undergået forandringer, idet de grundet det øgede tryk fra pålejringen er overgået i en plastisk tilstand og langs svaghedszoner har presset trias-jura lagene op (saltpuder) eller er trængt op gennem disse som saltdiapirer. Den lokale variation i tykkelse og udbredelse af de enkelte trias eller jura lag, der derved er opstået, er ikke indtegnet på kortene i denne artikel.

Trias-jura formationerne

I de følgende afsnit vil trias-jura formationerne blive kort beskrevet med hovedvægt på de aflejringer, der vil kunne være af interesse i forbindelse med udnyttelse af geotermisk energi (fig. 3). Trias formationerne vil i løbet af 1979 blive omdøbt (Bertelsen 1979), således at den germanske navngivning, der er anvendt i det følgende, vil blive erstattet af en dansk. Fejlen ved den tyske navngivning er, at enhederne er anvendt som både tids- og formationsenheder.

Trias lagene

Den nedre triassiske *Buntsandstein* serie repræsenterer en regressiv periode gennem hvilke overvejende kontinantale aflejringsforhold var fremherskende i det nordvesteuropæiske sedimentationsområde (fig. 4).

I Buntsandstein var Danmark opdelt i en leret provins, dækkende Det nordtyske Bassin, Ringkøbing-Fyn Højderyggen og den sydøstlige del af Det danske Delbassin, og en sandet provins, dækkende den centrale og nordvestlige del af Det danske Delbassin. Mellem de to provinser er der en gradvis overgang, som er iagttaget i boringerne Rønde 1, Gassum 1 og Mors 1.

I den lerede provins består Nedre Buntsandstein overvejende af rødlig brun og brun, siltholdig lersten med grønlige partier samt spredte forekomster af anhydrit. Mellem Buntsandstein minder om Nedre Buntsandstein, men karakteriseres af forekomsten af (mod syd) 2-3 velafgrænsede lagserier af siltsten og finkornet sandsten, der mod nord går over i én sandet enhed. Tilsvarende lag findes blottede på øen Helgoland i Nordsøen. Den samlede mængde sandsten i Nedre og Mellem Buntsandstein, er mindre end 50% i den lerede provins, og syd for Ringkøbing-Fyn Højderyggen endda mindre end 10%. Øvre Buntsandstein (Röt) repræsente-

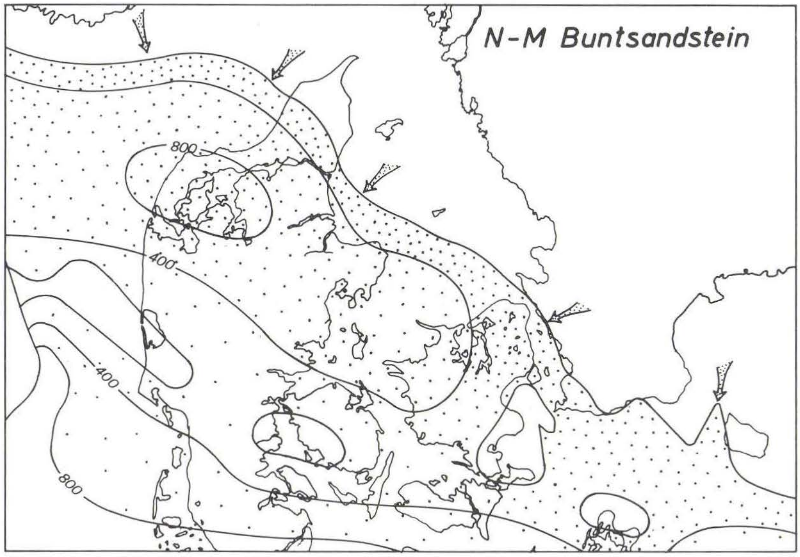

Fig. 4

res af grønlig grå og brunlig lersten vekslende med anhydrit og kalksten, samt sydligst med stensalt.

I modsætning til den lerede provins er lithologien i den sandede provins forholdsvis ensartet bestående af rødlig, leret, arkoselignende sandsten, der kun fremviser en svag influens af Röt transgressionen. Denne facies udgør den nedre del af Skagerrak Formationen, som er betegnelsen for de monotone, sandede, triassiske randaflejringer langs nord- og østranden af Det norsk-danske Bassin.

Buntsandstein serien er mod nord hovedsagelig kontinentale, fluviatile aflejringer afsat under aride til semi-aride forhold. Mod syd veksler kontinentale lag med brakvandsaflejringer. Sandfordelingen viser bl.a. at materialet ensidigt er transporteret fra nord og nordøst ind i bassinerne. De bedste reservoirbjergarter findes derfor antageligt i et bælte langs den nordlige og østlige rand af Det danske Delbassin, der flere steder er forkastningsbegrænset, som det bl.a. fremgår af svenske dybdeboringer i Skåne.

Röt seriens nedre del i den lerede provins repræsenterer lavvandede braktmarine transgressioner kommende fra sydøst. På grund af det tørre, varme klima har vandbalancen i perioder været overvejende negativ, dvs. at fordampningen har været større end vandtilførslen, hvorved de opløste salte er udfældet. Den øvre del af Röt serien er kontinentalt præget og minder i sammensætning om Nedre Buntsandstein. Den har ingen reservoirmæssig betydning.

De mellem triassiske *Muschelkalk* aflejringer består af vekslende lersten, mergelsten og kalksten med spredte forekomster af anhydrit. Sedimentfarven er overvejende grågrøn og grå, sjældnere brun og rødlig. Den nedre del af formationen er generelt rigere på kalksten og denne kalksten er ofte fossilførende. Den øvre del af formationen rummer færre kalksten, der hyppigt er dolomitiserede og anhydritførende, samt stedvis sandede indslag. Syd for grænsen, i Det nordtyske Bassin, forekommer stensalt i den mellemste del af formationen. Mod nord afløses formationen gradvist af Skagerrak Formationens sandsten (fig. 1). Muschelkalk formationens nedre lag er marine, medens den øvre del må tolkes som en lavvandet, periodevis tørlagt brakvandsdannelse. Stensaltforekomsterne i Nordtyskland viser, at der er tale om to transgressioner afbrudt af en regressiv inddampningsfase. Muschelkalk-havet trængte fra syd ind over det danske område (fig. 2). Formationen har næppe reservoirmæssig betydning, men de jævnaldrende sandsten i Skagerrak Formationen vil antagelig kunne udnyttes.

Nedre Keuper minder stærkt om Buntsandstein. Formationen består af rødlig brun, brun og grønlig, siltholdig lersten med spredte anhydritindeslutninger, samt øverst i formationen af enkelte velafgrænsede lag af siltholdig, finkornet sandsten, grågrøn og rødbrun, der ofte indeholder fint, forkullet plantemateriale. Mod nord tiltager sandindholdet og formationen går gradvist over i Skagerrak Formationen. Nedre Keuper består overvejende af kontinentale dannelser afsat under et tørt, varmt klima. Sandstensdannelserne øverst i formationen tyder på perioder med forøget nedbør. Sandstenslagene er potentielle reservoirer, medens den nedre del af formationen ikke kan tillægges nogen betydning i denne sammenhæng.

Mellem Keuper består af lersten og siltsten, rødbrun, brun og grå med enkelte anhydritindeslutninger og tynde lag af mergelsten og dolomitisk kalksten. I den centrale del af Det danske Delbassin forekommer to veludviklede serier af stensalt. Mod bassinranden afløses de to serier af anhydritrig lersten. Formationen er helt eller delvis borteroderet over dele af Ringkøbing-Fyn Højderyggen. Langs nordranden af Det danske Delbassin fortsatte sandstenssedimentationen (Skagerrak Formationen). Mellem Keuper består af vekslende kontinentale dannelser og brakvandsdannelser præget af et varmt og tørt klima. De to evaporitserier viser at fordampningen i to perioder har oversteget vandtilførslen til bassinet.

Under aflejringen af Mellem Keuper begynder pudedannelsen i perm saltet og formationen er derfor af uens tykkelse.

I Polen og Tyskland findes udbredte deltaiske sandsten (Shilfsandstein) mellem to evaporithorisonter svarende til de danske. Tilsvarende reservoirer er hidtil ikke påvist i Det danske Delbassin og formationen skønnes derfor ikke at have reservoirmæssig betydning.

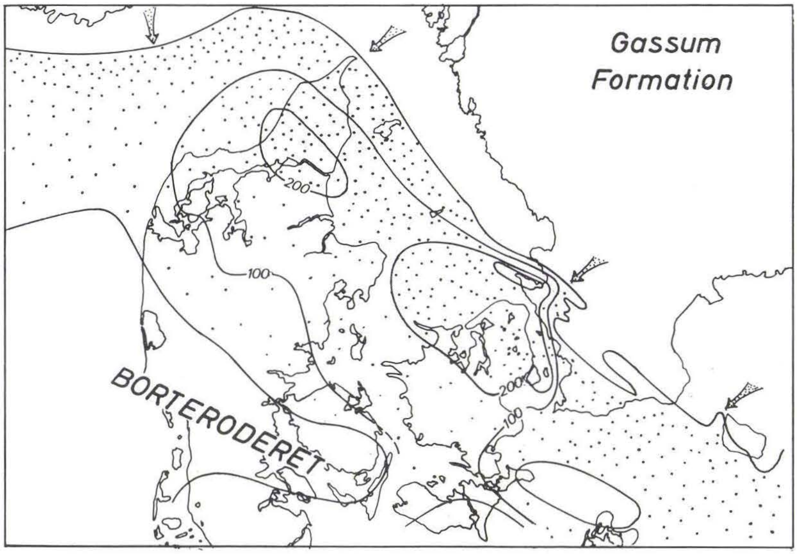

Fig. 5

Vinding Formationen består af vekslende lersten og kalksten. Lerstenen er kalkholdig med et varierende siltindhold. Mørkegrå til sort olivengrå farver dominerer. Anhydrit forekommer sporadisk i den nedre del. Kalkstenslagene findes på bestemte niveauer i serien og kan genkendes fra boring til boring. Nederst i formationen findes grå og brune, dolomitiske kalksten, medens den midterste del karakteriseres af grå og brune, oolitiske kalksten, og den øverste af tynde bånd af dolomitisk kalksten.

Serien er aflejret i brakvand med generelt ringe vanddybde. Medens kystnære forhold med periodisk udtørring synes at have hersket i den tidlige fase, må den øvre del af formationen betragtes som prodelta lersten afsat på noget dybere vand og tilhørende det nedenfor nævnte Gassum delta, som udbyggedes i forbindelse med en klimaændring fra tørre til mere nedbørsrige klimaforhold ved slutningen af triastiden.

Formationen er impermeabel og derfor uden reservoirmæssig betydning.

Gassum Formationen (fig. 5) består overvejende af fint til mellemkornede, lysegrå sandsten, der veksler med mørkere farvede lersten og siltsten. Kullag forekommer spredt. Formationen underdeles i tre enheder (members), men lokalt kan yderligere enheder forekomme. Den nederste enhed (G_1 Member) har gode reservoiregenskaber og er typisk udviklet som en serie, der nederst består af lersten, siltsten og opefter af sandsten med tiltagende grovkornethed. Den overliggende enhed (G_2 Member) domineres af organisk rige mørke lersten med underordnet forekomster af siltsten og lersten. Den øverste enhed (G_3 Member) består af grå og rødlige lersten overlejret af lyse grønliggrå sandsten og siltsten, der ofte indeholder glaukonit.

Gassum Formationen er tolket som en fluviatil – deltaisk aflejring. G_1 Member må opfattes som aflejringer fra det såkaldte Gassum delta, der i slutningen af trias voksede ud i bassinet. Det drejer sig om delta-front dannelser med tiltagende kornstørrelse op gennem serien i de centrale og sydlige dele af bassinet. Mod top af enheden er sandet aflejret i fletværkskanaler efterfulgt af »kulsvamp« dannelser i afsnørrede bugter og kanaler. G_2 Member ses som brakt-marine aflejringer, der stammer fra en stigning af havniveauet, hvorved deltafladen druknede. Det store indhold af organisk materiale skyldes antageligt et lavt iltindhold ved havbunden. G_3 Member repræsenterer en regressiv fase (faldende havniveau) hvor limniske betingelser kom til at herske i store dele af bassinet. Den øvre glaukonitførende silt- og sandsten i dette member er dog dannet ved den begyndende nedre jurassiske transgression, der førte til dannelsen af Fjerritslev Formationen (se nedenfor). Gassum Formationen er vurderet til at have gode reservoirkarakterer.

Overgangen trias-jura

På overgangen mellem trias og jura starter en fornyet indsynkning af Det danske Delbassin og aflejring af de nedenfor beskrevne marine lersten tager sin begyndelse i den centrale del af bassinet. Aflejring af de fluviatile-deltaiske sedimenter kaldet Gassum Formationen fortsætter mod nordøst i begyndelsen af jura. I Vendsyssel er store dele af Gassum Formationen således af nedre jurassisk alder.

Jura lagserien

Den nedre jurassiske *Fjerritslev Formation* består af ensartede, mørke lersten med et lille og varierende indhold af silt.

Lagserien er en marin shelfaflejring afsat under indsynkning af bassinet. Den nederste del er en lavtvandsserie med tynde kalk- og siltlag aflejret samtidig med dannelsen af den deltaiske Gassum Formation i Vendsyssel. Hovedparten af Fjerritslev Formationen er afsat på dybere vand, medens øverste del atter er en lavtvandssedimentation, der antagelig har fundet sted under lagunale betingelser. Formationen har ikke reservoirmæssig karakter.

Fjerritslev Formationen repræsenterer et begivenhedsforløb som var gældende for hele Nordsø området. Tilsvarende finkornede sedimenter genfindes i en række større eller mindre bassiner. At vi i dag finder disse lagserier i adskilte områder

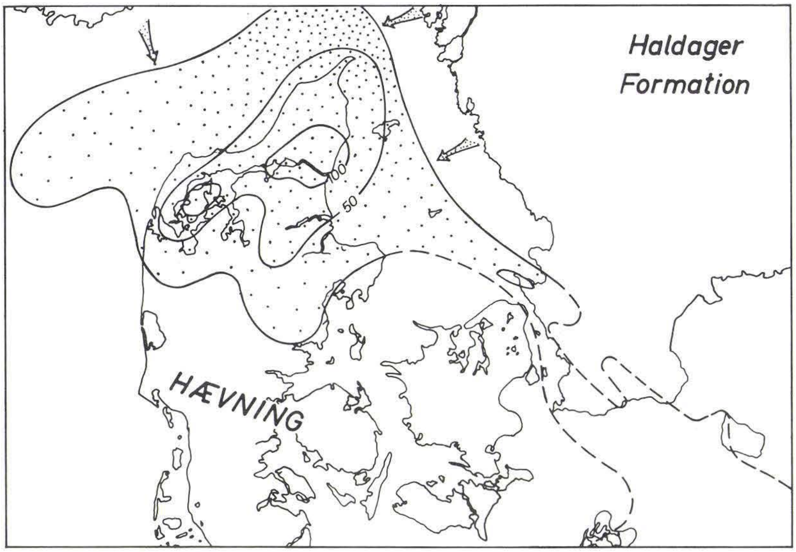

Fig. 6

skyldes dels tilstedeværelsen af delbassiner og dels erosion af lagene i de mellemliggende områder.

På overgangen nedre-mellem jura hæves således områderne langs Ringkøbing-Fyn Højderyggen og dele af eller hele Fjerritslev Formationen blev borteroderet. Den relative sænkning af havniveauet i mellem jura medførte at tilførselskanalerne mod nordøst byggede et delta ud i bassinet, Haldager deltaet. I denne periode aflejredes deltaaflejringer og kystnære havaflejringer i form af *Haldager Formationen* (fig. 6).

Den nederste del af Haldager Formationen, kaldet *Haldager Sand,* består af lysegrå, fint til mellemkornet sandsten og siltsten, der oftest er homogen og velsorteret. Krydslejring forekommer. Tykke lag af sandsten veksler med tynde lerlag og enkelte kullag. I den nordøstlige del af området, hvor lagserien har sin maximale tykkelse, kan den opdeles i flere underenheder svarende til rytmisk skiftende aflejringsbetingelser. Den nederste del er tolket som delta-front dannelser og den øverste som afsat i fletværkskanaler. Disse grovkornede sedimenter repræsenterer antagelig fornyet forkastningsaktivitet langs bassinets nordøstrand. Lagserien vurderes som havende gode reservoirkarakterer. Haldager Sandet overlejres af *Flyvbjerg Member,* der er en vekslende lagserie af forholdsvis tynde lag af sandsten, siltsten og lersten. Den repræsenterer hastigt skiftende aflejringsbetingelser, der har hersket på delta-fladen ved havets gradvise overskyldning af denne. Umiddelbart ovenpå Haldager Sandet er der aflejret sedimenter af formodet

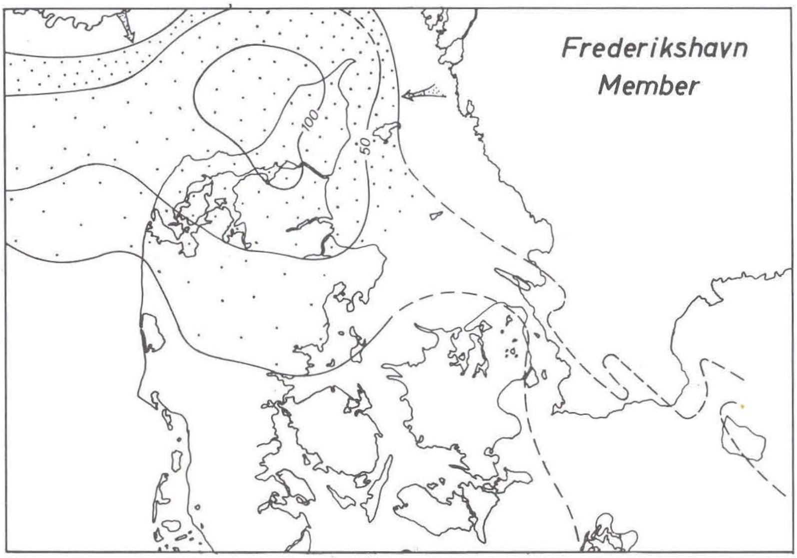

Fig. 7

ikke-marin karakter og derover lavtvands-marine sedimenter, som kan stamme fra en tidevandsflade.

Tilsvarende mellem jurassiske sedimenter er kendt fra andre dele af Nordsø området. Deltaaflejringer, kulførende lag og lavtvands havaflejringer er kendt fra store dele af Nordsøen visende en generel sænkning af havniveauet efterfulgt af en begyndende stigning i slutningen af mellem jura og begyndelsen af øvre jura.

Den øverste del af Flyvbjerg Member er af øvre jurassisk alder, og repræsenterer dermed begyndelsen af bassinets anden indsynkningsperiode i jura. Under denne indsynkning afsættes *Børglum Member*, der er en marin lerstens serie aflejret på den dybere del af shelfen. Den største indsynkning fandt sted i den centrale del af bassinet og mod vest i Nordsøen. Mod nordøst, i Vendsyssel, var der kun tale om en kortvarig periode, hvorefter kystnære littorale deltaiske forhold atter herskede der med aflejring af Frederikshavn Member (se nedenfor). Børglum Member er uden reservoirmæssig betydning.

Overgangen jura – kridt

På overgangen mellem jura og kridt sker der atter en hævning af området og mængden af groft materiale, der føres ud i bassinet, stiger, hvorved *Frederikshavn Member* dannes (fig. 7). Serien består af siltsten og finkornet sandsten, der veklser med siltholdig lersten. Tynde lag af kalksten forekommer i den øverste og nederste del af serien. Længst mod nordøst i Vendsyssel findes der få cm-tykke kullag i den øvre del af serien. Lagserien antages at have moderat gode reservoirkarakterer.

Lagserien er overvejende en marin aflejring. Mod øst og nordøst er den meget tyk og repræsenterer et stort tidsinterval, medens den mod vest tynder mærkbart ud og bliver mere finkornet. Lagserien afspejler således en generel sænkning af havniveauet i store dele af øvre jura og nedre del af nedre kridt. Mod nordøst er den nedre og øvre del af serien karakteriseret ved at indeholde fossiler og mineralkorn (glaukonit) stammende fra havet, medens den midterste del indeholder en stigende mængde plantemateriale, der er vasket ud i bassinet fra landområderne mod øst.

Overgangen jura-kridt er generelt en tektonisk urolig periode, og andre steder i Nordsø området ses en kraftig forkastningsaktivitet. Det danske Delbassin synes ikke at have været påvirket i mærkbar grad, men vulkanisk aktivitet i denne periode er dog påvist i Skåne.

Nedre kridt lagserien

I løbet af nedre kridt sker der atter en indsynkning af Det danske Delbassin, og i den sidste del af perioden oversvømmer havet hele det danske område således, at de yngste nedre kridt aflejringer henover Ringkøbing-Fyn Højderyggen hviler på trias lag.

I Det danske Delbassin er *Vedsted Formationen* aflejret over Frederikshavn Member og består af mørkegrå ler- og siltsten. Det er en marin aflejring, der i de kystnære områder mod nordøst veksler med mere grovkornede sedimenter.

Mod slutningen af nedre kridt ændrer sedimentationen karakter på to måder. For det første oversvømmes som nævnt hele landet. For det andet bliver sedimenterne stærkt kalkholdige. Det drejer sig primært om *Rødby Formationen*, som overvejende består af rødbrun mergel. Den dækker hele landet bortset fra Vendsyssel området, hvor den erstattes af grønlige, glaukonitholdige sedimenter. Vedsted og Rødby Formationerne har ingen reservoirmæssig betydning, medens de randnære grønsandstensaflejringer er gode men højtliggende reservoirer.

Hermed er indledt en ny hovedfase, idet Ringkøbing-Fyn Højderyggen atter dækkes af havet. Klimaet bliver atter tørt (tropisk) og havet tilføres derfor kun ringe mængder ler og sand. I stedet bundfældes slamkalk bestående af skeletdele fra planktoniske mikroorganismer, – øvre kridts hvide kalksten.

Litteratur

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A semi-automatic level-accurate groundwater sampler

Lars Jørgen Andersen

Andersen, L. J., 1979: A semi-automatic level-accurate groundwater sampler. *Danm. Geol. Unders., Årbog 1978, pp. 165-171, København, 1979**.

Large resources are spent in the chemical analysis of groundwater quality. Therefore, great care should be taken to make accurate sampling. Many types of sampling equipment based on pumpage between packers are available. However, fissured rock or gravel pack outside the screen may result in inflow of water from a different level than the packed level. However, this paper describes a groundwater sampler of the packer type which will sample groundwater from a usually screened interval of a well, guaranteeing level representativity.

The sampling procedure involves pumping from separated intervals above and bolow the sampled interval. The pumpage produces a simultaneous flow of water to an inflatable sampling vessel, installed within and totally separated from the flow through the pumping system. As distinct from earlier groundwater samplers of the packer type the described sampler is able to sample level-accurate groundwater from a usually screened well or open borehole penetrating an aquifer.

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During several projects within the field of hydrogeology, accurate sampling of groundwater from a given level is important, i.e. location of pollution, dating of groundwater, hydrochemical studies, saltwater intrusion etc. Most of the existing samplers do not insure sufficiently accurate sampling of the formation water in boreholes or screened wells, not even by the use of packers. Leakage between the packers and the borehole wall or screen often leads to a mixing of the sample with borehole water or water from other levels than the packed level.

Therefore, in 1976 the Hydrogeological Division at the Geological Survey of Denmark started to develop groundwater sampling equipment in order to

* After delivering of the manuscript the author was by personal communication from *Lucien Bertrand* informed about the existence of a Triple-Zone-Packer Prope developed by *BRGM Orléans* and patented by *C. Louis* in 1969. The prope was designed for determination of permeability normal to a borehole in fissured rocks. Elimination of permeability parallel to the borehole axis was established by injection of water at the same pressure through the three packed intervals.

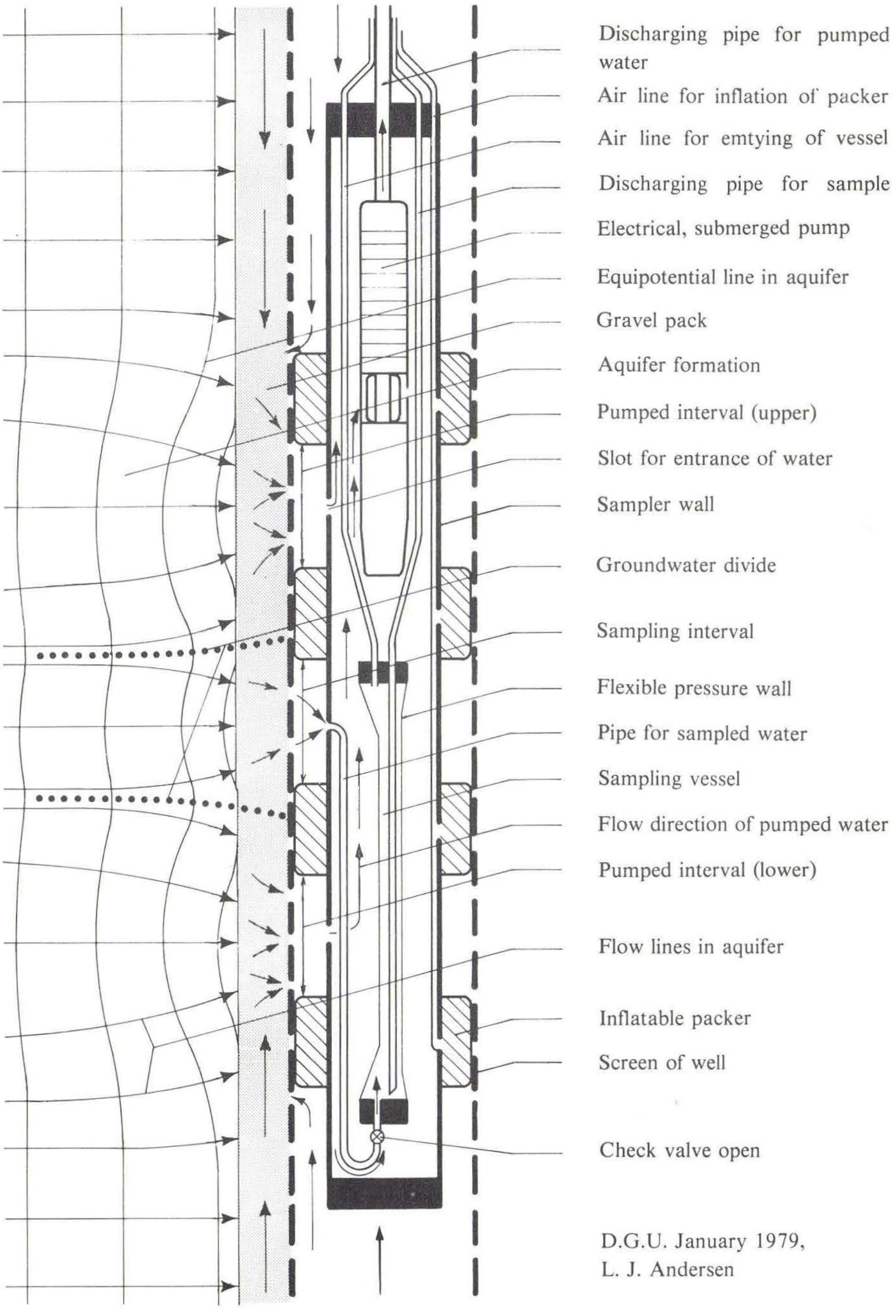

Fig. 1. Sampling equipment and schematic flow distribution during sampling.

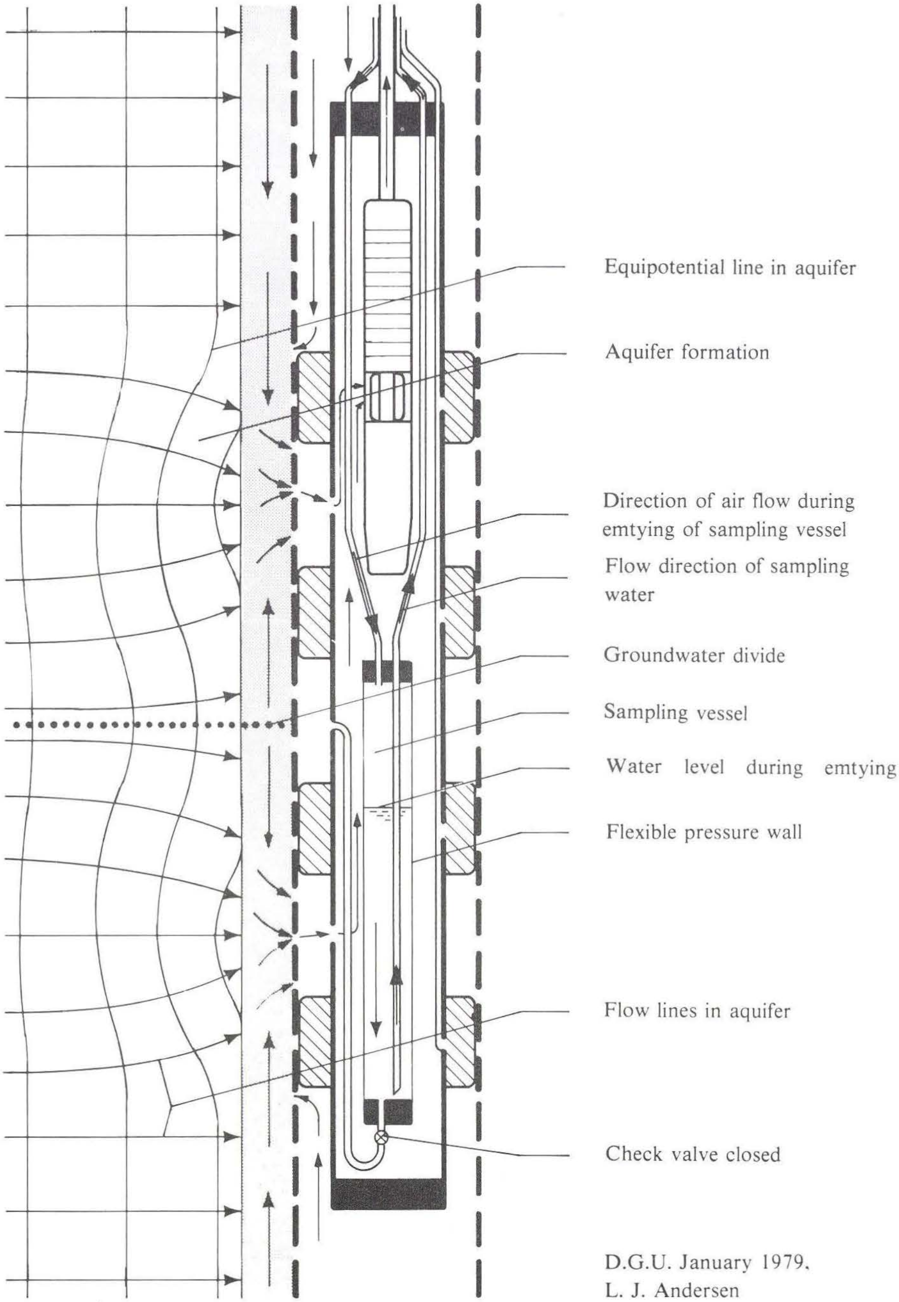

Fig. 2. Sampling equipment and schematic flow distribution during discharging of sample

improve the groundwater sampling technique. This publication mentions some fundamental conditions of accurate sampling of groundwater from a screened or open section of a well penetrating af waterbearing formation, and furthermore it describes sampling equipment for the establishment of these conditions as well as the mode of operation of the sampler.

Flow conditions in the aquifer outside the sampler

Conventional samplers take the water sample through pumping or suction from an interval separated from the rest of the well by packers. This way of sampling produces a converging groundwater flow within the sampling interval of the aquifer. Leakage around packers means inflow of water from the space outside the sampling interval, i.e. erroneous sample.

The sampler described below is based on the principle that a water sample taken from the central part of a diverging groundwater flow should possess good representativity of the water as the diverging conditions prevent lateral influx of water by continuous sampling. Therefore, the problem was to design and construct sampling equipment which will produce a diverging groundwater flow in the level of the sampling interval. Furthermore, the sampling rate was to be low enough to prevent a fundamental change in the flow conditions.

Description of the sampler

The sampler, shown in fig. 1, consists of a cylinder outside which 4 inflatable packers have been placed. Two of the intervals between the packers are pumping intervals, and the third one in the middle is the sampling interval. Inside the sampler a submerged pump and an inflatable pressure vessel for collection of the sampled water have been placed.

The sampler should have slots over the two pumped intervals for inflow and an aperture in the top for the discharging of pumped water. A tube containing a check valve connects the sampling interval with the sampling vessel.

A tube from the bottom of the vessel allows the sampled water to be discharged to the ground surface when commpressed air is added through an airline connected to the top of the sampling vessel.

Operation of the sampler

The sampler is lowered into the well and placed at the depth at which a groundwater sample is required. The packers are inflated and the pump started. The pumping creates a hydraulic gradient from the formation outside the sampling interval upwards and downwards to the inside of the sampler. As the water in the sampling vessel, because of its inflatability, has the same hydraulic head as that of the water passing the sampler, water from the sampling interval will flow into the vessel and fill it. Compressed air (or nitrogen) is added through the airline, and the vessel is emptied through the pipe leading to the ground surface. After that the pressure in the sampling vessel is released, and water will again flow into the vessel. The procedure is repeated until sufficient water has been taken from the sampled interval to flush out the borehole water confined between the packers due to their being inflated.

In fig. 1. the flow systems around and inside the sampler are illustrated schematically during the filling of the collecting vessel. In this case groundwater divides are surrounding the sampling interval upwards and downwards against the two pumped intervals. These conditions prevent water from other levels from flowing to the sampling vessel.

From fig. 2. the flow systems during the emptying of the vessel appear. In this case there is no flow of water to the sampling vessel, and a groundwater divide is established in the middle of the sampling interval, i.e. no flow of groundwater into the sampling interval.

Field tests of prototype

The sampler has been designed as a prototype. All parts in contact with the sampled water are made of PVC or rubber. As the pumped water is totally separated from the sampled water, the pump system and the pipe system are selected independently. The pump is an electrically driven submerged water well pump.

The prototype of the sampler has been designed for 6 in. screens. The sampler has been tested and used for sampling of groundwater from water wells at depths down to 50 m and a water level more than 10 m below surface. The sampler operates without any problems, and it has been checked that the water sample is accurately sampled due to the fact that it has been possible to localize a boundary between groundwater with and without nitrate based on water sampled with the sampler. The sampling time depends on the hydraulic conductivity of the waterbearing formation. In a normal waterbearing formation it takes only a few minutes to sample 4 litres of water. Until the first emptying stage has been finished, it is not possible to know whether the sampling vessel is full or not. By measuring the volume of the discharged sample, it is possible to determine whether the vessel has been full or not. If not, the sampling time has to be prolonged before emptying. However, the degree to which the vessel is full does not affect the quality of the sample.

When sampling is finished, the pressure in the collecting vessel increases to that of the groundwater of the sampling interval. By measuring the head inside the vessel the sampling time may be determined. By placing the upper orifice of the discharging pipe below the water table in an open vessel at the surface, it should be possible to observe when the pressure inside the pipe increases as a few bubbles of air will appear at the surface at increasing pressure. The orifice of the pipe should be lowered only one centimeter or so below the water table. If it is lowered too deep, no air will appear.

Bacteriological sampling

Finally, it should be mentioned that for desinfection of the sampling interval the sampler has been supplied with an electric heating element in the sampling interval for sampling of groundwater for bacteriological analysis.

Discussion of the sampler

The sampler will sample level-accurate groundwater samples from aribitrary levels of a screened interval in a normal water well.

If the sampling interval consists of impermeable rock, no water will be sampled, except in cases where gravel pack outside the screen connects the sampling interval with a waterbearing formation above or below the sampling interval. However, in such cases the collection of a sample will take more time as the driving force, the head difference between the groundwater of the sampling interval and the pumped water inside the sampler, will be low, and furthermore the pumping capacity will decrease. In such cases, the representativity of the sample may be bad as it may derive from levels above or below the sampling interval. In cases where the pumping produced divides around the sampling interval may deviate from a symmetrical arrangement normal to the well axis and slope in direction of the layer with the highest hydraulic conductivity.

A leakage around one or more of the packers will result in an increase of flow in the direction of the pump and a decrease of flow to the sampling vessel but never in an influx of water from outside the sampling interval. The head distribution prevents this.

As illustrated in figures 1 and 2, the pumpage results in a slight discharge of water from the whole screened part of the well, and only just above the upper and lower packers the directions of the flow will be from the well into the gravel pack or formation. However, this part of the flow will pass through the pumping system owing to the presence of the hydraulic boundaries, the groundwater divides, around the sampling interval.

Sampling equipment, by means of which it should be possible to take samples in wells of different diameters, is being developed at the Hydrogeological Division at the Geological Survey.

Acknowledgements. For valuable assistance during design, construction, and testing of the sampler I would like to thank the staff of the Hydrogeological Division, especially *Bjarne Madsen, Erik Clausen* and *Torben Jensen*, who has also made the drawings.

Dansk sammendrag

I nærværende artikel er beskrevet en grundvandsprøvetager af pakningstypen til udtagning af grundvandsprøver i filtersatte eller åbne vandboringer. Den består af et rør, på hvilket der er monteret 4 oppustelige pakninger, som adskiller 2 pumpeintervaller fra et prøvetagningsinterval beliggende mellem disse.

Inden i prøvetageren er der anbragt en dykpumpe, som pumper vand fra de to ydre afspærrede filterintervaller. Desuden indeholder prøvetageren en sammenklappelig prøvebeholder, som er placeret i pumpevandets strømsystem. Da prøvebeholderen er sammenklappelig, vil der herske samme tryk indvendig i den, som i pumpevandet. En slange indeholdende en contraventil, som kun tillader indstrømning af vand, forbinder prøvebeholderen med prøvetagningsintervallet. Så snart prøvetageren er anbragt, pakningerne er oppumpede og pumpningen på det øvre og nedre, afspærrede filterinterval påbegyndes, strømmer vand fra prøveintervallet ind i prøvebeholderen.

Pumpningen medfører, at der dannes grundvandsskel over og under prøvetagningsintervallet. Den udtagne vandprøve fra dette interval kan derfor ikke være forurenet med vand uden for dette. Prøvebeholderen tømmes ved tilførsel af trykluft eller kvælstof. Efter trykudligning i prøvebeholderen strømmer der atter vand fra prøvetagningsintervallet. Proceduren gentages, indtil vandet, der befandt sig i borehullet før prøvetageren anbragtes, er udvasket, hvorefter en repræsentativ grundvandsprøve kan udtages.

Prøvetagerens opbygning og strømningsforholdene i og uden for prøvetageren under fyldning og tømning fremgår af fig. 1 og 2.

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The programming practices in geology

Tom Svane Petersen and Gyrite Brandt

Petersen, T. S. and Brandt, G.: The programming practices in geology. *Danm. geol. Unders., Årbog 1978*, pp. 173-180. København 1979.

The purpose of this paper is to show a part of the essence of efficient geological programming. In this context, programming assumes the meaning of communication between the geologist and the computer. The programming process is subdivided into five parts, and a discussion of each of these parts is presented, special emphasis having been made on the step concerning the choice of programming languages.

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Due to widespread availability of computers and the accompanying facilities, these are now being used in nearly all sciences as tools for solving a large variety of problems. Geology has shared a part of this revolution. Geologists, however, have been slower in realizing and using the advantages of the computer than other scientists in fields. The main reason for this is related to the fact that geology is mainly a qualitative and descriptive science. In recent years large quantities of articles, dealing with computers, have been published. This is due to, among other things, the quantity of data that can be recived from the automatic analysis instruments. Many people can utilize programs for their work without having to know any of the basic facts about a computer. It is a necessity for the geologist to learn a programming language, and the number of these at the present stage is multifarious.

If the only person using the program is the programmer himself, then it is possible that adequate instructions may be kept in a loosely organised form in the programmer's own mind. It is most likely, however, that written notes will have to be made even for the programmer's personal use. If another person is to use the program, these instructions will have to be communicated to him, and the programmer will thus have to prepare a set of well-organised, detailed instructions in writing.

The subdivision of the programming process is a subjective matter, and in any attempt to define the different tasks it should be realized that these individual steps are interdependant. However, most experienced programmers will probably agree that the following steps make up a reasonable description of the major tasks involved in writing a program:

1) Problem definition.
2) Selection of algorithms and programming language.
3) Specification of program logic and structure.
4) Testing of the program.
5) Documentation.

These steps are certainly not independent. Appropriate written records should be made during the first steps; these will later make up a significant portion of the documentation as a whole.

Thus documentation is not a separate step but an intergral part of the programming. In the following sections we will discuss these steps, hoping to indicate some good geological programming methods and to show which programming languages are useful in geology.

Problem definition

The first obvious step in solving a problem in geology is to determine, in exact terms, what the actual problem is. The same is the case when a geologist wants to solve a problem with the aid of a computer. Though this may seem obvious, many geologists and other programmers will frequently start programming before they have an absolute understanding of the problem. There are several reasons why this is so, the first reasons usually being that the person who is faced with the problem does not thoroughly understand it. When the geologist and the programmer is the same person, he may be able to discipline himself so as to make an effort to define the problem properly before proceeding. In many cases some preliminary computation will be an aid in defining the problem, and this should be performed. When the geologist is not the programmer, he must be sure that the problem is welldefined, or else any cooperation with the programmer will be extremely difficult.

When the geologist is not the programmer, he must always remember that the programmer is confined to working on his own understanding of what he has been told. When considering the difficulty of communicating even the simplest ideas, it is no wonder that the programmer may misunderstand or misinterpret even the most rigid definition of the problem that the geologist has set up. The first step towards an understanding of the geological problem to be solved, is a personal meeting between the programmer and the geologist. Here the main difficulties should be discussed and eliminated before the working out of detailed specifications is begun.

The role of the programmer in this process should not be underestimated. The programmer is certain to have a greater appreciation of the capabilities and limitations of the computer than the geologist. It should also be noted that the geologist has probably made his definition based on co-operation with another geologist, and the programmer. The programmer will not have the background knowledge to enable him to interprete the definition. In the initial to specify the problem, there may be certain difficulties in making the definition ridgid enough. This may be because the problem may not be completely understood until more information is available in some cases, and this is a very common situation in geology! In other cases, it may be so that the solution to the orginal problem suggests an extension or modification that may be of interest. For these reasons it is necessary to maintain enough flexibility in the specifications and subsequently in the design of the program, so as to allow changes to be made easily. It is obvious that the problem definition and program specifications will be important parts of the final documentation, and therefore these parts should be made clear, by the geologist right from the beginning.

Selection of algorithms and programming language

Once the problem has been identified, the next step is to determine the methods to be used in solving it. In some cases these may have been determined by the specifications, in other they may depend heavily upon the language and equipment used. In geology the question of using a computer or desk calculater for programming procedure, depends on at least one of the following four criteria, (Harbaugh & Merriam 1968):

1) Volume of data to be processed.
2) Number of mathematical manipulations.
3) The volume of data to be retrieved.
4) Availability of the program.

In practice, the selection of algorithms does not involve many problems, as the solving of geological problems in general is not a complex affair, and it is also possible to consult the book by Knuth (1973).

When the necessary algorithms have been located, the next step for the geologist should be to determine whether related programs are already available, but obviously the amount of effort made in locating a program should be compared with the amount of effort required to write the program. In the event that the necessary programs are not available, there are perhaps programs which will accomplish the same task through a different, but perhaps acceptable program. Also, perhaps, an existing program could be modified to accomplish the task at hand. All of these possibilities should be investigated. Though no existing program seems to solve the entire problem, there may be an existing one that is applicable to a portion of it.

In the early days of computing, programs were written in numerics, which then were translated to numeric equivalents through a simple translation program. Development of the problem orientated languages began in the late 1950's and this development has progressed rapidly since, the result being that today's programmer is confronted by a nearly bewildering variety of tools. The most basic of these tools is microprogramming in wich the programmer has control of the gates, flipflows, and registers within the central processor, the minutest details concering each task having to be specified. The so-called machine language, or assembly language, is still the most common tool available to most programmers. The geologist should realize that the characteristics of the assembly languages are strongly dependent upon the characteristics of the computer itself, and the programs written in assembly language are generally unsuitable for any machine other than the one for which they have been written.

Beyond the assembly language we encounter a host of problem orientated languages, and these are the most useful for solving geological problems. These range from business data processing languages such ad Cobol, through mathematical-type languages such as Fortran and Algol, multiple-purpose languages such ad PL/1, list processing languages such as Lisp, pattern-driven languages such as Snobol to array-processing languages such as APL.

A difficult problem for the geologist is the selection of a programming language. Here, the issue is not only how flexible or sophisticated a programming language is, but also how widely used it is plays a great part when one is to make one's choice. For a specific survey or university this last problem is not of great importance, but if the geologist is interested in making the program available to other geologists, this is an essential problem. If one looks at the geological publications on computer programs issued within the last ten years, one will see that more than 90 percent of the programs have been written in fortran. Also, all computers have a Fortran compiler, including the mini-computers wich are in rapid development. So in all probability most geological institutions will have a computer in the near future. In view of the above, and at the same time considering that Fortran is a very easy language to learn, it seems that Fortran is the relevant language for geological programming.

Program logic and structure

The next step is for the geologist to define the logic and to determine the structure of the program. This phase is the most important as the coding and ease of reading of the program depends on it.

Some geologists may feel that parts in this phase are important enough to be regarded as steps in their own right. We have grouped them together so as to emphasise their interdependance. We have divided this step into three subsections:

1) Modularization.
2) Logic via flowchart.
3) Structure of the individual module.

The process of dividing the program into basic building blocks is known as modularization. While the idea is simple, its implementation is generally not. The major difficulties involved are the determination of a suitable set of subtasks for each task, and the decisions related to the defining of size of these. For a geologist, modularization may seem to be unnecessary but this is not so as it makes it easier for the programmer and the reader of the program to read it.

One common method of expressing the logic and structure of a program is using a flowchart, and this visual aid can also be used by the geologist for solving problems that are not even to be programmed! A flowchart is a schematic visual description of the logic of a program module. Normally, each module should be flowcharted unless its function is so simple that the logic is clear. Flowcharts are primarily intended as tools for human communication, and these must therefore not be too general or too detailed. If it is too general, it will be of no value, e.g. a chart that shows in- and output boxes is not very informative but technically correct. On the other hand a flowchart must not be too specific as it will be hard to read. It is difficult to say what a flowchart should show. A flowchart should reveal, to the reader, the function of the program and the logic of the program! because of this it is impossible to say how many coded lines each box should represent.

Modularization of the program is very important. The clarity of the program as a whole depends heavily on the structure of each individual module. With regard to the flowchart, complexity may be thought of as being by the number of nonsequential paths through the chart, and this is an exponential function of the number of decisions.

A program is easy to read if it is written sequentially. On the other hand if the resulting items in the output list appear in random order with respect to the display of these, then it will be extremely difficult to read.

Input and output data format may be determined as a part of the program specifications. Often these formats are not especially important with regard to the overall structure of the program however.

Input data format should be designed for maximum user convenience. Every effort should be made to determine what format and sequence would be natural from the geologists point of view, and any necessary reordering or reorganization should be an integral part of the program. If data manipulation is substantial, this will, of course, be included in the structuring and design of the program.

Output format is generally another matter. The design of the program may be very specific in terms of what information is to be written out, and when this is to be done. However, the specifications are addressed for identification of the output end.

The same standard of documentation should apply to the output as to rest of the program. The output documentation should be brief, and one should be able to read it separately. In particular, the output should begin with an introduction which identifies which program is being used, perhaps even stating the purpose of the program and the programmer's name. This should be followed by the identification of the problem, including any appropriate narrative description which includes a summary of the input data used in the run. The output data format should be so designed that it ensures maximum readability. Every data item should be positively identified, (including the input data value). This identification should be sufficient to allow for easy interpretation of the output by the geologist, but it should not clutter up the page. If the output information is printed in tabular form rows and columns should be identified and the columns aligned. Logical group of data should be separated by blank lines or page ejects. Identification, spacing and other good formatting practices should be used as a matter of course. The aim should be to produce an output that may be photographed and published without further editing, in the event that publication should become desirable.

Testing of the program

The first step to be taken by the geologist in this check-out procedure is to review the problem statement, the algorithms, data structures and the flowchart. By doing this, one should be able to reaffirm that the problem has been completely understood, and that the technique used for solving it will actually do so. A good idea is to get a geologist who is unfamiliar with the problem to examine the program and the program method. Whilst checking the program the geologist should make some calculations. The next step to be taken is the coding of the program. When the program has been coded, a print-out of it should be checked. The next hurdle is the compilation. Initially this should be done using the best diagnostic compiler available. A good diagnostic compiler is able to discover errors such as misspelt variable names, undefined variables etc. After a successful compilation an actual testing of the program can begin. The key to successful testing is that of good test data. The geologist should realize that the design of good test data is nearly as important as the design of the program itself. The test data should be designed so that it will test all coding, and the modules should be tested in as many combinations as is practicable. It is often virtually impossibly to test all the paths through the program but the most common ones should be tested, and all the segments of the code executed.

Documentation

There are two classes of documentation of a program: the technical documentation, and the operational documentation. The operational documentation should include the following items: 1) The complete problem statement. 2) Algorithms and data structure. 3) Description of the logic and the structure of the program (including flowchart). 4) A clear, sequentially numbered, commented program listing. 5) A definite statement of testing and verification procedures. This statement should include a listing of test data, a description of which program sections were tested by each data group, and a description of the verification procedure, 6) Operating instructions, including program deck structure, data deck structures, card formats, output format, error messages and other abnormal conditions.

Technical documentation is nearly the same as operational documentation. The difference is that most geologists are not particularly interested in the mechanics of the program and therefore do not want bulky documentation. Generally the problem statement may be condensed, and algorithms and data structures may be presented in only just sufficient details to enable the user to understand what the program does, and why it does it.

Conclusion: If one makes programs that are to solve geological problems, one must take note of the following points: Problem definition (a clear communication between programmer and geologist is needed here); a selection of algorithms; a specification of program logic and structure; a testing of the program and documentation.

One must make certain that one uses a widely used and flexible programming language, and also make sure that one's written description is clear and easily understood. These two points will make it possible for others to use the program without unnecessary complications.

Last but not least it is important to stress the need of programming for geology in general, and for the geologists themselves, in order that geology may remain a modern and up-to-date science.

Dansk sammendrag

Fortran fremhæves som det bedste sprog til løsning af geologiske problemstillinger.

Der foreslås og gennemgås en metodik, som geologer kan følge når de skal løse programmeringsopgaver.

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Oversigt over geologiske forskningsprojekter i Danmark og Færøerne

Peter B. Konradi og Kaj Strand Petersen

Konradi, P.B. & Petersen, K. Strand: Oversigt over geologiske forskningsprojekter i Danmark og Færøerne. Danm. geol. Unders., Årbog 1978, pp. 181-184. København, 1979.

The registration of geological research projects in Denmark and the Faroe Islands has proved successful. 60 new projects registrered in 1977 and 1978 have been marked on the following map which is meant as a supplementary sheet to the one published in the Årbog 1976.

Peter B. Konradi and K. Strand Petersen, Geological Survey of Denmark, Thoravej 31, DK-2400 Copenhagen NV.

Danmarks Geologiske Undersøgelse tog i 1976 initiativ til løbende at registrere geologiske forskningsprojekter i Danmark og Færøerne. Det første års registrering blev publiceret i DGU Årbog 1976, pp. 115-119 (Sørensen & Konradi 1978). Der blev i 1977 og 1978 registreret 60 nye projekter. Områderne for disse projekter er illustreret på medfølgende oversigtskort efter samme retningslinier som i Årbog 1976.

Om de registrerede projekter kan der ganske kort nævnes følgende inden for de forskellige emnegrupper. I besvarelserne dominerer projekter inden for hydrogeologi og råstofgeologi, som for en stor dels vedkommende er styret af den nyere tids miljølovgivning og andre lovbundne opgaver. Dette har ligeledes haft indflydelse på emnegrupperne sedimentologi, geokemi og geofysik samt geoteknik, hvor der dog også indgår mere forskningsrettede projekter som f.eks. studiet af tunneldale i Nørrejylland og aldersrelationer i Prækambrium på Bornholm. De geothermiske undersøgelser, som pågår i det nordlige Jylland ved Års, involverer både geokemi og geofysik.

Inden for geobotanik, som i Årbog 1976 er kaldt palæobotanik, er aktiviteterne især knyttet til studiet af de Sen Weichsel og Holocæne aflejringer, som de fremtræder i vore moser. Emnegrupperne geomorfologi, glacialgeologi samt kvartærstratigrafi synes at være emnekredse, hvor der stræbes mod en landsdækkende bearbejdelse af de glaciale aflejringer med henblik på en isstrømskronologi.

Inden for mikropalæontologien omfatter projekterne især stratigrafien inden for Danien, Selandien og Kvartær. Makropalæontologiske studier af Prækvartæ-

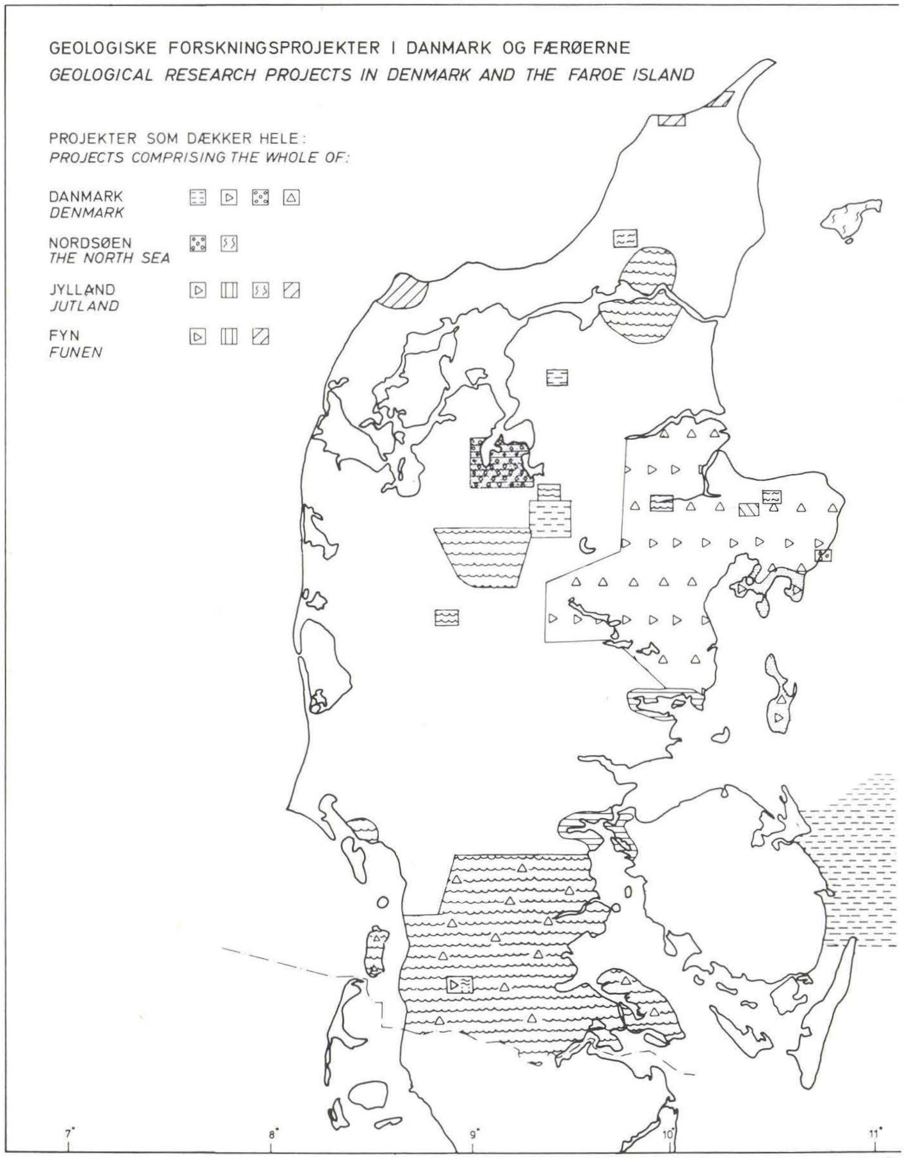
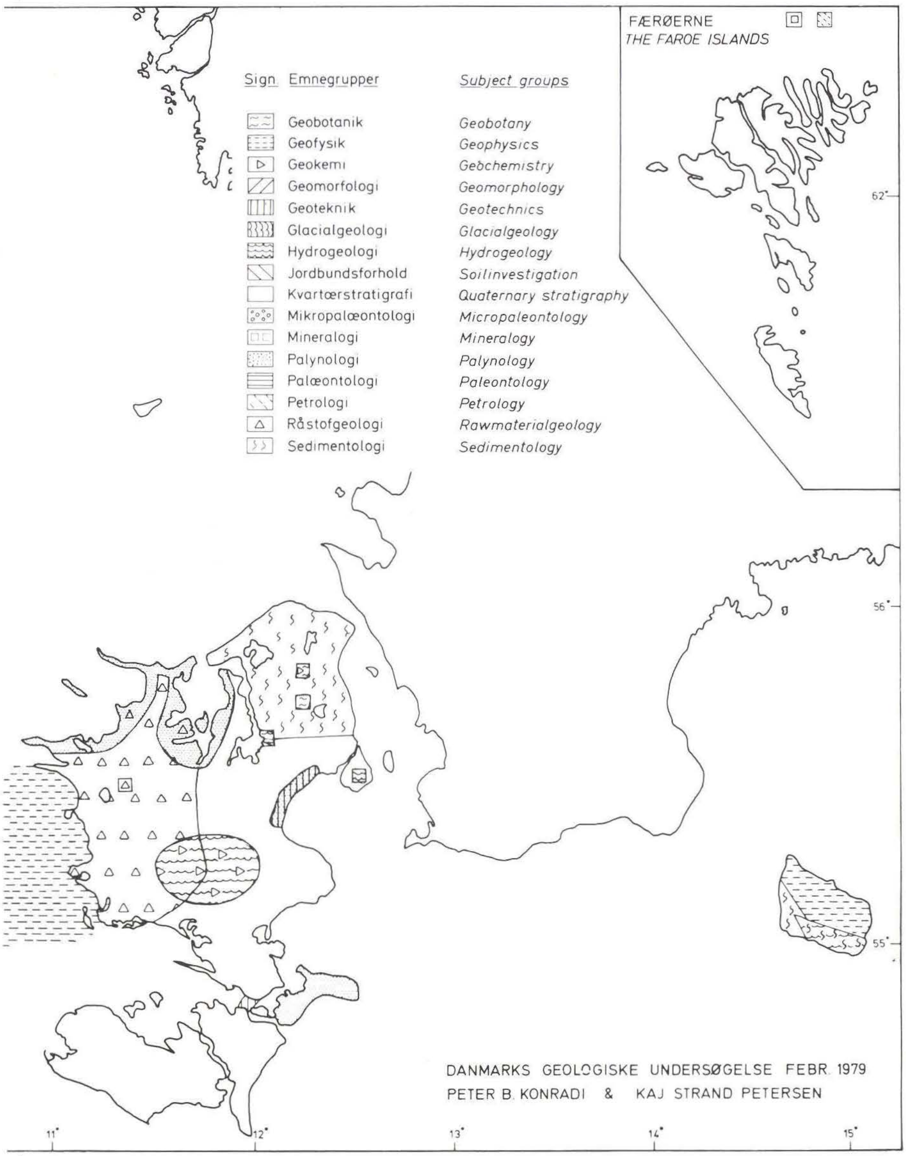


Fig. 1. Aktivitetsområder for geologiske forskningsprojekter.


FÆRØERNE
THE FAROE ISLANDS
Sign Emnegrupper Subject groups
Geobotanik Geobotany
Geofysik Geophysics
Geokemi Geochemistry
Geomorfologi Geomorphology
Geoteknik Geotechnics
Glacialgeologi Glacialgeology
Hydrogeologi Hydrogeology
Jordbundsforhold Soilinvestigation
Kvartærstratigrafi Quaternary stratigraphy
Mikropalæontologi Micropaleontology
Mineralogi Mineralogy
Palynologi Palynology
Palæontologi Paleontology
Petrologi Petrology
Råstofgeologi Rawmaterialgeology
Sedimentologi Sedimentology
62°
56°
55°
DANMARKS GEOLOGISKE UNDERSØGELSE FEBR. 1979
PETER B. KONRADI & KAJ STRAND PETERSEN
11°
12°
13°
14°
15°

ret pågår ved Fakse og Arnager og af Kvartæret i forbindelse med arkæologiske undersøgelser af Jernalderskaldynger langs Jyllands østkyst for at fastlægge de yngre strandlinieforløb.

Inden for emnegruppen jordbundsforhold undersøges de mineralogiske ændringer i podzoleringens tidlige stadier i en brunjord og en ung podzol.

Af nytilkomne projekter kan iøvrigt henregnes den systematiske kortlægning, der er startet i Viborg egnen. Denne redegøres der dog for andetsteds i denne årbog.

DGU har modtaget forespørgsler om projekter inden for større geografiske områder fra forskellig side. I forbindelse hermed kan der nævnes, at DGU med fordel kunne modtage oplysning om publikationer i forbindelse med projekter og således gøre status over resultaterne af de geologiske forskningsprojekter.

Registret udarbejdes af Almengeologisk afdeling på DGU, hvortil forespørgsler og bidrag til registret bedes rettet. Spørgeskemaer vil ligeledes kunne rekvireres her. DGU vil rutinemæssigt udsende spørgeskemaer hvert forår.

Litteratur

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II. Række – II. Series

112. *Karen Luise Knudsen:* Middle and Late Weichselian marine deposits at Nørre Lyngby, northern Jutland, Denmark, and their foraminiferal faunas. Dansk sammendrag: Midt og sen Weichselien marine aflejringer ved Nørre Lyngby, Nordjylland, Danmark, og deres foraminifer-faunaer. 1978. 44 p. 7 pls.

III. Række – III. Series

44. *Leif Banke Rasmussen:* Geological aspects of the Danish North Sea sector. With a report on the wells Dansk Nordsø E-1, E-2, F-1, G-1, H-1, I-1, J-1, and K-1. Dansk sammendrag: Geologiske træk fra den danske Nordsø sektor. Med rapport over boringerne Dansk Nordsø E-1, E-2, F-1, G-1, H-1, I-1, J-1 og K-1. 1978. 85 p.

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1976 Editor: *Olaf Michelsen.* 1978. 152 p. 2 pls.
Contents: *Svend Th. Andersen*: Local and regional vegetational development in eastern Denmark in the Holocene, pp. 5-27. *Harald Krog*: The Late Weichselian freshwater beds at Nørre Lyngby. C-14 dates and pollen diagram, pp. 29-43. *Jóhannes Jóhansen*: The age of the introduction of *Plantago lanceolata* to the Shetland Islands, pp. 45-48. *Jens Stockmarr:* Den prækvartære overflade ved Juelsminde, Danmark, pp. 49-52, pl. 1. *Valdemar Poulsen*: *Dalmanitina* beds (late Ordovician) on Bornholm, pp. 53-87. *Arne Villumsen* and *Bent Grelk Larsen*: Sedimentological and microprobe studies of the lime tufas at Årestrup, Zealand, pp. 89-114. *Henning Sørensen* og *Peter B. Konradi*: Oversigt over geologiske forskningsprojekter i Danmark og Færøerne, pp. 115-119. *Arne Vagn Nielsen:* Sigurd Hansen (1900-1973). – Mere end 50 års geologisk virke for DGU, pp. 120-138. *Sigurd Hansen*: Sidste nedisnings maksimumsudbredelse i Syd- og Midtjylland, pp. 139-152.

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luation method for detection of lithology and hydrocarbons in the Danish North Sea well M-1x, 113-129, pl. 1.

Serie A - Series A

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Serie B - Series B

2 *Olaf Michelsen*: Stratigraphy and distribution of Jurassic deposits of the Norwegian-Danish Basin. 1978. 28 p.

3 *Finn Bertelsen*: The Upper Triassic - Lower Jurassic Vinding and Gassum Formations of the Norwegian-Danish Basin. 1978. 26 p.

1215 VIBORG

PRÆKVARTÆROVERFLADENS HØJDEFORHOLD

Tolket på grundlag af boringer og daglokaliteter

SIGNATURFORKLARING

÷20 ÷30 Højdekurver for prækvartæroverfladen (m)

÷40 Usikkert forløb af højdekurverne (m)

585 Boringens DGU arkiv nr.

585 ● Borestedets beliggenhed

585 ÷21.5 Kote for prækvartæroverflade

585 GS Bjergartssymbol

29 < 10 Kote for bund af boring, der ikke når prækvartæret

594 > ÷24 Kote for top af prækvartær ligger højere end den anførte størrelse

Mønsted 1. ■ 38 ZK Daglokalitet (øvrige data analoge med boring)

Højtliggende saltstruktur

Centrum for dybtliggende struktur

Forkastning i prækvartærlagene

Øvre tertiær, overvejende sandede sedimenter

Nedre tertiær, overvejende lerede sedimenter

Tertiær, danien kalksten

Kridt, senon kalksten

67|68 77|78 DGU atlasbladnumre

1:100000

1000 m 0 1 2 3 4 5 km

Danmarks Geologiske Undersøgelse
Planlægningsafdelingen

Topografisk grundmateriale er Geodætisk Instituts 1 cm kort

Reproduceret med tilladelse (A. 881/71) af Geodætisk Institut

København 1978

GEOLOGISK TOLKNING: Knud Binzer og Leif Aabo Rasmussen
KORTFREMSTILLING: Steffen Krøyer

TRYK: C. A. BACKHAUSEN ApS, KØBENHAVN

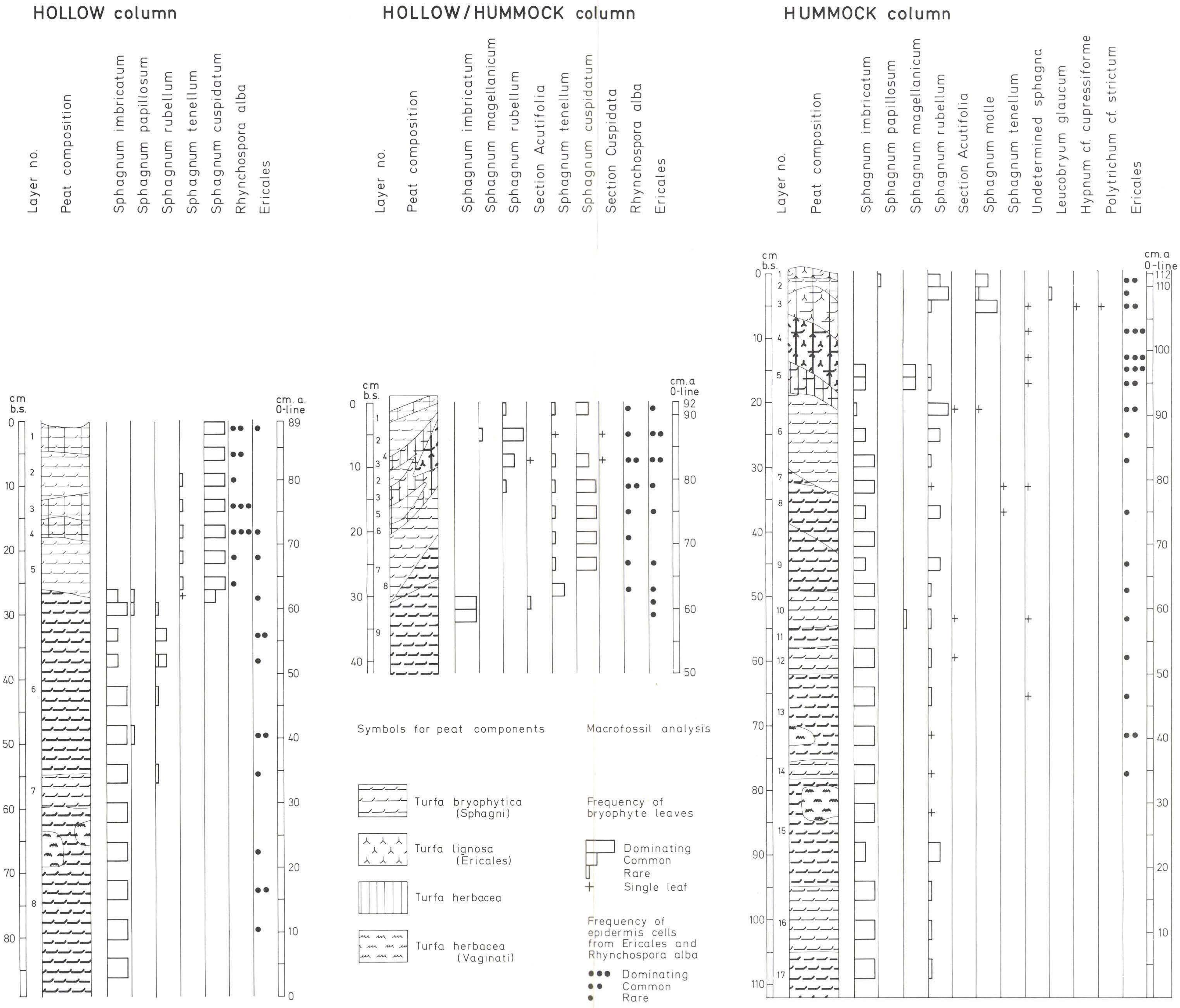


Plate I. Macrofossil diagrams.

DRAVED MOSE

HOLLOW COLUMN, 1973

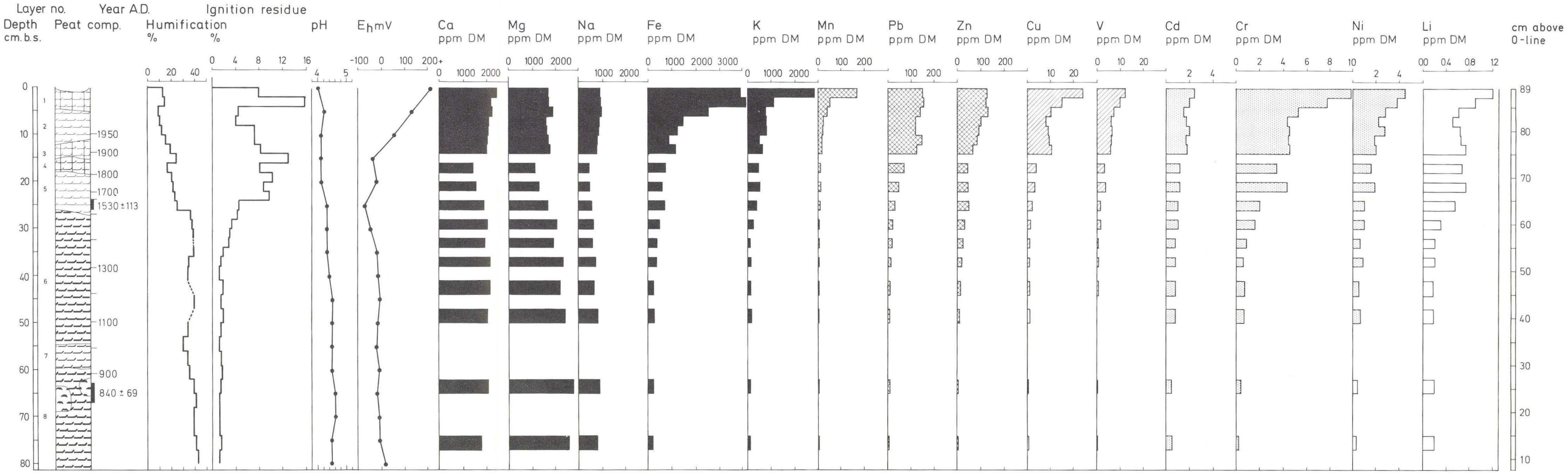


Plate 2. Hollow column, 1973. The peat composition symbols are shown in plate 1.

DRAVED MOSE

HUMMOCK COLUMN, 1973

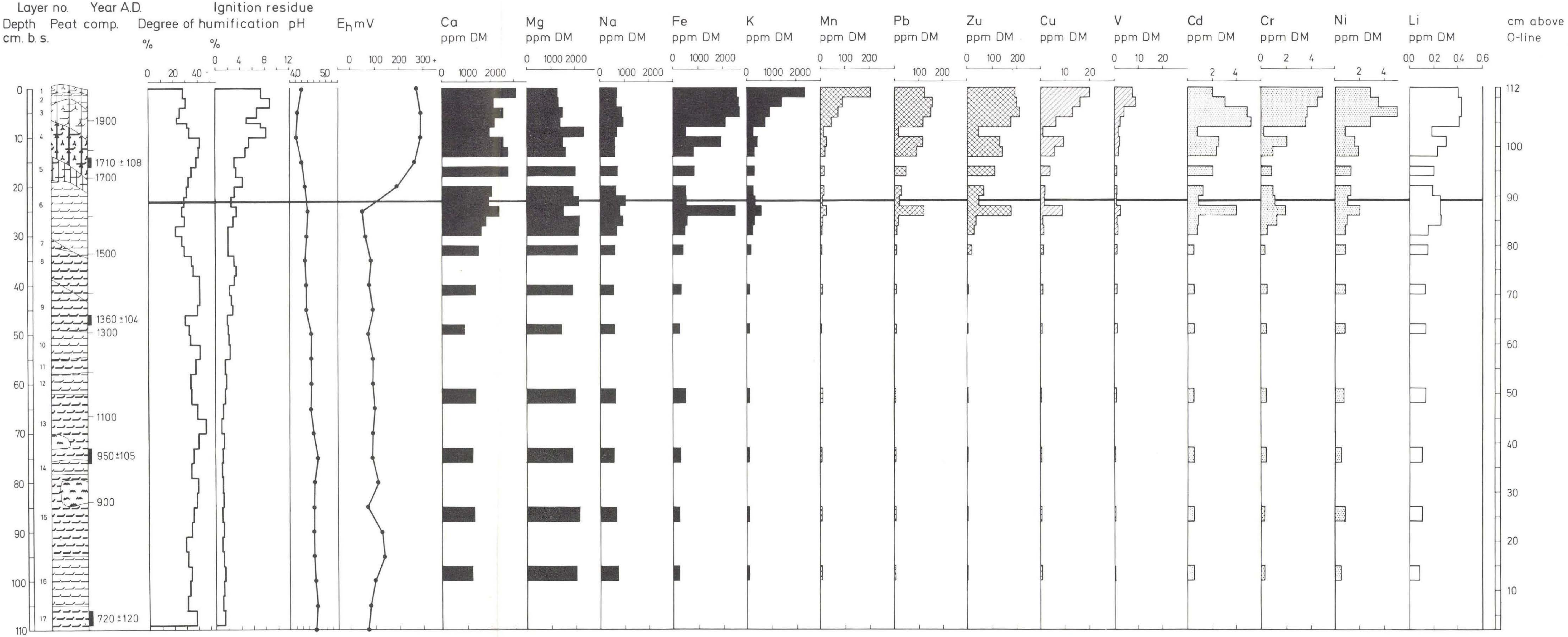


Plate 3. Hummock column, 1973. The peat composition symbols are shown in plate 1. The thick line at 23 cm below surface (b.s.) indicates the hollow column surface.

Jurassic Sections

Lithostratigraphically subdivided

DGU 1976 Olaf Michelsen

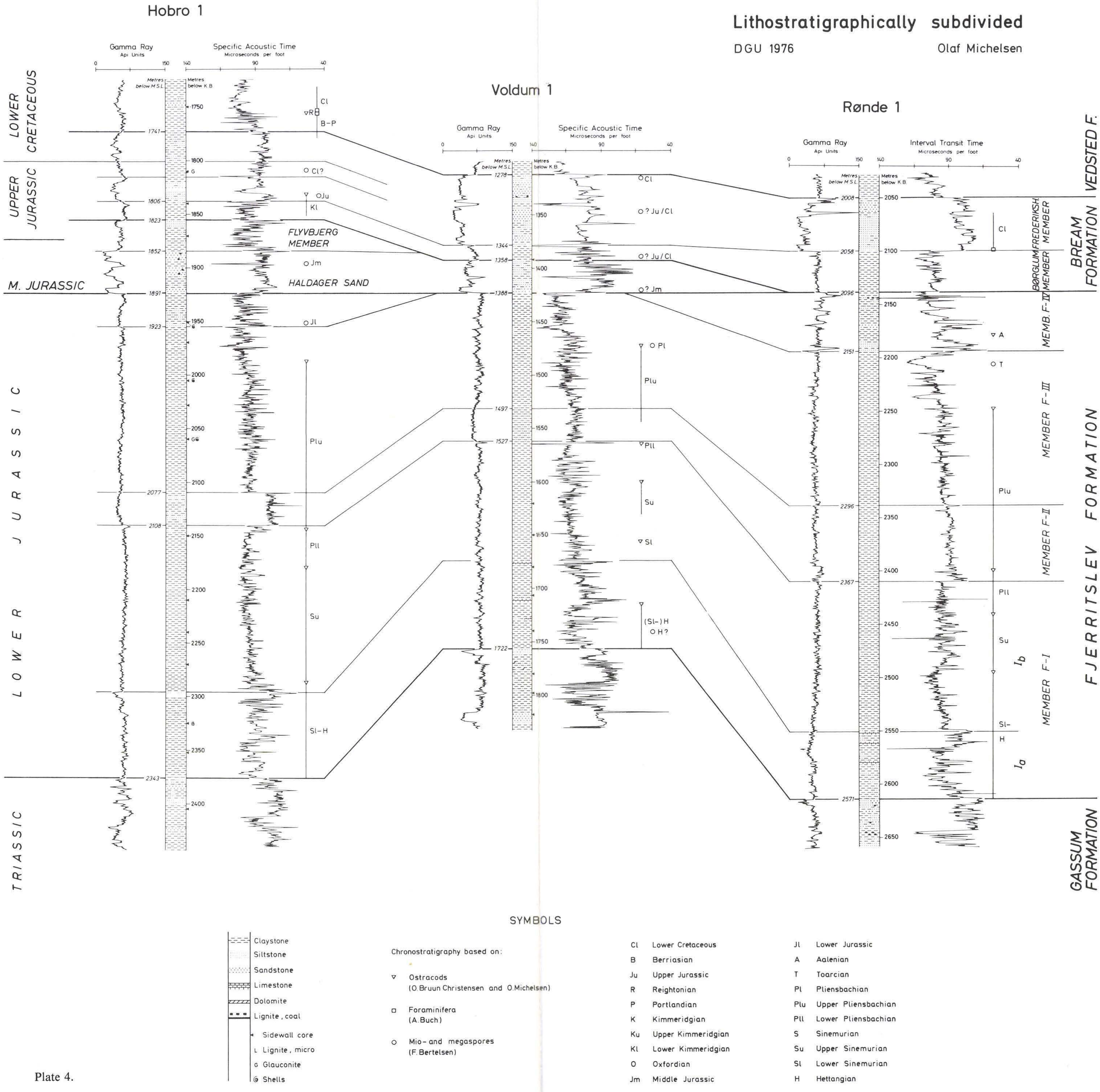


Plate 4.

Plate 5.

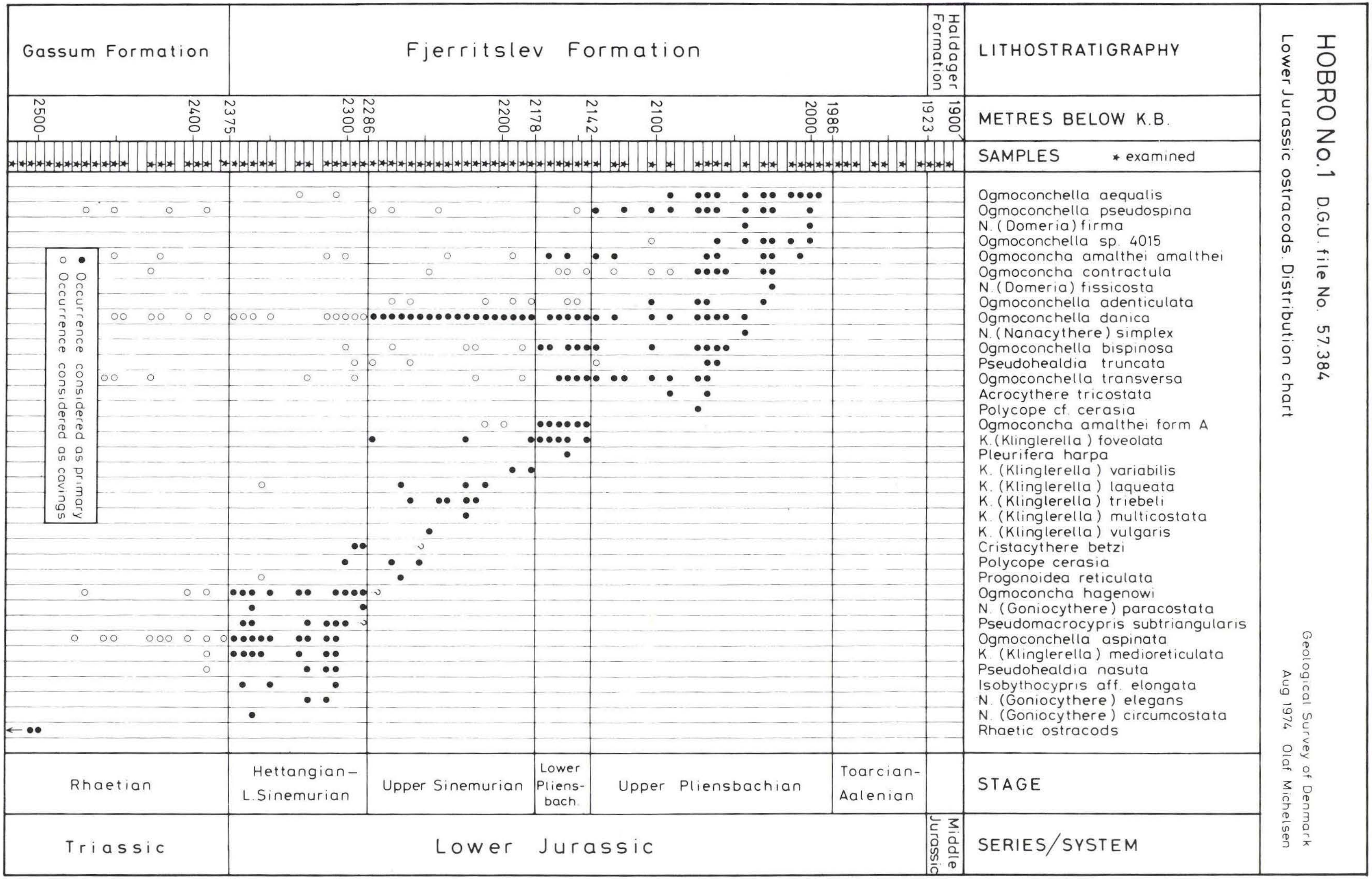
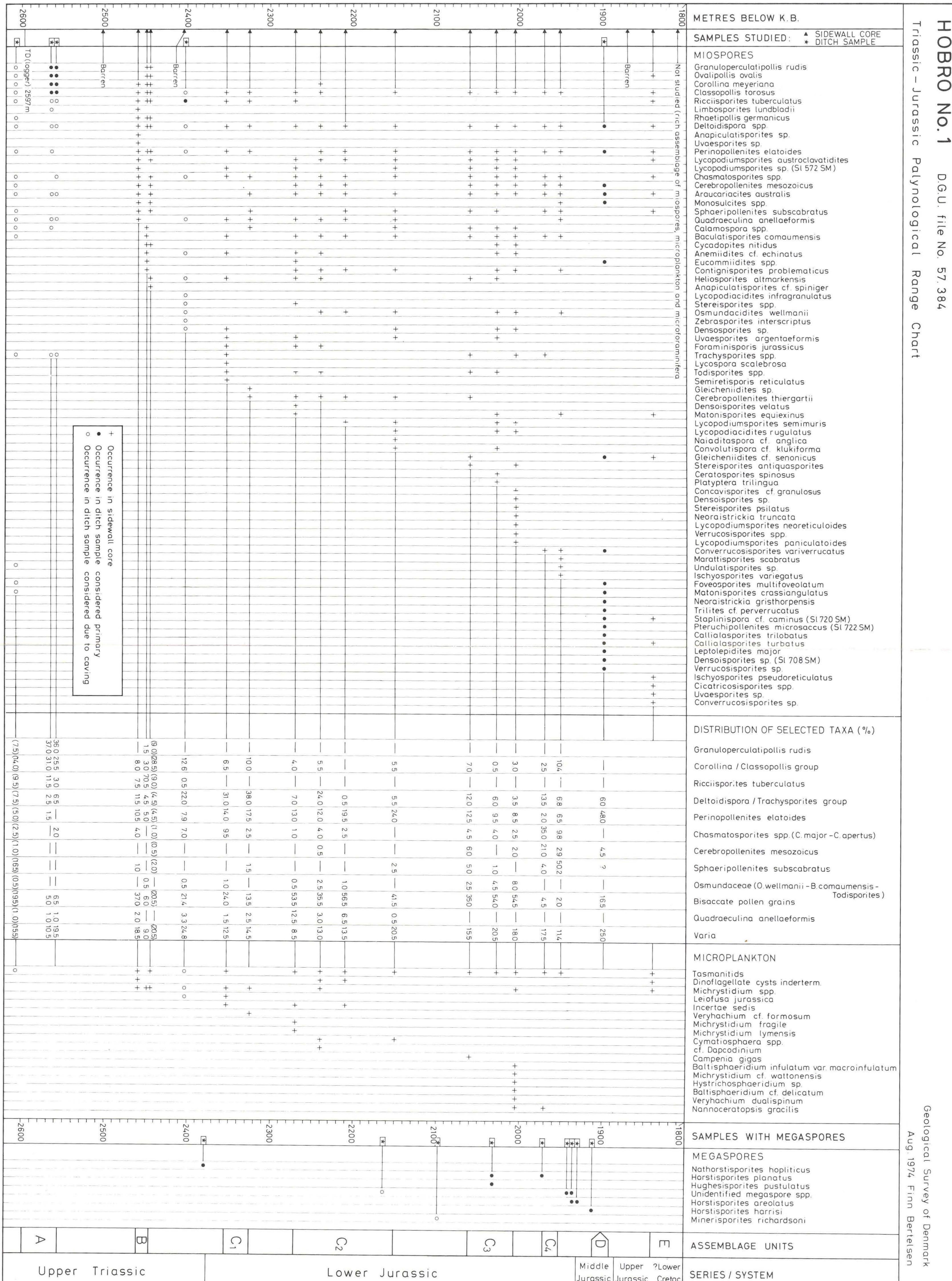

HOBRO No.1 D.G.U. file No. 57.384
Lower Jurassic ostracods. Distribution chart
Geological Survey of Denmark
Aug 1974 Olaf Michelsen
LITHOSTRATIGRAPHY
Gassum Formation
Fjerritslev Formation
Haldager Formation
METRES BELOW K.B.
2500
2400
2375
2300
2286
2200
2178
2142
2100
2000
1986
1923
1900
SAMPLES
* examined
● Occurrence considered as primary
○ Occurrence considered as cavings
Ogmoconchella aequalis
Ogmoconchella pseudospina
N. (Domeria) firma
Ogmoconchella sp. 4015
Ogmoconcha amalthei amalthei
Ogmoconcha contractula
N. (Domeria) fissicosta
Ogmoconchella adenticulata
Ogmoconchella danica
N. (Nanacythere) simplex
Ogmoconchella bispinosa
Pseudohealdia truncata
Ogmoconchella transversa
Acrocythere tricostata
Polycope cf. cerasia
Ogmoconcha amalthei form A
K. (Klinglerella) foveolata
Pleurifera harpa
K. (Klinglerella) variabilis
K. (Klinglerella) laqueata
K. (Klinglerella) triebeli
K. (Klinglerella) multicostata
K. (Klinglerella) vulgaris
Cristacythere betzi
Polycope cerasia
Progonoidea reticulata
Ogmoconcha hagenowi
N. (Goniocythere) paracostata
Pseudomacrocypris subtriangularis
Ogmoconchella aspinata
K. (Klinglerella) medioreticulata
Pseudohealdia nasuta
Isobythocypris aff. elongata
N. (Goniocythere) elegans
N. (Goniocythere) circumcostata
Rhaetic ostracods
STAGE
Rhaetian
Hettangian – L. Sinemurian
Upper Sinemurian
Lower Pliensbach.
Upper Pliensbachian
Toarcian – Aalenian
SERIES/SYSTEM
Triassic
Lower Jurassic
Middle Jurassic

Plate 6.


HOBRO No. 1
D.G.U. file No. 57.384
Triassic – Jurassic Palynological Range Chart
Geological Survey of Denmark
Aug. 1974 Finn Bertelsen
METRES BELOW K.B.
SAMPLES STUDIED: ▲ SIDEWALL CORE * DITCH SAMPLE
TD (logger) 2597m
Barren
Not studied (rich assemblage of miospores, microplankton and microforaminifera
MIOSPORES
Granuloperculatipollis rudis
Ovalipollis ovalis
Corollina meyeriana
Classopollis torosus
Ricciisporites tuberculatus
Limbosporites lundbladii
Rhaetipollis germanicus
Deltoidispora spp.
Anapiculatisporites sp.
Uvaesporites sp.
Perinopollenites elatoides
Lycopodiumsporites austroclavatidites
Lycopodiumsporites sp. (Sl 572 SM)
Chasmatosporites spp.
Cerebropollenites mesozoicus
Araucariacites australis
Monosulcites spp.
Sphaeripollenites subscabratus
Quadraeculina anellaeformis
Calamospora spp.
Baculatisporites comaumensis
Cycadopites nitidus
Anemiidites cf. echinatus
Eucommiidites spp.
Contignisporites problematicus
Heliosporites altmarkensis
Anapiculatisporites cf. spiniger
Lycopodiacidites infragranulatus
Stereisporites spp.
Osmundacidites wellmanii
Zebrasporites interscriptus
Densosporites sp.
Uvaesporites argentaeformis
Foraminisporis jurassicus
Trachysporites spp.
Lycospora scalebrosa
Todisporites spp.
Semiretisporis reticulatus
Gleicheniidites sp.
Cerebropollenites thiergartii
Densoisporites velatus
Matonisporites equiexinus
Lycopodiumsporites semimuris
Lycopodiacidites rugulatus
Naiaditaspora cf. anglica
Convolutispora cf. klukiforma
Gleicheniidites cf. senonicus
Stereisporites antiquasporites
Ceratosporites spinosus
Platyptera trilingua
Concavisporites cf. granulosus
Densoisporites sp.
Stereisporites psilatus
Neoraistrickia truncata
Lycopodiumsporites neoreticuloides
Verrucosisporites spp.
Lycopodiumsporites paniculatoides
Converrucosisporites variverrucatus
Marattisporites scabratus
Undulatisporites sp.
Ischyosporites variegatus
Foveosporites multifoveolatum
Matonisporites crassiangulatus
Neoraistrickia gristhorpensis
Trilites cf. perverrucatus
Staplinispora cf. caminus (Sl 720 SM)
Pteruchipollenites microsaccus (Sl 722 SM)
Callialasporites trilobatus
Callialasporites turbatus
Leptolepidites major
Densoisporites sp. (Sl 708 SM)
Verrucosisporites sp.
Ischyosporites pseudoreticulatus
Cicatricosisporites spp.
Uvaesporites sp.
Converrucosisporites sp.
+ Occurrence in sidewall core
• Occurrence in ditch sample considered primary
○ Occurrence in ditch sample considered due to caving
DISTRIBUTION OF SELECTED TAXA (%)
Granuloperculatipollis rudis
Corollina / Classopollis group
Ricciisporites tuberculatus
Deltoidispora / Trachysporites group
Perinopollenites elatoides
Chasmatosporites spp. (C. major – C. apertus)
Cerebropollenites mesozoicus
Sphaeripollenites subscabratus
Osmundaceae (O. wellmanii - B. comaumensis - Todisporites)
Bisaccate pollen grains
Quadraeculina anellaeformis
Varia
MICROPLANKTON
Tasmanitids
Dinoflagellate cysts inderterm.
Michrystidium spp.
Leiofusa jurassica
Incertae sedis
Veryhachium cf. formosum
Michrystidium fragile
Michrystidium lymensis
Cymatiosphaera spp.
cf. Dapcodinium
Campenia gigas
Baltisphaeridium infulatum var. macroinfulatum
Michrystidium cf. wattonensis
Hystrichosphaeridium sp.
Baltisphaeridium cf. delicatum
Veryhachium dualispinum
Nannoceratopsis gracilis
SAMPLES WITH MEGASPORES
MEGASPORES
Nathorstisporites hopliticus
Horstisporites planatus
Hughesisporites pustulatus
Unidentified megaspore spp.
Horstisporites areolatus
Horstisporites harrisi
Minerisporites richardsoni
ASSEMBLAGE UNITS
A
B
C1
C2
C3
C4
D
E
SERIES / SYSTEM
Upper Triassic
Lower Jurassic
Middle Jurassic
Upper Jurassic
?Lower Cretac
2600
2500
2400
2300
2200
2100
2000
1900
1800