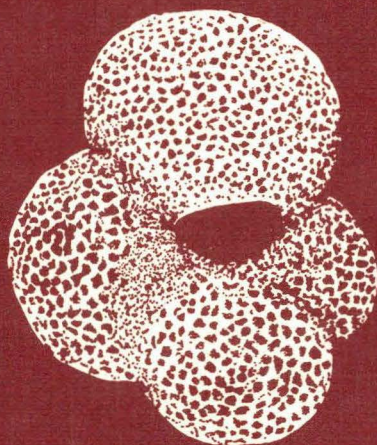


Danmarks Geologiske Undersøgelse
Geological Survey of Denmark . Yearbook 1974

Årbog 1974



I kommission hos C. A. Reitzels Forlag
København 1975

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D. G. U. Årbog 1974
er sat med Linotype Times
og trykt i 1200 eksemplarer
hos Andelsbogtrykkeriet i Odense.
Bogen er trykt på ekstraglittet 250, 120 g
og plancherne på Top-Cote 106, 120 g
fra a/s De forenede Papirfabriker.
Klicheerne er lavet af Tutein & Koch,
og fototavlerne af F. Hendriksens Eftf.
ISBN 87 421 0643 5

Redaktion: Leif Banke Rasmussen
Olaf Michelsen

Date of publication: 1975-09-18

Contents

Indhold

Madsen, Lars: Approximate geothermal gradients in Denmark and the Danish North Sea sector	5
Bertelsen, Finn: Triassic palynology and stratigraphy of some Danish North Sea boreholes	17
Larsen, Gunnar and Friis, Henrik: Triassic heavy-mineral associations in Denmark	33
Andersen, Svend Th.: The Eemian freshwater deposit at Egersund, South Jylland, and the Eemian landscape development in Denmark	49
Stockmarr, Jens: Biostratigraphic studies in Late-Weichselian sediments near Böllingsö	71
Aaby, Bent: Cykliske klimavariationer de sidste 7500 år påvist ved undersøgelser af højmoser og marine transgressionsfaser	91
Dinesen, Arne: The growth spiral in some planktonic foraminifera from the Eocene of Denmark	105
Publications issued 1974	139
Plates 1–15	141

Approximate geothermal gradients in Denmark and the Danish North Sea sector

Lars Madsen

Madsen, Lars: Approximate geothermal gradients in Denmark and the Danish North Sea sector. *Danm. geol. Unders., Årbog 1974*, pp. 5–16. København, 18. september 1975.

Approximate values of the geothermal gradient are calculated from temperature measurements in thirty onshore exploration wells and thirteen Danish North Sea exploration wells. A regional contour map is presented and discussed in relation to the major geological features in the area. Estimates of the thermal conductivity and the heat flow are given. Average values for the geothermal gradient, the thermal conductivity and the heat flow in the onshore area are determined to $23.2^{\circ}\text{C}/\text{km}$, $0.0058 \text{ cal cm}^{-1}\text{s}^{-1}^{\circ}\text{C}^{-1}$ and $1.34 \mu\text{cal cm}^{-2}\text{s}^{-1}$ respectively.

With the intention of investigating the regional variation of the geothermal gradient in Denmark and the Danish North Sea sector, approximate values of this gradient have been calculated for thirty of the deepest onshore exploration wells (drilled in the period 1950–1968) and thirteen Danish North Sea exploration wells (1966–1970). The area in which the well Dansk Nordsø B-1 (1967) is located has belonged to the German sector since the border treaty of 1971.

A few relatively deep wells in the central part of the North Jylland Salt-dome Province have been omitted. These wells were all terminated in the rocksalt of salt structures, and were excluded from the regional analysis by reason of the anomalous temperature fields which exist in and around salt-domes.

The temperature data were mainly obtained during runs of electrical logs by the firm Schlumberger for the Danish American Prospecting Company and since 1962 for Dansk Undergrunds Consortium.

The temperature data

Single temperature measurements in boreholes are usually made with mercury thermometers, which for absolute measurements have an accuracy in the order of 0.01°C . The temperature data from the wells in question are bottom hole and/or maximum temperatures, the latter also normally cor-

responding to the temperature close to the bottom of the borehole. Besides measurements at the final depth, data were often available of intermediate log runs from the most recent wells.

Temperatures measured at the bottom of boreholes a relatively short time after cessation of the drilling activities do not represent the temperature of the undisturbed formation. The circulating drilling mud will have a cooling effect, while the mechanical action of the drilling bit will have a tendency to increase the temperature. Geothermal gradients calculated from temperatures which have not been corrected for these factors are probably lower than the true gradients by 10–15 % (Evans and Coleman 1974).

Only for a minority of the wells under consideration is there information

Table 1. Onshore temperatures and temperature gradients.

Well	Depth below surface in metres	Temperature in °C	Geothermal gradient in °C/km	Formation
Aabenraa 1	2342	65.5	25.3	Pre-Zechstein
Arnum 1	1829	54.5	23.2	Pre-Zechstein
Børglum 1	1516	37.0	19.1	Rhaetic
Fjerritslev 1	907	30.0	24.3	Lower Jurassic
Fjerritslev 2	2059	55.0	22.8	Lower Jurassic
Flyvbjerg 1	1695	40.0	18.9	Keuper
Frederikshavn 2	1026	32.0	23.4	? Triassic
Frederikshavn 3	1003	32.0	23.9	? Triassic
Gassum 1	3036	115.5	35.4	Bunter
Glamsbjerg 1	905	28.0	22.1	Pre-Cambrian
Grindsted 1	1647	67.0	35.8	Pre-Cambrian
Haldager 1	1517	71.0	41.5	Lower Jurassic
Horsens 1	1726	44.0	20.9	Keuper
Hønning 1	1922	44.0	18.7	Bunter
Lavø 1	2438	51.0	17.6	? Keuper
Mors 1	5215	133.0	23.1	Triassic
Nøvling 1	3669	95.0	23.1	Silurian
Ringe 1	1435	40.5	22.7	Lower Permian or Eocambrian
Rødby 1	1530	41.0	21.6	Bunter
Rødby 2	2720	74.5	26.0	Rotliegendes
Rødekro 1	1645	39.0	18.9	Pre-Zechstein
Rønde 1	5237	138.0	23.2	Silurian
Slagelse 1	2972	87.0	26.6	Lower Cambrian or Eocambrian
Thisted 1	908	38.0	33.0	Triassic
Tønder 1	3085	71.0	21.1	Zechstein
Tønder 2	3194	93.0	24.1	Rotliegendes
Uglev 1	1240	54.0	35.3	Rock Salt
Ullerslev 1	1058	34.5	25.1	Triassic
Vedsted 1	2065	53.0	22.3	Rhaetic
Ørslev 1	2564	74.0	25.7	Lower Carboniferous

available about the elapsed time between cessation of circulation and temperature measurement. The given times lie in the interval 3–30 hours, with the majority below 10 hours. This distribution can also be assumed to be representative for the remaining wells.

For the wells where at each depth of measurement a registration has been made at more than one time after cessation of circulation, e.g. after 3 hrs. 5 hrs. 13 hrs. and 25 hrs., it has been possible to plot the temperatures versus time and draw a smooth curve through the points. The asymptotic value of this curve will give a better approximation to the true formation temperature (see e.g. Hedemann 1967). It has been possible to use this method for a few of the most recent onshore wells and for nearly all the North Sea wells. For the remaining wells, the measured temperatures have been used without any correction.

Another uncertainty factor for the determination of the undisturbed formation temperature is that palaeotemperatures may be expected in the underground, stemming from previous periods of glaciation. From models of the temperature variation at the surface it is possible to calculate the resulting decrease in the geothermal gradient. A maximum influence of about 10 % can be expected for a depth of 1000 m, and the influence can be neglected for depths exceeding 1500 m (Kappelmeyer and Haenel 1974, p. 95). As the decrease in the gradient depends on the local variation in surface temperature in the past, it is not possible to make a general correction. Of the wells under consideration, seven have depths of 900–1200 m, and the remaining ones are about 1500 m or deeper. For these reasons no attempt has been made to correct for palaeotemperatures.

Table 2. Offshore (in the North Sea area) temperatures and temperature gradients.

Well	Depth below sea bottom in metres	Temperature in °C	Geothermal gradient in °C/km	Formation
A-1	1740	52.5	27.3	Danien
A-2	1965	74.5	33.9	Upper Cretaceous
B-1	3497	113.5	31.6	Rotliegendes
C-1	3142	87.5	26.8	Pre-Zechstein
D-1	3477	75.5	22.4	Rotliegendes
E-1	4011	129.5	30.6	
E-2	2123	72.0	31.6	
F-1	2342	81.0	33.4	
G-1	3731	118.5	30.6	
H-1	2079	72.0	31.8	
I-1	3820	132.0	31.8	
J-1	1906	76.5	38.5	
K-1	2198	74.0	35.2	

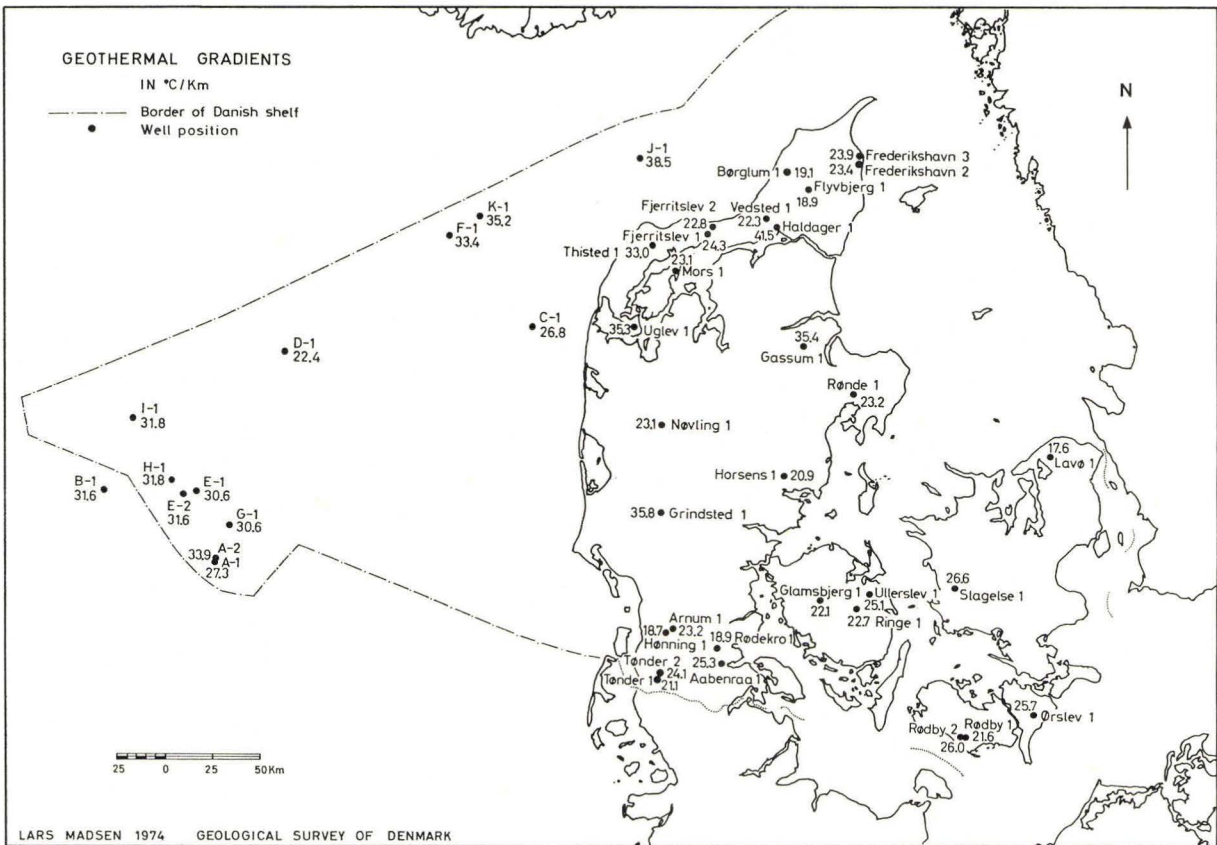


Fig. 1.

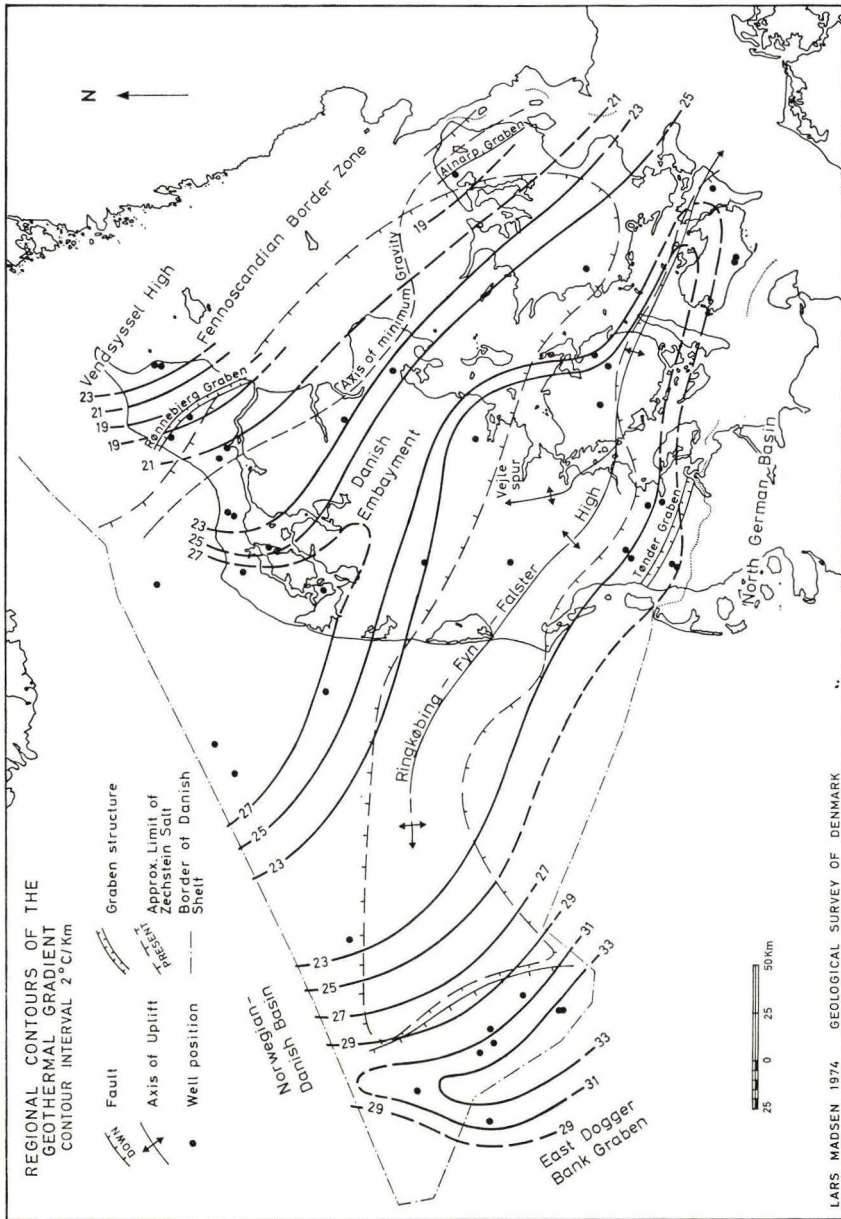


Fig. 2.

Calculation of the geothermal gradients

For the calculation of the onshore gradients a surface temperature of 8°C has been applied, representing the average mean annual temperature for the whole country. Offshore, the sea bottom temperatures have been determined from the temperature versus waterdepth curve given in Evans and Coleman 1974.

The depths have been corrected to ground level and sea bottom for onshore and offshore wells respectively. With the exception of Rønde No. 1 and Nøvling No. 1 (Henriksen in Rasmussen *et al.* 1971 and 1973) these depths have not been corrected for the deviation of the borehole from the vertical. This implies that the applied depths are somewhat too high, but as the deviation from the vertical is mostly of a relatively small order, it is estimated that the resulting uncertainty in the gradients is of a lower order than the error stemming from the temperatures. However, both factors tend to give too low gradients.

If only one temperature measurement is available from a well, the calculated gradient must be regarded as an average gradient between the surface (or sea bottom) and the depth of that measurement. If more than one temperature determination was available an average gradient was calculated by fitting a regression line to the values with the condition, that it should have an intercept with the temperature axis equal to the surface or sea bottom temperature at the well location.

Table 1 and 2 show the calculated geothermal gradient and the value of the deepest temperature determination for each well together with the depth and stratigraphical position of this determination (further information about the stratigraphy and lithology of the wells can be found in Sorgenfrei and Buch 1964, Rasmussen *et al.* 1971 and 1973, Rasmussen 1972 and 1974). A description of the stratigraphy and lithology of the eight most recent wells in table 2 is being worked out by the geologists at the Geological Survey and will be published by Rasmussen in Danm. geol. Unders., III. række, 44 (in preparation).

The calculated gradients together with the position of the wells are shown in fig. 1.

Discussion of the geothermal gradients

As the geothermal gradient is a function of depth, and the gradients have been determined from wells of different depths, they are not strictly comparable. However, if the relatively high values for the wells Gassum No. 1, Grindsted No. 1 and Haldager No. 1 are considered to be caused by local

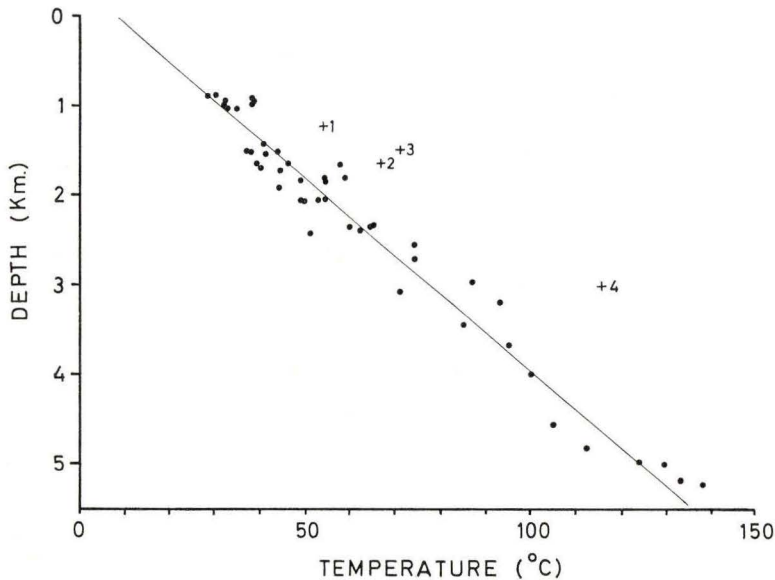


Fig. 3. A plot of temperature versus depth for the thirty onshore wells. The regression line has a slope of 23.2°C/km and an intercept of 8.2°C . Data from the Uglev 1 (+1), Grindsted 1 (+2), Haldager 1 (+3) and Gassum 1 well (+4) have been excluded from the analysis.

features, and if for the onshore area the main weight is put on the wells which have been drilled to depths below the Zechstein salt, or which have been drilled where the salt is thin or absent, it is possible to see a regional distribution of the values for the geothermal gradient. A tentative contouring is shown in fig. 2 together with the main structural elements in the area (mainly from Sorgenfrei 1966 and 1969). The general trend of the contours is northwest-southeast.

Low geothermal gradients often correspond to positive structural elements, while high values are found in deep sedimentary basins. It can be seen that an elongate minimum zone is situated on the Ringkøbing-Fyn-Falster High, while the Danish Embayment and the East Dogger Bank Graben represent areas of maximum values.

Considering the onshore area the gradient decreases regionally from about 25°C/km to lesser than 20°C/km in the direction southsouthwest-northeast towards the Fennoscandian Shield. The maximum indicated by the wells Frederikshavn No. 2 and 3 may be relatively local.

Fig. 3 shows a plot of temperature versus depth from all wells in table 1. Data from intermediate log runs have also been included. A standard program has been used to fit a regression line to the points (Gassum No. 1,

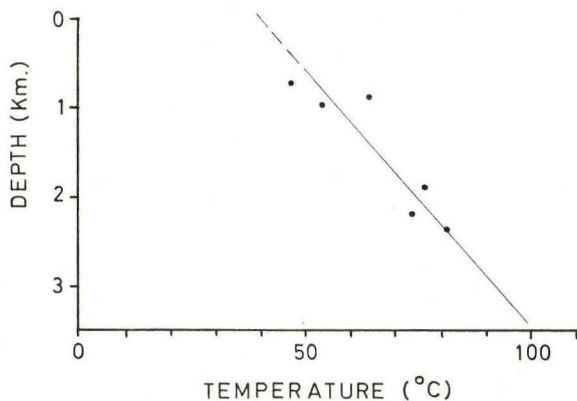


Fig. 4. A plot of temperature versus depth for the wells Dansk Nordsø F-1, J-1 and K-1. The regression line has a slope of $17.5^{\circ}\text{C}/\text{km}$ and an intercept of 39.5°C .

Grindsted No. 1, Haldager No. 1 and Uglev No. 1 have been excluded as representing local anomalies). The line has an intercept with the temperature axis of $8.2^{\circ}\text{C} \pm 1.9^{\circ}\text{C}$ and a slope of $23.2^{\circ}\text{C}/\text{km} \pm 0.7^{\circ}\text{C}/\text{km}$, which can be regarded as a minimum average value for the geothermal gradient in Denmark.

The maximum zone of the Danish Embayment continues with increasing values towards the northwest in the North Sea area. The temperatures for

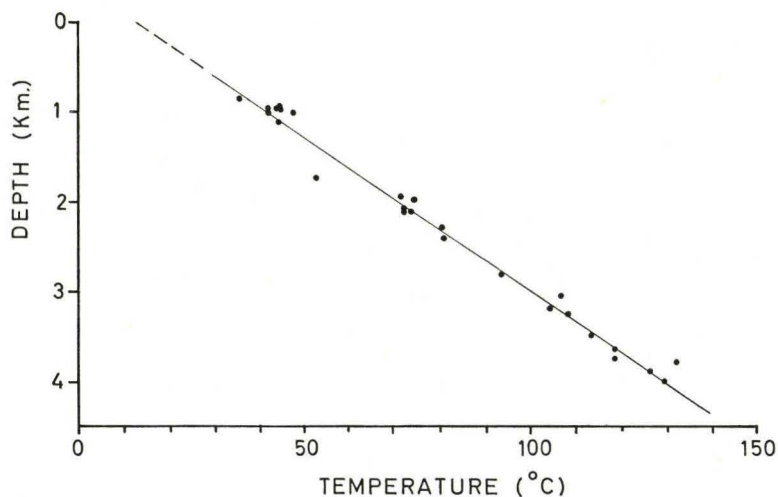


Fig. 5. A plot of temperature versus depth for the eight wells in the East Dogger Bank Graben (Dansk Nordsø A-1, A-2, B-1, E-1, E-2, G-1, H-1 and I-1). The regression line has a slope of $29.2^{\circ}\text{C}/\text{km}$ and an intercept of 12.9°C .

the three wells Dansk Nordsø F-1, Dansk Nordsø J-1, and Dansk Nordsø K-1 are plotted versus depth in fig. 4. A regression line fitted to the points has an intercept of $39.5^{\circ}\text{C} \pm 6.2^{\circ}\text{C}$ and a slope of $17.5^{\circ}\text{C}/\text{km} \pm 3.8^{\circ}\text{C}/\text{km}$; if the line is determined with the condition that the intercept with the temperature axis must be 7.2°C (average sea bottom temperature at the three wells) it will have a slope of $35.5^{\circ}\text{C}/\text{km}$. It is obvious that the straight line is not an appropriate model for these data. There must be a high gradient in the upper layers relative to the deeper ones. Concerning the geology of the area it is known that several salt domes and salt walls are present and that the wells Dansk Nordsø F-1 and K-1 are situated on or near such structures. The well Dansk Nordsø J-1 is located in the area where the Triassic to Lower Cretaceous sequence reaches its maximum value in the Danish North Sea area with values exceeding 6 km (Childs and Reed 1975, fig. 4).

The minimum of the Ringkøbing-Fyn-Falster High continues in a north-west direction along the High. From here the geothermal gradient increases towards the southwest and reaches a maximum of about $33^{\circ}\text{C}/\text{km}$ in the East Dogger Bank Graben. The order of the contour values for this area is in good accordance with earlier published data for other sectors in the North Sea (Harper 1971 and Evans and Coleman 1974).

In fig. 5 is shown a plot of temperature versus depth for the eight wells in the East Dogger Bank Graben. The line fitted to the points has an intercept of $12.9^{\circ}\text{C} \pm 1.7^{\circ}\text{C}$ and a slope of $29.2^{\circ}\text{C}/\text{km} \pm 0.7^{\circ}\text{C}/\text{km}$. If the condition is made that the intercept must be 7.3°C (average of the sea bottom temperatures) then the slope will be $31.2^{\circ}\text{C}/\text{km}$. This implies that the gradient is higher in the uppermost layers than indicated by the line model.

The East Dogger Bank Graben as a part of the Central Graben is an area characterized by a very thick sequence of Tertiary sediments (low thermal conductivity) and by salt piercement structures. These are probably the main reasons for the high gradient values in this area.

The as yet sole Danish productive oil field, the Dan field is located in the area of maximum gradient values. In this connection it is interesting to note the theories of Klemme 1972 (see Evans and Coleman 1974) that high geothermal gradients enhance petroleum mobility and therefore also enhance migration to structural traps.

Estimation of the heat flow

No Danish determination exists of thermal conductivities for the sediments in the area under consideration. Therefore an estimate of thermal conductivities for the North Sea sediments (Evans and Coleman 1974) has been

applied. For each of the onshore and offshore wells the average thermal conductivity and the heat flow have been estimated.

The estimated values of the thermal conductivities for the onshore wells (Gassum, Grindsted, Haldager and Uglev have been omitted) have an average of $0.0058 \text{ cal cm}^{-1}\text{s}^{-1}\text{°C}^{-1}$ and a standard deviation of $0.0007 \text{ cal cm}^{-1}\text{s}^{-1}\text{°C}^{-1}$.

The average of the values for the wells in the East Dogger Bank Graben is $0.0046 \text{ cal cm}^{-1}\text{s}^{-1}\text{°C}^{-1}$ with a standard deviation of $0.0005 \text{ cal cm}^{-1}\text{s}^{-1}\text{°C}^{-1}$.

The corresponding values for the heat flow are $1.34 \mu\text{cal cm}^{-2}\text{s}^{-1} \pm 0.27 \mu\text{cal cm}^{-2}\text{s}^{-1}$ for the onshore wells and $1.43 \mu\text{cal cm}^{-2}\text{s}^{-1} \pm 0.16 \mu\text{cal cm}^{-2}\text{s}^{-1}$ for the wells in the East Dogger Bank Graben.

It is seen that there is a significant difference between the thermal conductivity for the onshore and the East Dogger Bank Graben area. The relatively low value for the latter is explained by the fact that the Tertiary and Cretaceous sediments, which have a low conductivity, constitute the main part of the stratigraphy in the wells located in this area.

The average values for the heat flow in the two areas indicate a decrease towards the onshore area, but it must be noted that the standard deviations are relatively large and that the temperatures from the offshore wells are to some degree corrected to higher values closer to the true formation temperatures while this is only done for a couple of onshore measurements.

Values of $0.90\text{--}1.00 \mu\text{cal cm}^{-2}\text{s}^{-1}$ are common for the heat flow in Precambrian areas; therefore a decrease towards the Fennoscandian Shield could be expected.

A trend analysis of 7th order has been made by Haenel 1974 based on heat flow data from a large part of Europe (however none from the area of Denmark and the North Sea). On his map the contours representing heat flow values of 1.2 and $1.4 \mu\text{cal cm}^{-2}\text{s}^{-1}$ cross Denmark and the North Sea, thereby showing an agreement with the figures estimated above.

Conclusions

Despite the uncertainty factors in the data and the calculations it seems justified to conclude that the order of the values for the geothermal gradient and the heat flow in the Danish area is as could be expected regarding its location relative to the Fennoscandian Shield and the North Sea area.

Dansk sammendrag

For 30 af de dybeste efterforskningsboringer indenfor dansk landområde (perioden 1950–68) samt 13 danske Nordsøboringer (1966–70) er der på grundlag af temperaturer, målt i borehullet, beregnet tilnærmede værdier af den geotermiske gradient. Tabel 1 og 2 giver for hver boring den beregnede gradient og den dybeste temperaturbestemmelse, samt dybden og det stratigrafiske niveau for sidstnævnte. På fig. 1 er vist placeringen af boringerne sammen med værdien af den geotermiske gradient.

Et regionalt konturkort over den geotermiske gradient (fig. 2) viser, at en minimumszone er beliggende over Ringkøbing-Fyn-Falster Højderyggen, mens Det danske Sænkingsområde og Øst Dogger Banke Graven udgør områder med relative maksima. Indenfor det danske landområde aftager gradienten regionalt fra omkring 25 °C/km mod sydsydvest til mindre end 20 °C/km mod nordøst i retning mod Det fennoskandiske Skjold. Et plot af temperaturerne mod dybderne for landboringerne er vist på fig. 3. En ret linie tilpasset punkterne efter mindste kvadraters metode har en hældning på 23,2 °C/km, hvilket kan opfattes som en mindste middelværdi for den geotermiske gradient i Danmark. I det veldefinerede maksimum over Øst Dogger Banke Graven antager gradienten værdier på mere end 33 °C/km.

Ud fra publicerede data for varmeledningsevnen for Nordsøsedimenter er der bestemt en middelværdi for varmeledningsevnen på 0,0058 cal cm⁻¹s⁻¹°C⁻¹ og 0,0046 cal cm⁻¹s⁻¹°C⁻¹ for henholdsvis det danske landområde og Øst Dogger Banke Graven. Den relativt lave værdi i Øst Dogger Banke Graven skyldes, at hovedparten af de gennemborede lag udgøres af tertiære og kretaciske sedimenter, der har en forholdsvis lav varmeledningsevne. Der er endvidere bestemt en middelværdi for varmestrømningen på 1,34 µcal cm⁻²s⁻¹ og 1,43 µcal cm⁻²s⁻¹ for henholdsvis landområdet og Øst Dogger Banke Graven. Dette indikerer med forbehold for usikkerhed ved bestemmelserne, at varmestrømningen aftager i retning mod det danske landområde. Da værdier i størrelsesordenen 0,90–1,00 µcal cm⁻²s⁻¹ er almindelige for prækambriske områder, kunne det forventes, at værdierne for den geotermiske gradient og varmestrømningen aftog i retning mod Det fennoskandiske Skjold.

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Triassic palynology and stratigraphy of some Danish North Sea boreholes

Finn Bertelsen

Bertelsen, Finn: Triassic palynology and stratigraphy of some Danish North Sea boreholes. *Danm. geol. Unders., Årbog 1974*, pp. 17–32, pl. 1. København, 18. september 1975.

Palynofloras ranging in age from Anisian to Rhaetian are described from the Danish North Sea sector. Anisian-Ladinian (Muschelkalk) assemblages were recovered from the basal part of the Dansk Nordsø A-2 borehole situated in the Central Graben. Rhaetian assemblages occur in the Dansk Nordsø F-1 and the Dansk Nordsø K-1 boreholes drilled in the northwestern part of the Danish Embayment. The Triassic red beds are generally non-palyniferous with rare productive horizons.

Triassic palynological information from the North Sea offshore area has hitherto been limited to some profiles lying on an E-W directed line through the southern part of the North Sea Basin (Geiger & Hopping 1968). The present study intends to extend the published knowledge of the offshore Triassic deposits by giving the results of palynological investigations carried out within the Danish sector. Due to the rapidly developed palynological research on the British onshore Triassic (Warrington 1974) the stratigraphical "breakdown" of the offshore mainly non-marine deposits has to some degree been successful. However, the occurrence of vertically limited palyniferous sequences, which cause serious trouble in British onshore Triassic correlations seems to be repeated as a norm of the offshore area too.

The Danish offshore area comprises parts of four structurally determined deposition centre during the Triassic (Text-fig. 1): 1) To the north the northwesterly extension of the Danish Embayment, 2) to the west, part of the Central Graben, 3) to the south, a northern part of the North German Basin and 4) the Horn Graben connecting the Danish Embayment with the North German Basin (Childs & Reed 1975).

The Triassic deposits generally show a change from continental arenaceous red beds in the Early Triassic to a more pelitic red bed facies in the Middle-Late Triassic. During the Middle-Late Triassic, evaporitic carbonates, anhydrite and rock salt were also deposited. The climatic change

from arid to humid conditions at the beginning of Rhaetian time, which led to formation of extensive greyish arenaceous and pelitic deposits in northwestern Europe, is also traced in the offshore area (Larsen 1966, Childs & Reed 1975 a.o.).

The present investigation deals with the Triassic sequence of the Dansk Nordsø A-2 borehole situated in the Central Graben (Text-fig. 1), and the Dansk Nordsø F-1 and the Dansk Nordsø K-1 boreholes drilled in the western extension of the Danish Embayment (Text-fig. 1). The materials investigated are almost exclusively in the form of ditch sample cuttings. The profiles have therefore been analyzed and described in descending order to exclude contaminants from the results as far as possible.

Depths are given in feet below Kelly Bushing or in metres below the Mean Sea Level. If the depths have been corrected by means of Schlumberger logs these statements are printed in italics.

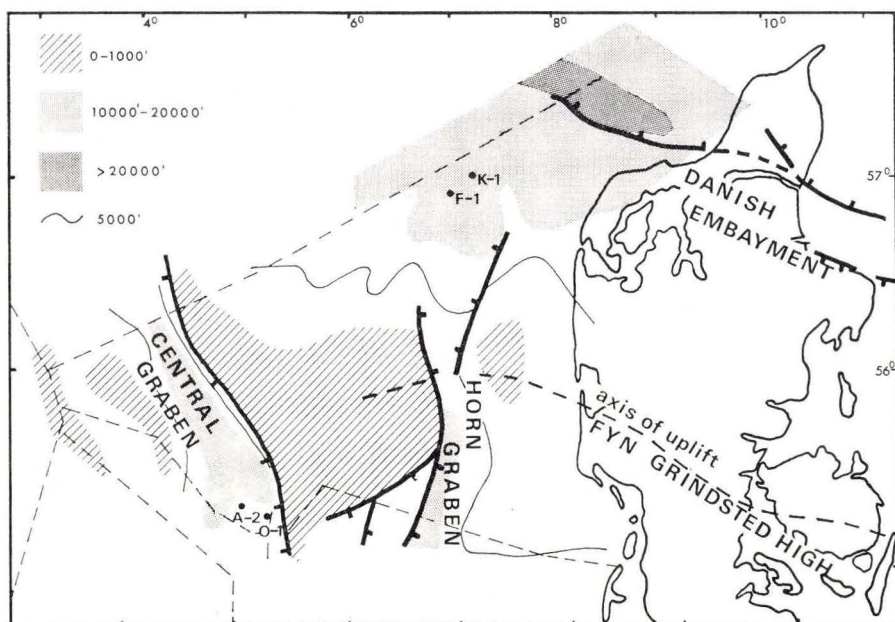
Dansk Nordsø A-2: 10050' – 11143' (3027 m – 3360 m)

Geology

The geology of the Triassic section is in a shortened version given in Rasmussen (1974). The section is composed predominantly of redbrown continental claystones with anhydrite. Near the base of the section (base of borehole) a rock salt bed occurs. The Triassic sequence is abruptly overlain by Middle Jurassic sandstones and shales.

Miospores are found to occur in the lower part of the sequence only and a more detailed lithological description of this palyniferous section is given below. The description is made by Michelsen (1967) and is based on a semiquantitative analysis of cuttings. Unfortunately, no electrical logs have been measured in this section.

- 10750'–10792' Claystone, sticky, brown, slightly calcareous (see 10480'–10580') dominates in 10750'–10770'. Anhydrite dominates in 10770'–10792'. Presumably there is an even transition. Claystone, light greenish grey, occurs subordinate with 20 %–30 %, increasing downwards.
- 10792'–11070' Rock salt, clear, white, dominates with minor inclusions of anhydrite.
- 10792'–10830' and 10850'–10870': Anhydrite slightly



Text-fig. 1. Map showing Triassic-Lower Cretaceous offshore isopachs, main structural features and location of the discussed boreholes (after Childs & Reed 1975 a.o.).

increasing. Random occurrence of light greenish grey claystone.

10940'–11070': Redbrown claystone increases downwards; random occurrence of anhydrite and light greenish grey claystone.

11070'–11110' Claystone, redbrown, dominates with 40 %–50 %. Claystone, light greenish grey, increases to 25 %–30 %. Anhydrite somewhat increasing in proportion to the above section; rock salt decreases to ca 10 %. There is no distinct lithological boundary at 11070'.

Materials and methods

To reduce the content of Jurassic contaminants in the slides the following technique was found to give good results. Initially conc. HCl was added to the sample consisting of washed cuttings 0.1 mm–1 mm in size. The slightly calcareous palyniferous Triassic cuttings broke down immediately, whereas the rather hard Jurassic cuttings reacted more slowly. By decanting the suspension after some minutes the majority of the caved material was

retained in the beaker. The suspension was processed by standard methods without using oxidizing agents.

The following ditch samples (10' intervals) were investigated without HCl separation -10020', -10080', -10160', -10280', -10400', -10520', -10640', -10760', -10880' and -11080'. Having proved the presence of miospores in the latter sample only, the following samples were processed with use of the primary HCl separation: -10770', -10780', -10790', -11070', -11090', -11100' and -11110'. A test preparation of isolated cuttings of a redbrown claystone from sample -10760' proved to be barren.

Results

Two distinct miospore assemblages have been recovered. The youngest one occurs in the sample interval 10760'–10790' just above the rock salt bed. Single specimens from this assemblage are found in the sample interval 11070'–11090' as contaminants. The oldest assemblage was recovered from the two deepest available samples of the borehole, sample interval 11090'–11110'.

The younger assemblage: 10760'–10790' (3244 m–3253 m)

The following taxa were recovered:

Sample -10770'	Microspores	4
	<i>Apiculatasporites plicatus</i> Visscher, 1966 (3)	
	<i>Porcellispora longdonensis</i> (Clarke)	
	Scheuring 1970 (1)	
	Bisaccate pollen grains	4
	<i>Lunatisporites</i> sp. (1)	
	Varia	3
	Total	11
Sample -10780'	Microspores	39
	<i>Apiculatasporites plicatus</i> Visscher, 1966 (14)	
	<i>Porcellispora longdonensis</i> (Clarke) Scheuring, 1970 (11)	
	<i>Aratrisporites saturni</i> (Thiergart) Maedler, 1964 (5)	
	Bisaccate pollen grains	40
	<i>Illinites chitonoides</i> Klaus, 1964 (1)	
	<i>Triadispora</i> spp. (8)	

<i>Caytonipollenites pallidus</i> (Reissinger)	
Couper, 1958 (3)	
<i>Sulcatissporites kraeuseli</i> Maedler, 1964 (1)	
<i>Umbrososaccus keuperianus</i> Maedler, 1964 (3)	
<i>Protodiploxypinus</i> spp. (1)	
Varia	3
<hr/>	
Total....	82
Sample -10790' Microspores	6
<i>Porcellispora longdonensis</i> (Clarke) Scheuring,	
1970 (2)	
Bisaccate pollen grains	28
<i>Illinites chitonoides</i> Klaus, 1964 (3 or 4)	
<i>Striatobietites aytugii</i> Visscher, 1966 (1)	
<i>Triadispora</i> spp. (3)	
<i>Alisporites</i> spp. (2)	
<i>Umbrososaccus keuperianus</i> Maedler, 1964 (1)	
<hr/>	
Total....	34

The assemblage shows an interesting co-existence of typical Neotriassic taxa such as *P. longdonensis* and *A. saturni* (cf. Mädlar 1964, Geiger & Hopping 1968 and Scheuring 1970) and a Palaeo-Mesotriassic form, *Apiculatasporites plicatus* (Visscher 1966, Visscher & Commissaris 1968, Warrington 1974). Important also is the absence of *Ovalipollis ovalis* Krutzsch, 1955, which is a very frequently recorded and common species in the Middle and Upper Keuper deposits of Northwest Europe. This species has also been recovered from another borehole in the Central Graben, the Dansk Nordsø 0-1 borehole (Text-fig. 1) where together with *P. longdonensis* it forms a typical Carnian "Gipskeuper" assemblage, both taxa being abundant. *O. ovalis* is therefore present regionally and would be expected to occur in the samples in question if the assemblage is younger than Late Anisian/Ladinian, which seems to be the most reasonable stratigraphical designation on the basis of the above given information. The bisaccate pollen grains, of which only a minor portion has been identified, have so far not been found to be stratigraphically indicative.

The older assemblage: 11090'–11110' (3344 m–3350 m)

The following taxa were recovered:

Sample -11100'	Microspores	28
	<i>Apiculatasporites plicatus</i> Visscher, 1966 (7)	
	Bisaccate pollen grains	77
	<i>Illinites chitonoides</i> Klaus, 1964 (1)	
	<i>I. kosankei</i> Klaus, 1964 (2)	
	<i>Striatobietites aytugii</i> Visscher, 1966 (1)	
	<i>S. balmei</i> Klaus, 1964 (1)	
	<i>Lunatisporites</i> spp. (9)	
	<i>Triadispora</i> spp. (10)	
	<i>Alisporites</i> spp. (5)	
	<i>Protodiploxypinus potonie</i> (Maedler) Scheuring, 1970 (1)	
	<i>P. sittleri</i> (Klaus) Scheuring, 1970 (3)	
	<i>Granosaccus</i> cf. <i>sulcatus</i> Maedler 1964 (9)	
	Total. . . .	118
Sample -11110'	Microspores	10
	<i>Cyclotriletes granulatus</i> Maedler, 1964 (2)	
	<i>Apiculatasporites plicatus</i> Visscher, 1966 (7)	
	cf. <i>Aequitriradites minor</i> Maedler, 1964	
	Bisaccate pollen grains	17
	<i>Illinites kosankei</i> Klaus, 1964 (1)	
	<i>Angustisulcites klausii</i> Freudenthal, 1964 (1)	
	<i>Striatobietites balmei</i> Klaus, 1964 (1)	
	<i>Triadispora</i> spp. (2)	
	<i>Protodiploxypinus fastidioides</i> (Jansonius) Warrington, 1974 (1)	
	<i>P. sittleri</i> (Klaus) Scheuring, 1970 (1)	
	<i>Granosaccus</i> cf. <i>sulcatus</i> Maedler, 1964 (1)	
	Total. . . .	27

The older assemblage is seen to be composed of 65 %–75 % bisaccate pollen taxa. Stratigraphically important is the occurrence of such taxa as *Striatobietites balmei* and *Protodiploxypinus sittleri*, which according to Geiger & Hopping (1968) are reported from deposits referred to Upper Buntsandstein and Lower-Middle Muschelkalk. Thus, referring to *S. balmei*, they state (p. 30): "Its 'top occurrence' has been taken in operational petroleum geology as marking the top of the Middle Muschelkalk".

Among the various palynofloras described from Upper Buntsandstein and Muschelkalk successions within the North Sea Basin, special attention

is paid to the assemblages of the West Lancashire Kirkham Mudstones recently described by Warrington (1974). It is seen, that all of the above listed species, with the exception of *Cyclotriletes granulatus*, are recorded within the range zone of *Aequitriradites minor*. Most of these taxa are long-ranging, but noteworthy however is the range of the morphologically distinctive species *Granosaccus* cf. *sulcatus*. This species appears within the range zone of *A. minor* and persists above the upper range limit of the latter, and it has been proven identical with the Danish specimens (Pl. 1) attributed to this taxon (Warrington in correspondance). Warrington does not discuss the correlation of the section to the European standard zonation. However, the range of *A. minor* still seems at present to be known to be restricted to Muschelkalk equivalents (Taugourdeau-Lantz 1974) and the assemblage recovered in the Dansk Nordsø A-2 borehole is therefore most probably not older than these Muschelkalk assemblages. As the major lower and middle parts of the Northwesteuropean Muschelkalk sediments are traditionally referred to the Anisian stage, the older assemblage is tentatively referred to the Anisian.

Concluding remarks on the studied interval of the Dansk Nordsø A-2 borehole

It seems reasonable on the basis of the palynological results obtained to compare the salt bed member and the surrounding miosporebearing beds with the halitic Muschelkalk sequences published from the southern North Sea area by Geiger & Hopping (1968).

There is a good correlation, both lithologically and palynologically, with the sequences referred to the Middle Muschelkalk in the Leman Field and "North Holland" (composite profile).

The prevailing red bed facies in the three profiles indicate corresponding marginal environments in the three areas during the Mesotriassic. The facial development of the Dansk Nordsø A-2 sequence is therefore in accordance with the idea of a restricted Muschelkalk transgression from S-SE into the North German Basin as expressed by Sorgenfrei (1969) a.o. The profiles from the southern part of Jutland (Sorgenfrei & Buch 1964) show that the sequences here referred to the Muschelkalk are developed as grey claystones, marls and limestones without rock salt, i.e. in a more "Muschelkalk-like" facies, and that they are not comparable lithologically with the Dansk Nordsø A-2 profile.

The grey shales and sands etc. which abruptly overlay the studied red beds are of Middle Jurassic age, and Rhaetic elements have at least not been traced. There seems, therefore, to be an important hiatus between the

studied section, of which the uppermost barren part for lithological reasons is compared with the German Lower or Middle Keuper, and the Jurassic series. However, this hiatus is most certainly to be regarded as a local erosion phenomenon, which may be explained by local halokinetic movements in the structure. In this connection it may be added that the presence of Rhaetic and Liassic shales has been demonstrated in other boreholes in the Danish part of the Central Graben.

Dansk Nordsø F-1: 6820' – 7945' (2042 m – 2384 m)

Geology

The pre-Jurassic sequence of the Dansk Nordsø F-1 borehole was originally referred to the Upper Triassic in internal reports by Stenestad (1969) and Michelsen (1969). This assumption was based on lithostratigraphical reflections alone, as marine Rhaetic deposits were not proved in this borehole (Christensen 1969), contrary to expectations. The "Triassic" sequence is overlain by marine Lower Jurassic shales with L. Sinemurian ostracod faunas (Michelsen 1975).

The sequence, which is briefly described lithologically in Rasmussen (Danm. geol. Unders., III. række, 44. – In preparation) is built up mainly of alternating argillaceous and arenaceous red beds. Only the uppermost 250' show a different ('Rhaetic') lithological character. As part of the latter beds proved palyniferous, a full lithological description of these beds (Stenestad 1969) is cited below.

- | | |
|-----------------|---|
| 6820' – 6845' | Sandstone, fine-grained, light grey, with glauconite, pyrite |
| 2042 m – 2049 m | and calcitic matrix. Beds of limestone, fine-grained, light grey, with glauconite and mica, probably occur. |
| 6845' – 6940' | Shale, blackgrey, micro-micaceous, non-calcareous. Silt- |
| 2049 m – 2078 m | stone, grey, micro-micaceous, non-calcareous. Siltstone, purple, rich in mica, slightly calcareous to non-calcareous. |
| 6940' – 7070' | Sandstone, coarse-grained, light grey, quartzitic, with |
| 2078 m – 2118 m | subordinate beds of claystone and siltstone, greybrown, with lignite and mica, slightly calcareous. |

Materials and methods

Cuttings (0.1–1 mm) of the following ditch samples were processed by standard methods:

6800'–6820', 6820'–6840', 6880'–6900', 6940'–6955', 6980'–7000', 7040'–7060', 7090'–7110', 7130'–7160', 7260'–7275', 7310'–7340', 7360'–7380', 7420'–7440', 7480'–7490', 7540'–7550', 7600'–7610', 7630'–7640', 7680'–7690', 7720'–7750', and 7790'–7810'. In addition, two side wall cores were available for preparation: 7855' and 7905'.

Results

Two assemblages have been recovered. The youngest one occurs in the sandstone bed 6940'–7070', and the oldest one is recovered from the ditch sample 7680'–7690'. All samples are highly contaminated by Jurassic caved material.

The younger assemblage: 6940'–7070' (2078 m–2118 m)

It is not possible to prove the Triassic by means of palynomorphs in the three uppermost samples, –6820', –6840' and –6900'. The uppermost record of Triassic miospores is in sample –6955', i.e. within the uppermost part of the lower of the above described sandstone beds (6940'–7070'). The assemblage is characterized by abundant *Ricciisporites tuberculatus* Lundblad, 1954, and accessory rare taxa such as *Densosporites foveocingulatus* Schulz, 1967, *Aratrisporites* spp. and *Rhaetipollis germanicus* Schulz, 1967.

Elements of this assemblage are traced in all of the subsequent samples. It is, however, a general experience that the Triassic (and other) red beds in the North Sea Basin are commonly non-palyniferous and the occurrence of the assemblage below the lower grey sandstone is therefore considered secondary. The available side wall cores were in fact barren too.

In Britain, equivalent assemblages characterized, among other things, by an acme of *Ricciisporites tuberculatus* are reported from the Westbury Beds of the Rhaetic Formation. They constitute the upper part of the *Rhaetipollis* Zone of Orbell (1973). In the underlying Grey Marls member the *Rhaetipollis* Zone assemblages show acmes of genera of the Circumpolles group: *Corollina*, *Classopollis* and *Granuloperculatipollis*.

Identical vertical changes in composition of the palynofloras, from dominance of Circumpolles taxa (especially *Granuloperculatipollis rudis* Venkatachala & Góczán, 1964) to dominance of *R. tuberculatus* have recently been found by the present author in boreholes in the central part of the Danish Embayment in East Jutland. The boundary of the floral change approximates the Lower/Middle Rhaetic boundary (*sensu germanica*) in these sections, partly dated by means of ostracods. Due to the parallelism

thus demonstrated in the uppermost Triassic microfloral development in the British Midlands and in the northern part of Jutland it seems reasonable to refer the recovered assemblage to the upper part of the *Rhaetipollis* Zone as found in the Westbury Beds.

In recent investigations, Morbey & Neves (1974) attempt a correlation of the British Rhaetic Formation with a proposed stratotype section for the Rhaetian stage in the Kendelbachgraben of Austria by means of palynostratigraphy. Their correlation implies that the Westbury Beds (Member) assemblages of the Bunny Hill borehole are of Late Rhaetian to Early Hettangian age. A survey by the present author of the distribution of the zonal index species of Morbey & Neves in the range diagrams of Orbell makes it clear that most of these species are rare and rather randomly distributed within the Westbury Beds. They are therefore not readily suitable for correlative purposes. Important however, is the information in Morbey & Neves (1974, p. 170) that *Heliosporites reissingeri* (Harris) Chaloner, 1969 is abundant at the base of the FG Subzone, which in the section of Kendelbachgraben embraces the boundary between the Rhaetian stage *sensu lato* (Morbey & Neves) and the Hettangian stage. A study of the diagrams of Orbell shows that *H. reissingeri* is rare in the Westbury Beds, but abundant in the overlying White Lias. This may indicate that the Westbury palynofloras as a rule are of Late Rhaetian age, if a rather diachroneous nature of this member is accepted.

The age of the recovered microflora is therefore indirectly correlated to the Upper Rhaetian.

The older assemblage: 7680'–7690'

Sample 7680'–7690' which coincides with an extreme maximum peak of the gamma ray curve (Text-fig. 2) is unexpectedly rich in plant materials (and ? mica), and seems to contain a primary palynoflora. *Ovalipollis* spp. dominate, but rare *Triadispora* spp. are also observed. *Ovalipollis* is a typical and common genus in Neotriassic deposits but range up into the Jurassic, whereas *Triadispora* spp. as far as is known are restricted to the Triassic, preferably to the pre-Rhaetic. The assemblage is presumed to be of Carnian or Norian age on the basis of the known distribution pattern of the two genera (Geiger & Hopping 1968, Scheuring 1970). However, a Ladinian age cannot be excluded, which could imply that an equivalent to the German Lettenkohlensandstein may occur in this borehole.

No stratigraphically indicative or believed primary specimens were observed below 7690'.

Dansk Nordsø K-1: 6514' – 7525' (1948 m – 2256 m)

Geology

The sequence of the Dansk Nordsø K-1 borehole compares well with that of the Dansk Nordsø F-1 borehole discussed above. As in the latter borehole, the upper beds are developed in a "Rhaetic" facies distinctly different in colour from the subsequent red beds. The Dansk Nordsø K-1 profile differs however from the Dansk Nordsø F-1 profile by the presence of ca. 40' of marly, greybrown limestones on top of the red bed section. Miospores regarded as originating from the sequence have only been recovered from the upper grey coloured beds and the lithological description given below (Bertelsen *et al.* 1970) is therefore restricted to comprise these beds only. A shortened lithological description of the total profile of the borehole is given in Rasmussen (Danm. geol. Unders., III. række, 44. – In preparation). The sequence studied is overlain by grey shales with Hettangian ostracod faunas (Michelsen 1975).

6514' – 6738' Sandstone, with gravel, unconsolidated, uncoloured to
1948 m – 2017 m slightly yellowish or greyish, consisting of subangular
quartz grains and some feldspar grains. Two further types
of sandstone occur in the interval: 1) sst., fine grained,
silty, white to greywhite with matrix of illite-like mineral
and 2) sst., middle-grained, greyish, well consolidated.
At ca. 6660' occur one or more coalbeds, blackbrown,
slightly glistening.

6738' – 6822' Claystone, silty, slightly calcareous to non-calcareous,
2017 m – 2042 m dark grey, slightly darker than above, with minor beds of
sandstone, greyish-brown and coal, blackbrown, slightly
glistening.

Materials and methods

The following ditch samples (taken out at 30' intervals) were processed by standard methods: –6530', –6560', –6590', –6620', –6650', –6680', –6770', –6830' and –7120'. Due to the meagre results obtained in the Dansk Nordsø F-1 red beds, only two samples from these beds were processed.

Results

The samples –6530', –6560', –6620', and –6650' yielded limited numbers of Jurassic palynomorphs and the upper part of the sandstone interval

6514'–6738' is most probably non-palyniferous, the Jurassic miospores being considered to be contaminants.

In the samples –6680', –6770', –6830' and –7120' was recovered an assemblage identical with the younger assemblage of the Dansk Nordsø F–1 borehole. In addition to the dominant *Ricciisporites tuberculatus*, *Limbo-sporites lundbladii* Nilsson, 1958 and *Rhaetipollis germanicus* were found. Especially the uppermost sample is rich in lignite and the top occurrence of the microflora is believed to coincide with the top of the coal beds at ca 6660'.

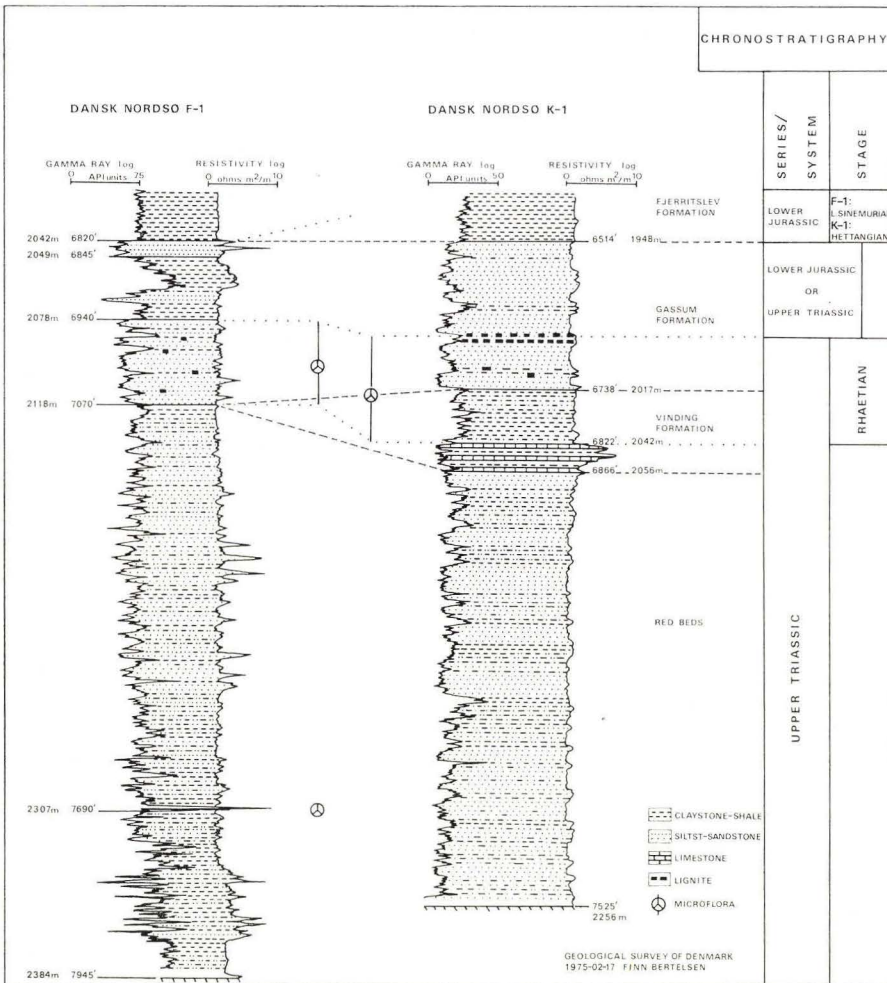
The samples –6770' and –6830' contain several specimens of the dinoflagellate cyst *Rhaetogonyaulax rhaetica* (Sarjeant) Loeblich & Loeblich, 1968. The presence of this species thus indicates a marine influence during this part of the sequence. In Britain *R. rhaetica* is reported from the Grey Marls, the Westbury Beds and the Cotham Beds (Orbell 1973, Warrington 1974), and was originally described from the Cotham Beds (Sarjeant 1963). According to Morbey & Neves (1974), *R. rhaetica* seems to be restricted to the Rhaetian stage *sensu lato* (Morbey & Neves), at least with respect to the extension of its lower range.

The microflora occurring in the sample –7120' is considered to be due to contamination. Isolated cuttings of the dominant rock type of the sample, a light greyish claystone, were found to be non-productive. Regarding the recovery of the sample –6830' it has not yet been clarified whether this (limestone-bearing) part of the sequence is palyniferous.

Concluding remarks on the studied sections in the Dansk Nordsø F–1 and the Dansk Nordsø K–1 boreholes

The present investigation has proved a Triassic age for at least the upper parts of the studied sections. It has also demonstrated that uniform Rhaetian palynofloras occur in the two borings, and that these palynofloras compare closely with the assemblages from the British Westbury Beds. In the central part of the Danish Embayment in East Jutland identical assemblages referred to the Middle Rhaetic *sensu germanica* have been proven too. Furthermore, in the Dansk Nordsø F–1 borehole an older, monotoneous *Ovalipollis* assemblage of possible Ladinian to Norian age was recorded within the generally barren red beds.

In both boreholes the uppermost arenaceous beds of the sections referred to the Triassic seem to be non-palyniferous. In the above-mentioned sections of eastern Jutland (which are still subject to clauses of confidentiality) a corresponding sterility is observed in the uppermost arenaceous beds of the Gassum Formation, which is generally referred to the Rhaetic (cf. Larsen



Text-fig. 2. The chronostratigraphical division of the Triassic sequences of the Dansk Nordsø F-1 and Dansk Nordsø K-1 boreholes and their correlation. The presumed primary ranges of the recovered microfloras are also shown.

1966). These latter beds are overlain by shales of the Fjerritslev Formation with well-defined Hettangian ostracod faunas (O. Michelsen, personal communication) and their stratigraphical position is therefore restricted to the Rhaetian/Hettangian transition.

The studied sections in the two North Sea boreholes are, as described earlier, overlain by Lower Jurassic shales, which are included in the Fjerritslev Formation by Michelsen (1975) (see also Text-fig. 2). In the Dansk Nordsø K-1 borehole these shales basally contain a Hettangian ostracod

fauna, whereas the basal shales of the Dansk Nordsø F-1 borehole are slightly younger according to Michelsen, being characterized by a Lower Sinemurian fauna. Chronostratigraphically the probably barren beds are therefore to be referred to the Upper Triassic/Lower Jurassic transition, and they are for that reason found to be more or less isochronous with the uppermost beds of the Gassum Formation in the mentioned boreholes in East Jutland.

Lithostratigraphically the sandstone interval 1948 m–2017 m (6514'–6738') of the Dansk Nordsø K-1 section is referable to the Gassum Formation. The underlying mainly dark grey, partly marine claystones of the interval 2017 m–2042 m (6738'–6822') and the subsequent, limestone bearing interval 2042 m–2056 m (6822'–6866') are considered to belong to the Vinding Formation defined in Larsen (1966).

In the Dansk Nordsø F-1 section the interval 2042 m–2118 m (6820'–7070') is referred to the Gassum Formation and the Vinding Formation is found not to be present in this borehole. It must be stressed, however, that an alternative correlation is possible, since interval 2042 m–2078 m (6820'–6940') may also be regarded as part of the Fjerritslev Formation. Due to the traces of purple siltstones described from the shaly section 2049 m–2078 m (6845'–6940'), which is merely a "Triassic feature", the latter correlation seems less reliable.

As regards the red bed sequences, only one sample in the Dansk Nordsø F-1 profile (–7690') proved productive. This sample of Ladinian-Norian age indicates that at least the major part of the red beds in this borehole are of Upper Triassic age. The proximity of the Dansk Nordsø K-1 borehole may justify the assumption that the corresponding beds in that borehole are also from the Upper Triassic.

In the lowermost part of the Dansk Nordsø F-1 profile, the resistivity log seems to indicate the presence of limestones, but such rocks are not mentioned in the description. The claystones, however, are described as being calcareous and the presence of Muschelkalk equivalents is therefore a possibility, although not very likely. All red beds are for that reason referred to the Upper Triassic, as seen in Text-fig. 2.

Dansk sammendrag

I artiklen redegøres for resultaterne af palynologiske undersøgelser foretaget i de triassiske afsnit i de tre danske Nordsø-boringer: Dansk Nordsø A-2, Dansk Nordsø F-1 og Dansk Nordsø K-1.

I boringen Dansk Nordsø A-2 beliggende i *the Central Graben*, er trias-afsnittet, 3027 m–3360 m (10050'–11143') udviklet som kontinentale "red beds" indeholdende en basal stensaltforekomst. I lagene umiddelbart over og under saltlagene påvistes

mikrofloraer af sandsynlig Anisien-Ladinien alder. Det sporeførende, halitiske afsnit er som helhed sammenlignet med saltførende lagserier i den sydlige del af Nordsøen, der kan korreleres til mellem Muschelkalk i Tyskland.

I borerne Dansk Nordsø F-1 og Dansk Nordsø K-1 med position i den vestlige del af Det danske Sænkingsområde forekommer mikrofloraer af rhætisk alder i lagserier, der lithologisk må henføres til Gassum Formationen. I boringen Dansk Nordsø K-1 påvistes tillige tilstedeværelsen af marint rhæt i en lagserie, der kan refereres til Vinding Formationen. De underliggende "red beds" fandtes generelt at være gølge, men i en enkelt prøve i F-1 profilet lykkedes det dog at påvise en mikroflora af øvre triassisk alder. Med forbehold er de gennemborede "red beds" derfor som helhed henregnet til øvre trias. Undersøgelsesresultaterne fra de to sidstnævnte borer er sammenstillet i tekstfigur 2.

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Triassic heavy-mineral associations in Denmark

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Larsen, Gunnar and Friis, Henrik: Triassic heavy-mineral associations in Denmark. *Danm. geol. Unders., Årbog 1974*, pp. 33–47, pl. 2. København, 18. september 1975.

The investigation comprises heavy-mineral analyses of 14 samples from the Triassic sequence of Denmark. The geological significance of the heavy-mineral associations is discussed. In the Bunter a "Garnet province" including the South Danish/North German region occurs, supposedly of Scandinavian origin. Along the margin of the basin towards Fennoscandia a marginal facies of coarse arkoses is found. The heavy-mineral associations of these arkoses are interpreted as reflecting a detritus supply from locally exposed rocks. In the Keuper associations an inkling is given of a subdivision in heavy-mineral provinces, which locally are strongly obliterated by diagenetic destruction.

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Triassic deposits in Denmark are known from a few outcrops in the southern part of the island of Bornholm (map fig. 1 b) (Hansen, 1942) and from several borings in other parts of the country made since 1935 (Gregersen & Sorgenfrei, 1951; Sorgenfrei & Buch, 1964; Rasmussen, 1972, 1974).

In the borings the Triassic sections have been subdivided and correlated mainly from lithological properties. Compared with the German Triassic four major units are recognized:

Rhaetic: dark shales and light sandstones.

Pre-Rhaetic Keuper: reddish-gray variegated claystones and marlstones with intercalations of sandstones and evaporites.

Muschelkalk: grayish marly limestones.

Bunter: red, clayey sandstones intercalated with evaporites.

Lithologically the Rhaetic deposits differ from the other Triassic deposits whereas they are similar to those of the Jurassic and Lower Cretaceous. For this reason the Rhaetic has been treated in connection with the Jurassic and

Fig. 1 a.

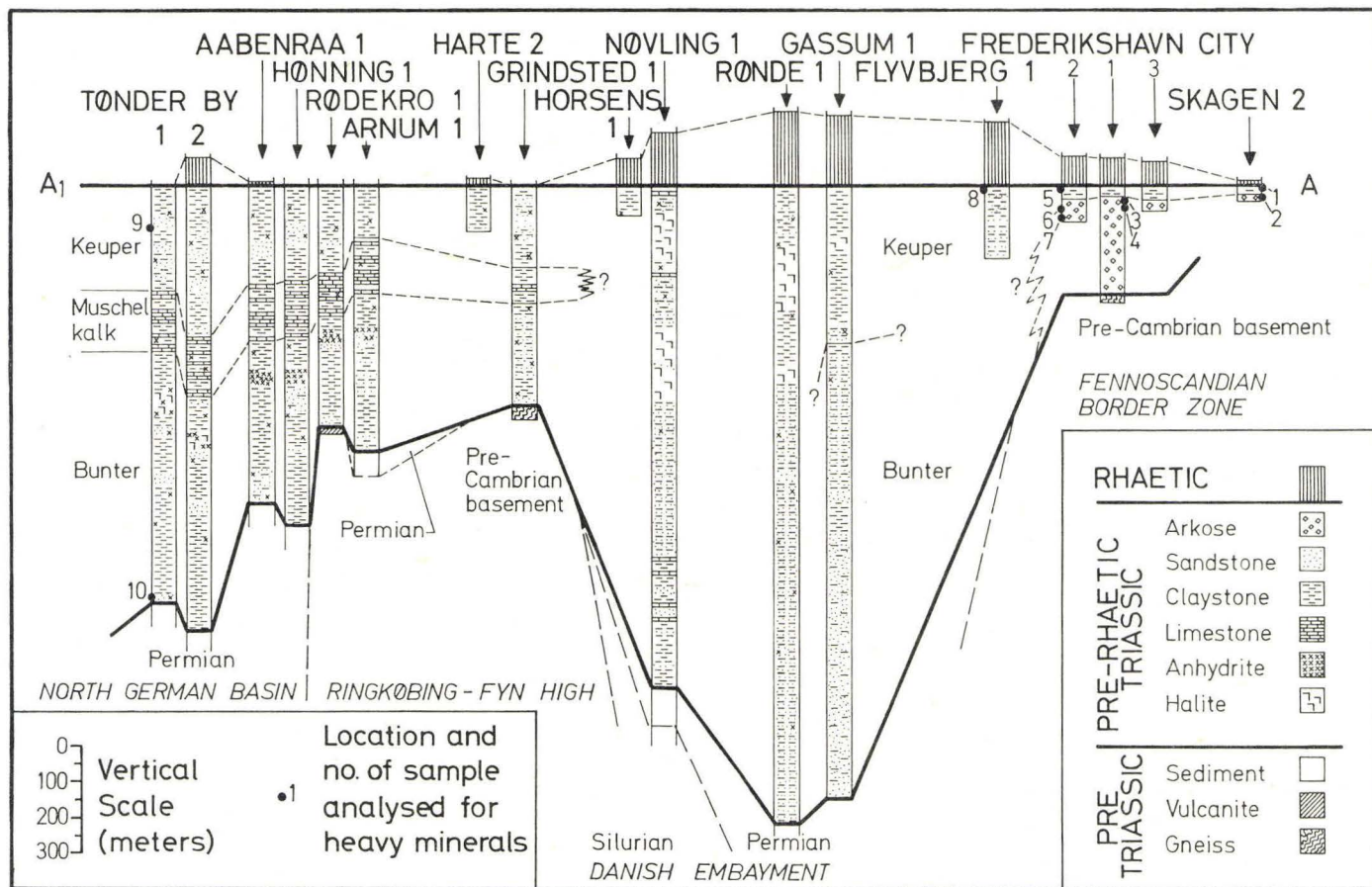
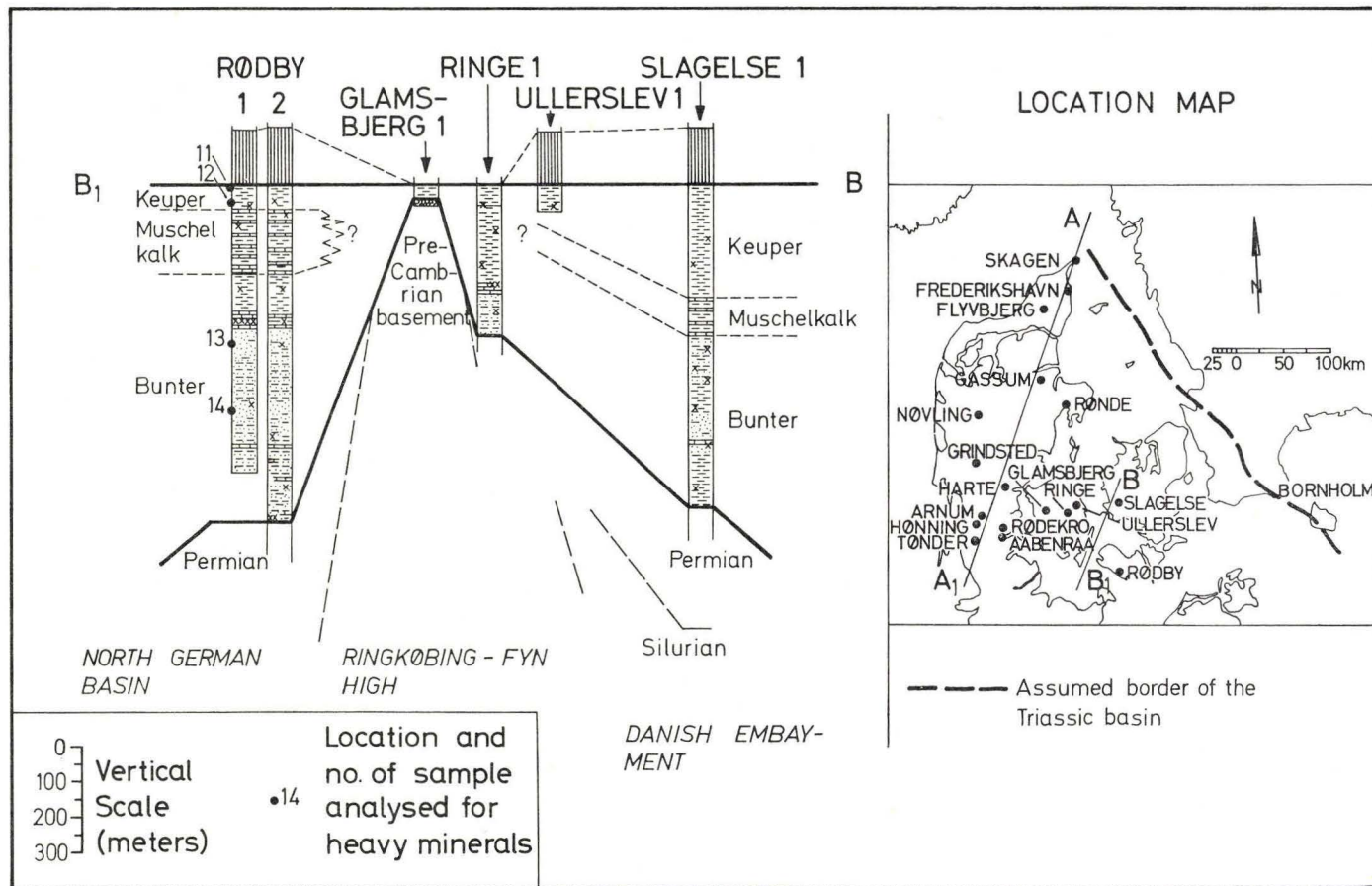


Fig. 1 b.



Lower Cretaceous in a previous work (Larsen, 1966). In this study samples from other parts of the Triassic sections have been analysed in a similar way. The origin of the sediments is discussed from interpretations of the heavy-mineral associations. Previously the subject has been briefly treated by Larsen (1967).

The Triassic sequence and the sample material

A total of 14 samples have been analysed. This is only a very poor representation of the entire Triassic sequence which is illustrated by the cross-sections in figs. 1 a and 1 b. These sections demonstrate the main features of the lithology in the pre-Rhaetic sequence as it appears from a number of deep borings. Compilation has been made from Sorgenfrei and Buch (1964) and Dinesen (1971, 1973). The surface of the pre-Rhaetic Keuper was used as base-line.

Some features of the regional development which may be seen from the figures will be pointed out briefly.

The deep structure (The North German Basin, The Ringkøbing-Fyn High, The Danish Embayment, The Fennoscandian Border Zone) is clearly reflected.

The southernmost borings represent the conditions in the northern parts of the North German Basin. Here Triassic is found resting on Permian deposits. The Bunter, which makes up a considerable part of the sequence, contains a well developed horizon with evaporites, referred to the Röt. Muschelkalk is represented by marine deposits which in the Rødby 1 boring are fossiliferous (Sorgenfrei & Buch, 1964). To the east the Keuper deposits, which are mainly claystones, are rather thin. In the western part the thickness increases and beds of sandstone occur as intercalations in the clayey sequence.

From the North German Basin the thickness of the Triassic sequence decreases towards the Ringkøbing-Fyn High where in the most elevated parts Precambrian gneisses form the substrate.

In the Danish Embayment a very thick sequence of Triassic deposits were laid down on a substrate of Permian sediments. The stratigraphic subdivision seems to be reliable as far as the southern parts are concerned as here parts of the sections are referred to Muschelkalk. In the central parts of the Danish Embayment the subdivision is less certain, as no beds are referred to Muschelkalk with certainty. According to Sorgenfrei (1969) and Dinesen (1971) the thick salt layers may correspond completely or partially to the German Muschelkalk, but this has not yet been verified.

Towards the Fennoscandian Border Zone the Triassic sequence thins out

Table 1. Localization of analysed samples. Depths are below rotary table.

Sample no.	Boring	Core depth
1	Skagen 2	1850'–1860'
2	»	1960'–1967'
3	Frederikshavn City 1	3450'–3460'
4	»	3460'–3470'
5	Frederikshavn City 2	3175'–3178'
6	»	3380'–3386'
7	»	3448'–3468'
8	Flyvbjerg 1	1483–1489 m
9	Tønder By 1	3527'–3537'
10	»	7053'–7056'
11	Rødby 1	2237'–2257'
12	»	2301'–2314'
13	»	3775'–3790'
14	»	4486'–4506'

Table 2. Composition of non-opaque heavy-mineral fraction.

Sample no.	Zircon	Rutile	Anatase	Tourmaline	Titanite	Kyanite	Staurolite	Garnet	Epidote	Hornblende	Other minerals
1	9	9	–	8	6	1	1	16	42	6	2
2	1	3	–	4	19	–	–	67	3	+	3
3	17	12	–	9	37	–	–	24	1	–	–
4	15	8	–	9	24	–	–	43	1	–	–
5	78	11	2	1	3	–	–	2	1	–	2
6	9	1	–	2	17	–	–	71	–	–	–
7	19	–	1	5	36	–	–	39	–	–	–
8	43	20	8	11	–	–	–	17	–	–	1
9	1	7	–	19	43	–	+	27	–	–	3
10	37	4	–	8	–	–	–	51	–	–	–
11	36	20	1	22	–	1	8	7	1	–	4
12	14	28	6	42	–	2	–	6	–	–	2
13	34	3	–	11	–	–	–	52	–	–	–
14	17	4	5	20	–	–	2	52	–	–	–

rapidly. Here coarse arkoses are found directly on the Precambrian basement, and Keuper-clays overly these arkoses, which are clearly a marginal facies, probably corresponding to the Kågeröd Formation in Skåne (Sweden) (Troedsson, 1942). Therefore these rocks are referred to the

Triassic, although it must be stressed that the age of the arkoses is not clarified.

As mentioned, the 14 samples represent a very limited part of the Triassic sequence. Furthermore, as seen from figs. 1 a and 1 b, only the northernmost and southernmost regions of the depositional area in Denmark are represented by samples. The localization of the individual samples is shown in table 1.

The heavy-mineral analyses

Heavy-mineral analyses have been made on the grain-size fraction 75–250 μm from which the heavy-minerals were separated by means of bromoform (S.G. = 2.89). Upon mounting in Clearax (R.I. = 1.666) the composition of the non-opaque fraction was estimated by counting 200 mineral grains from each sample. The results of the analyses are shown in table 2.

Geological interpretation of the heavy-mineral analyses

The heavy-mineral analyses of table 2 reveal some features of the genetic history of the sediments. These features are discussed below.

1. Bunter

Bunter is represented by analyses from the borings Tønder By 1 and Rødby 1. In the map (fig. 2) these analyses have been put together with comparable analyses from Helgoland and Schwedeneck in Germany (Sindowski, 1957) and Höllviken in Sweden (Brotzen, 1950). Referring to figs. 1 a and 1 b the stratigraphic position of the samples from the Danish localities is assumed to be lower and middle Bunter as they occur below the evaporite horizon referred to the Röt. The German occurrences represent middle Bunter (Sindowski, 1957). The material from Höllviken represents the upper part of the Bunter sequence.

As seen from fig. 2 the heavy-mineral associations from Helgoland, Tønder, Schwedeneck and Rødby are so alike that they must be assumed to represent a continuous heavy-mineral province, which might be called the "Garnet province" as garnet constitutes more than 50 % of the non-opaque heavy-minerals. The stable minerals zircon, rutile and tourmaline constitute the remaining part of the associations.

To the south in the German Triassic basin the sediments have been

supplied mainly from southerly and easterly directions. Here the heavy-mineral associations are of more miscellaneous composition. As a rule the stable minerals dominate while garnet is represented in rather small amounts (Sindowski, 1957). According to Heim (1966) apatite is a characteristic component in parts of the German Bunter.

These features indicate that the "Garnet province" is genetically unrelated to the southernmost occurrences and as suggested by Sindowski (1957) the material is assumed to be of northern origin. The source area may have been parts of the Ringkøbing-Fyn High and/or Fennoscandia.

Concerning the nature of the source area it is a question whether it was dominated by older sediments or by crystalline basement rocks. The nature of the grain texture may yield conclusive evidence in this connection. It should be mentioned that according to Heim (1966) many of the garnets from parts of the middle Bunter of Helgoland are large idiomorphic grains. In the Danish material wearing of the garnets is not pronounced. This indicates that the material has not been reworked and so probably does not originate from old sediments but from basement rocks.

According to Noe-Nygaard (1963) the basement rocks of the Ring-

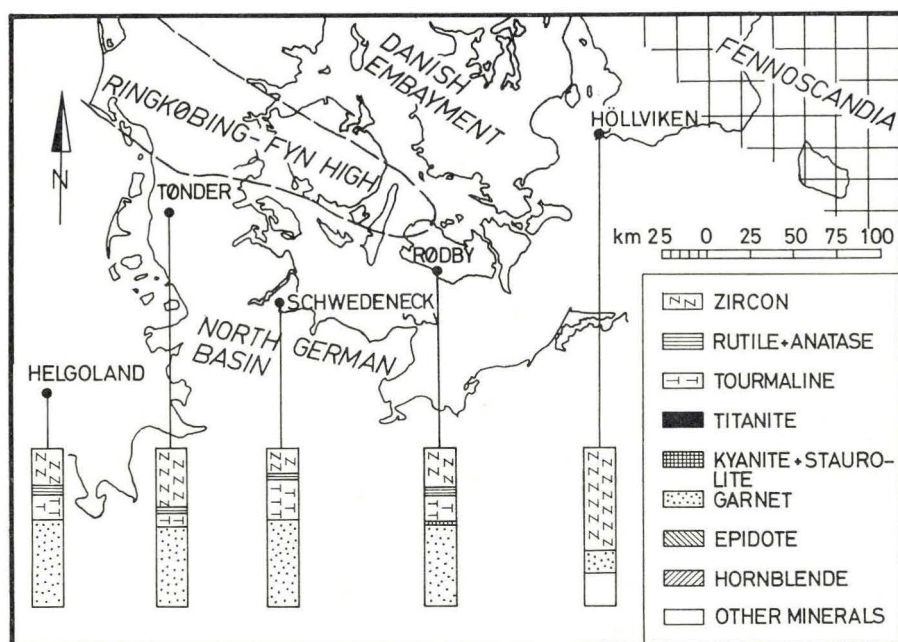


Fig. 2. Location and heavy-mineral associations of samples from the Bunter. The analyses from Helgoland and Schwedeneck are given by Sindowski (1957), the analysis from Höllviken by Brotzen (1950).

købing-Fyn High as known from a few borings do not contain garnet in appreciable amounts. Only in the Arnum boring was a block of garnet-hornblende-biotite gneiss found, indicating that garnet-bearing basement is present in the vicinity of this locality. Considering that this is the only occurrence of garnet-bearing basement rocks from the Ringkøbing-Fyn High known at present and that considerable parts of the High were already covered in early Bunter time (cf. Grindsted 1) it seems unlikely that the rather widespread "Garnet province" originated from the Ringkøbing-Fyn High. Furthermore it should be mentioned that the Rhaetic heavy-mineral associations, which according to the distribution of sedimentary facies must be assumed to have originated from the High, only contain small amounts of garnet (Larsen, 1966).

Thus it is suggested that the Fennoscandian Shield was source area for the "Garnet province" of the Bunter. However a more precise specification is hardly possible. On the other hand it should be mentioned that an almost identical heavy-mineral association is found in the Rhaetic of the Gassum 1 boring (Larsen, 1966). This might reflect that the source area of the "Garnet province" was of considerable extent. It is unlikely that the heavy-mineral associations of the sediments reflect the composition of the source area directly as some of the less stable minerals (e.g. hornblende) may have been removed during the genesis of the sediments, either by weathering or by later diagenesis.

To illustrate the effects of diagenesis it should be mentioned that the garnet grains generally are only slightly corroded, and some completely non-corroded grains are still present. Considering the great depth of the samples (sample no. 10: 7053'–7056') this feature seems surprising. In comparison to this, sediments from corresponding depth within the Danish Embayment display evidence of very intense diagenetic mineral destruction (Larsen, 1970).

So far only the "Garnet province" has been discussed. As seen from fig. 2 the heavy-mineral association of Höllviken strongly diverges from the homogenous "Garnet province". This is probably explained by the position of this locality, close to the margin of the Bunter depositional basin. In this marginal position the locally exposed source rocks may have influenced the composition of the sediments radically, as also proposed by Brotzen (1950).

2. Triassic marginal facies against Fennoscandia

The coarse arkose in northern Jylland (fig. 1 a) is interpreted as a marginal facies of the Triassic basin. Probably such a marginal facies is developed

along the entire border zone between the basin and the Fennoscandian source area, cf. the Kågeröd Formation in Skåne (Sweden).

Analyses from Skagen and Frederikshavn, together with analyses representing the Kågeröd Formation at Ottarp, Skromberga and Höllviken are presented on the map (fig. 3). The analysis from Höllviken is given by Brotzen (1950).

A distinctive feature of the occurrences in northern Jylland is the large amount of titanite. In the material from Skåne the extremely high content of garnet at Ottarp and Skromberga is remarkable, and the differences between the Danish and the Swedish arkoses are conspicuous. However this is to be expected of a coarse marginal arkose formed by detritus of mainly locally exposed rocks.

Both old sediments and basement rocks are known to have been exposed in the source area of the Kågeröd Formation (Troedsson, 1942). However the heavy-mineral associations show no sure signs of contributions from

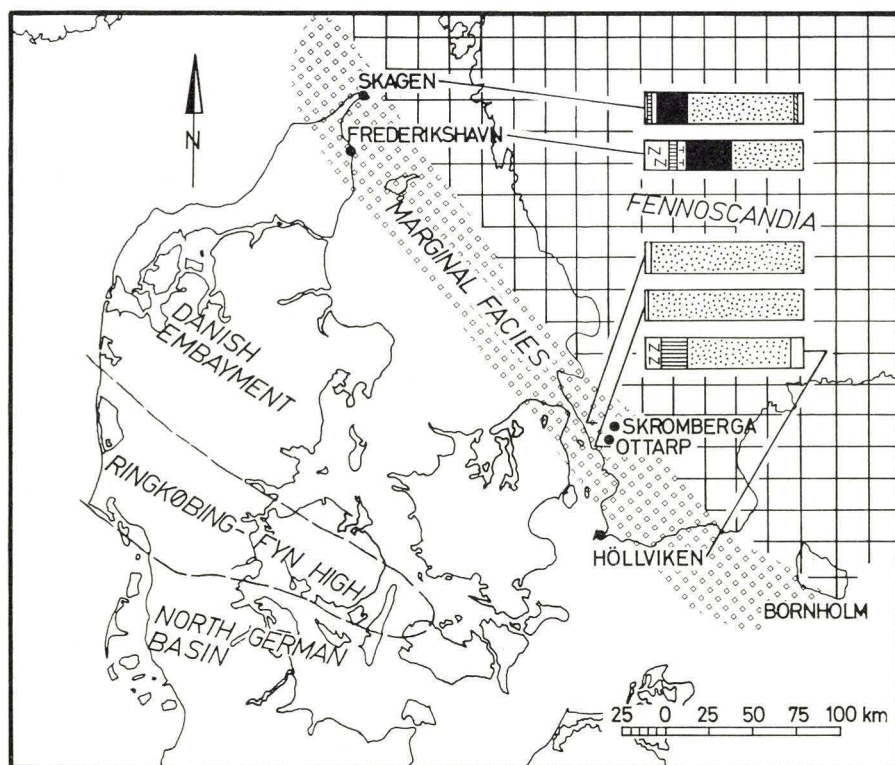


Fig. 3. Location and heavy-mineral associations of samples from the Triassic marginal facies. The analysis from Höllviken is given by Brotzen (1950). (See fig. 2 for legend to the heavy-mineral diagrams).

recycled older sediments. This may indicate that the supply from older sediments was very poor in heavy-minerals.

Also the material from northern Jylland seems to originate mainly from basement rocks. Garnets without signs of wear, some of them idiomorphic (plate 2, A) are presumed to have been derived directly from the crystalline rocks. This feature is most pronounced in the Skagen boring. Some of the zircons, tourmalines and garnets are rounded, especially in the Frederikshavn boring, indicating that parts of the material is recycled sediments. The large content of titanite is a peculiar feature which probably indicates a crystalline parent material, though the grain texture indicates that the original grain surfaces have been strongly modified by corrosion (plate 2, B). Not only titanites are corroded. Etched epidotes (plate 2, C–E) and staurolites have also been found from the Frederikshavn boring. In contrast to the Frederikshavn material epidote is found to be quite fresh in the Skagen material. Furthermore garnets from both borings are corroded to variable degrees. Compared to the Skagen boring the Frederikshavn boring generally shows evidence of a more intense diagenetic dissolution. As the Frederikshavn material occurs at greater depth than the Skagen material, this feature is in agreement with the general situation in the Danish Embayment where the intensity of diagenetic dissolution increases with depth (Larsen, 1970).

3. Keuper

From the Keuper sequence heavy-mineral analyses have been made on samples from Skagen, Frederikshavn, Flyvbjerg, Rødby and Tønder. All analyses refer to more or less sandy beds in the otherwise mainly clayey deposits. These analyses are shown in the map (fig. 4) which also gives an analysis of kaolinitic sand from Julegaard on Bornholm (Gry, 1936).

It is clear from the figure that the heavy-mineral associations are rather different from one region to another. The possible origin of the individual associations is discussed below.

The Skagen association is dominated by unstable minerals with epidote as the main component. This association is very close to that of the overlying Rhaetic beds (Larsen, 1966). Supported by information from the distribution of sedimentary facies, the Rhaetic association was assumed to originate from an area of Fennoscandia localized E or NE of Skagen. The same origin is suggested for the present material. The source area was probably a gneiss-complex of mainly intermediate metamorphic facies. During disintegration in the source area the influence of chemical weathering obviously was very small. Neither did diagenetic processes change the

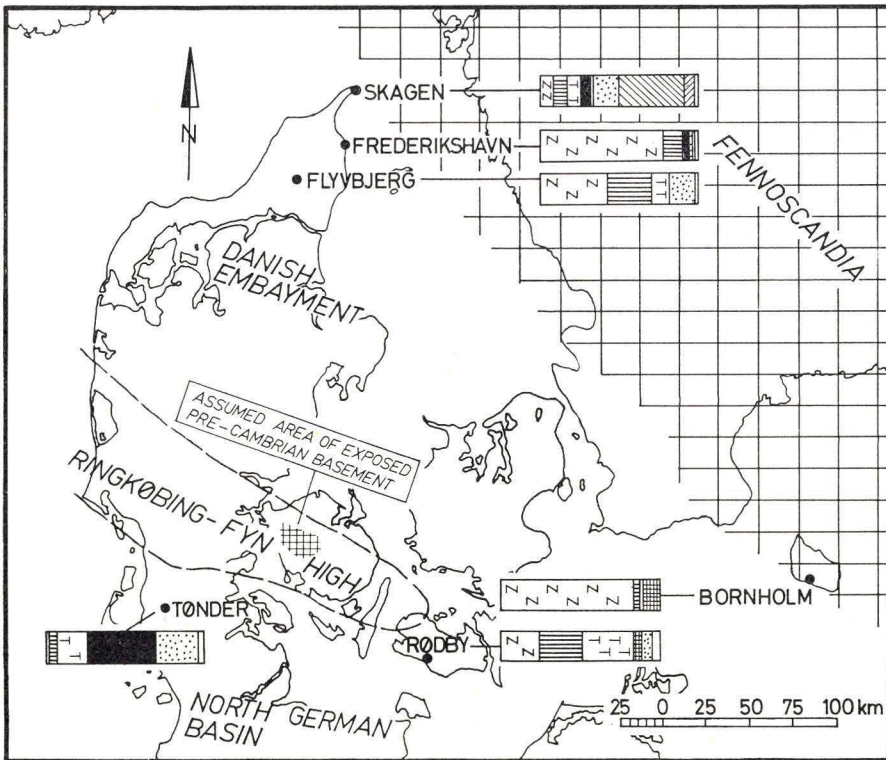


Fig. 4. Location and heavy-mineral association of samples from the pre-Rhaetic Keuper. The analysis from Julegaard (Bornholm) is given by Gry (1936). (See fig. 2 for legend to the heavy-mineral diagrams).

mineralogical composition appreciably as only few mineral grains are slightly corroded. At Frederikshavn a stable, zircon dominated association is found. The association from Flyvbjerg is very similar as it is also dominated by the stable minerals, although to a lesser degree. These associations may be regarded as the result of excessive chemical dissolution during weathering and/or diagenesis. The study of Rhaetic-Jurassic-Lower Cretaceous sediments demonstrated that intensive diagenetic destruction of heavy-minerals also dominates in the deeper parts in northern Jylland (Larsen, 1966, 1970). In this connection it is assumed that the strong dominance of stable heavy-minerals in Frederikshavn and Flyvbjerg was caused mainly by diagenetic dissolution. Furthermore it should be pointed out that zircon occur more frequently than tourmaline. This feature is common to the Rhaetic-Liassic associations in the entire northern Jylland (Larsen, 1966, fig. 41). This may suggest the outline of an extensive northern Keuper-Rhaetic-

Liassic heavy-mineral province in which the original uniform composition has been modified by subsequent diagenetic dissolution.

The occurrence of kyanite and staurolite in the Keuper-association of Bornholm demonstrates that the material was derived from a source area outside Bornholm (Gry, 1936).

The heavy-mineral associations in Rødby are very similar to those of the Rhaetic-Liassic deposits above (Larsen, 1966). Referring to the distribution of sedimentary facies in the Rhaetic deposits, these sediments were interpreted as being recycled from older sediments exposed on the Ringkøbing-Fyn High. The Keuper-association probably originated from the same sedimentary source area. Thus a southern Danish heavy-mineral province seems to exist, reflecting a considerable permanence in detritus production and supply in Keuper-Liassic times.

In Tønder the heavy-mineral association is noteworthy for its large content of titanite. The titanites are generally fresh without signs of corrosion or extensive mechanical wear (plate 2, F-G). Also garnets are only slightly worn; furthermore biotites with an idiomorphic outline are found (plate 2, H). From these features it is deduced that the main part of the material was derived from a crystalline source area which was not very distant from Tønder. Thus it is natural to suggest that parts of the Ringkøbing-Fyn High supplied these sediments. The analysis refers to a sandy sequence within the Keuper. This part of the Keuper sequence is thought to correspond to the German Schilfsandstein. Wurster (1964) demonstrated that the Schilfsandstein was laid down by a system of rivers draining areas of Fennosarmatia. In this connection the sandbed in Tønder could have been deposited by a stream originating on the Ringkøbing-Fyn High and draining areas where the basement was still free from overlying sediments. The Glamsbjerg area obviously was a possible source area. From Noe-Nygaard (1963) it is known that the basement at Glamsbjerg contains the heavy-minerals zircon, titanite, apatite, hornblende and biotite. This composition is not identical to the heavy-mineral association in Tønder where apatite and hornblende are missing, while in Glamsbjerg tourmaline and garnet are absent. However, during weathering the unstable minerals apatite and hornblende may have been destroyed and tourmaline and garnet may have been supplied from other sources. This is only one possible explanation and others might be taken into consideration. However, it is important that the most conspicuous component of the Tønder association, the titanite, may be assumed to originate from the basement of the Ringkøbing-Fyn High. Furthermore it should be mentioned that Gry (1948) registered a remarkable high content of titanite from the Harte boring in beds which according to Christensen (1962) are of Keuper age.

As mentioned only faint traces of diagenetic dissolution of the heavy-minerals are seen in the Tønder association. This feature corresponds to the general tendency of the examined material that evidence of diagenetic dissolution are less pronounced south of the Ringkøbing-Fyn High than at corresponding depth in the Danish Embayment. However it must be emphasized that this conclusion is based on a very limited number of analyses.

Final remarks

During this study an attempt has been made to shed light on some of the problems concerning the origin of the Triassic deposits in Denmark. The general assumption that the sediments were supplied from Fennoscandia and the Ringkøbing-Fyn High has been illustrated. The location of the heavy-mineral associations and their mutual similarities and differences suggests the contours of a subdivision of the basin into heavy-mineral provinces. The varying influence of different source areas on the sediment production seems to be the main controlling condition for delineation of these provinces. However the picture is not very clear, partly because diagenetic mineral destruction in places was so intense that the original character of the associations may have been obliterated. Furthermore the examined material only represents small sections of the total Triassic sequence in Denmark.

Acknowledgements. The authors would like to thank Prof. Dr. H. Füchtbauer, Institut für Geologie, Ruhr Universität, Bochum, for information on literature concerning heavy-minerals in the German Triassic, and Dr. J. R. Wilson who kindly improved the English manuscript.

Dansk sammendrag

Trias aflejringerne udgør en betydningsfuld del af den danske undergrund. Det hidtidige kendskab til disse aflejringer er i det væsentlige begrundet i lithologiske undersøgelser. Med dette arbejde søges vor viden om det præ-rhætiske trias udbygget med nogle tung-mineralanalysers vidnesbyrd.

Hovedtræk af lagseriens lithologiske opbygning er vist i tværprofilerne fig. 1 a og 1 b, hvor overfladen af det præ-rhætiske keuper er benyttet som referenceniveau. I figurerne er analyseprøvernes lokalisering vist. Som det ses, repræsenterer disse prøver kun et beskedent udsnit af den samlede lagserie.

Resultatet af tungmineralanalysen er vist i tabel 2. Tolkningen af disse mineralselskabers geologiske baggrund rummer flg. hovedpunkter.

For buntsandsteins vedkommende er de danske analyser sammenholdt med tilsva-

rende fra Nordtyskland og Sverige, fig. 2. Det ses, at selskaberne i det syddanske og nordtyske område, d.v.s. i det nordlige strøg i Det nordtyske bassin, indbyrdes er så ens, at de kan antages at udgøre en sammenhængende tungmineralprovinc. Ud fra karaktermineralet betegnes den »Granat-provinsen«. Det findes sandsynligt, at den er af nordlig oprindelse, med et fennoscandisk grundfjeldskomplex som denudations-område. Den diagenetiske mineralopløsning efter aflejringen synes ikke at have været særligt omfattende.

Langs trias aflejringsfeltets afgrænsning mod Fennoscandia optræder en randfacies af grovkornede arkoser. Kortet fig. 3 viser nogle nordjydske og skånske tungmineralselskaber fra denne randfacies. Det antages, at disse er opstået ved nedbrydning fortrinsvis af grundfjeldsbjergarter exponeret langs bassinranden.

Kortet fig. 4 viser tungmineralselskaber i keuper. I det nordjydske område svarer selskaberne så nøje til dem, man møder i de overliggende rhæt-lias lag, at der tegner sig et billede af en større nordjydsk keuper-rhæt-lias tungmineralprovinc, opstået ved nedbrydning af fennoscandiske grundfjeldsbjergarter. I de dybereliggende dele af lagserien har diagenetiske opløsningsprocesser øjensynlig ført til en ret gennemgribende ændring af den oprindelige mineralbestand. Tungmineralselskabet i Rødby har stor lighed med de rhæt-lias selskaber, man møder både i Rødby og Ullerslev. Der kan således opstilles en syddansk keuper-rhæt-lias tungmineralprovinc, hvis oprindelse antages at være fortrinsvis ældre sedimenter lokaliseret i Ringkøbing-Fyn højderyggen. Tønder selskabet har et bemærkelsesværdigt stort titanitindhold. Sandsynligvis er dette selskab opstået ved nedbrydning af titanitholdigt grundfjeld i de højereliggende endnu ikke sedimentklædte dele af Ringkøbing-Fyn højderyggen. Betragtes analyseresultaterne under ét spores en tendens til at de dybereliggende lag i det nordjydske område er stærkere præget af diagenetisk mineraldestruktion end lag på tilsvarende dybde syd for Ringkøbing-Fyn højderyggen.

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The Eemian freshwater deposit at Egersund, South Jylland, and the Eemian landscape development in Denmark

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Andersen, Svend Th.: The Eemian freshwater deposit at Egersund, South Jylland, and the Eemian landscape development in Denmark. *Danm. geol. Unders., Årbog 1974*, pp. 49–70, pls. 11–15, København, 18. september 1975.

The interpretation of the Eemian pollen diagrams from lake deposits is hampered by the insufficient information about the differentiation of the regional vegetation in plant associations. Pollen diagrams from very small hollows or soils record successions of single communities. At Egersund a succession of *Betula-Pinus-Ulmus*, *Fraxinus*, *Corylus*, *Tilia*, and *Tilia-Carpinus* phases is recorded. *Tilia* forest is lacking further northward in Denmark. A picture of the Eemian vegetational differentiation and landscape development in Denmark is obtained by comparison with other sites.

Lake deposits are to be preferred for a study of general interglacial vegetational conditions by pollen analysis because their pollen content is least affected by local hydroseres. However, two difficulties may hamper an understanding of the true interglacial vegetational conditions, (1) we do not know whether the plants recorded in the pollen mixtures found at the various levels were associated in a uniform vegetation or formed a mosaic of various associations and (2) we do not know the true importance of the various vegetational components. It has been pointed out several times that pollen spectra from lake deposits cannot be assumed to reflect the contemporary vegetational composition exactly because of differential pollen dispersal, but this term has been used rather confusingly as it has not always been clear which mechanism was meant. The following may influence pollen dispersal.

(1) Pollen productivity, which varies greatly according to Andersen (1970) and distorts the pollen spectra.

(2) Pollen release into the transporting air streams. This process is quite effective in trees because the flowers are situated in the tree tops, where the wind speeds are high and vertical mixing strong, (Andersen, l.c. and in

print) and less effective in low herbaceous plants, particularly forest herbs and entomophilous herbs with closed flowers.

(3) Transportation efficiency, which in the opinion of Tauber (1965) is highly variable. However, differences in transportation efficiency are probably not as large as estimated by that author. Pollen transported above the vegetation must be a main component of the pollen rain on lakes that are not too small, and pollen may be filtered from those parts of such a cloud which pass the top layer of the vegetation. The filtration efficiencies do not vary greatly at normal wind speeds even when the pollen grains are of different size orders (Andersen, in print), and the pollen representation rates found from lakes and bogs do not differ from those calculated within forests (Andersen 1970).

Pollen diagrams from Eemian lake deposits and regional pollen assemblage zones (p.a.z.) of the Eemian

Pollen diagrams from Eemian lake deposits at Herning and Hollerup in Denmark (Fig. 1) were published in Andersen 1964 and 1966. The following regional p.a.z. can be distinguished (the letters refer to Andersen, l.c.).

- E 7 *Pinus*
- E 6 *Picea-Pinus-Alnus*
- E 5 *Picea-Carpinus-Alnus*
- E 4 *Quercus-Corylus-Alnus*
- E 3 *Quercus-Fraxinus*
- E 2 *Betula-Pinus-Ulmus*
- E 1 *Betula*

The zone numbers are indicated on the pollen diagram from Herning, reproduced in Plate 11. The percentages were based on the tree pollen sum including *Corylus* and *Taxus*. At Kollund in southernmost Jylland (Fig. 1) a *Tilia-Corylus-Alnus* p.a.z. occurs between the *Quercus-Corylus-Alnus* and the *Picea-Carpinus-Alnus* p.a.z. (Jessen and Milthers 1928).

The pollen spectra from the Herning pollen diagram were re-calculated with the correction factors found in Andersen 1970, and the new percentages are indicated on the same diagram. The pollen productivity of *Taxus* was considered to be similar to the other high pollen producers as suggested by Beug (in Jung et al. 1972). The *Populus* pollen frequencies were not changed.

The differences between the original and the re-calculated pollen curves

on Plate 11 are not excitingly large. This is mainly due to the fact that most of the trees represented are large pollen producers, and hence a correction does not alter the picture greatly.

One may notice that (1) *Fraxinus* was probably considerably more important within the forest, particularly in the *Quercus-Fraxinus* p.a.z. (E 3), (2) an *Alnus* increase in the *Picea-Carpinus-Alnus* p.a.z. (E 5) is eliminated, and the *Alnus*-frequencies are nearly the same throughout the larger part, and (3) *Picea* becomes somewhat more important.

If differential transportation is important, the trees with large pollen grains would have been more important within the forest. This might be true for *Carpinus* and *Picea* in particular, but it is impossible to estimate such an effect at present. The true vegetational composition cannot have deviated greatly from the one obtained here, unless the filtration efficiencies for *Carpinus* and *Picea* pollen differed greatly from that of the other tree pollen.

The corrected pollen diagram from Herning may be substantiated by pollen analyses from small hollows such as the one from the Holocene reported in Andersen 1973. Such pollen analyses might also elucidate the problem of how the various trees were associated, because the pollen analyses from sites of that kind are likely to record only the community that grew in the immediate neighbourhood. Very small hollows from the Eemian are of course difficult to locate. However, one was found near Egersund in southernmost Jylland, and, because of its importance, material was secured in spite of rather difficult sampling conditions. To this may be added that the deposit contains abundant *Tilia*-remains, which lack at most other Eemian sites in Denmark. Single pollen spectra from other similar sites are also mentioned below.

Vegetational development at Egersund, Flensborg Fjord

Site

The interglacial peat at Egersund is situated at the bottom of Flensborg Fjord at Egersund town (Fig. 1). The water depth is 1.40 m, and the distance from the shore is 65 m. The peat extends only 5×5 m horizontally. It is located 5 m northwest of a large boulder and on a line extending from the fence between the properties Storegade 42 and 44 of Egersund town. The peat occupies a hollow, probably a kettle-hole, in boulder clay, which constitutes the sea bottom around the peat.

The peat was discovered during a low water episode in 1935, and was seen again in 1949. The site was re-located by the author and samples down to 20 cm below the surface were secured by swim divers in 1967. In

1970 a float was brought to the location, and a core was extracted with a piston sampler (Merkt and Streif 1970).

Johs. Iversen made a pollen analysis in 1935 and decided that the peat was of Last Interglacial age. He noticed abundant *Tilia* pollen.

The pollen analyses reported below have confirmed that the peat is of Eemian age, and the boulder clay around it is Saalian. Weichselian boulder clay is present in the cliff which borders Flensborg Fjord north of the site and presumably covered the submarine peat before it was removed by wave erosion in the Holocene.

Lithology

The description of the lithology is based on the samples dug out in 1967 and the core from 1970. The peat was situated under a thin layer of living rhizomes of *Zostera marina* and contained channels dug by *Pholas* in its topmost part. The peat layers are extremely hard and compact.

- A. 0– 6 cm Brown slightly humified peat with many rootlets. The core contained a piece of wood at 0–5 cm (*Salix* sp.)
- B. 6–105 cm Reddish brown peat, which consists mainly of decayed wood (identifiable remains of *Salix* sp. (6–18 cm), cf. *Corylus* sp. (52–70 cm), and cf. *Juniperus* sp. (90 cm)). Slightly stratified. The layering inclined 15° at the top and was horizontal below 46 cm.
- C. 105–115 cm Yellowish brown slightly sandy gyttja with much decayed wood, slightly stratified.
- D. 115–151 cm Greyish brown argillaceous sand with a few pebbles.
- E. 151–155 cm Greyish brown slightly argillaceous sand with pebbles.

The sediment symbols in Plates 13 and 14 are in accordance with Troels-Smith (1955).

Macrofossils

Macrofossils were washed from the 1967-samples and the core. They were kindly identified by Professor G. F. Mitchell, Dublin. The identifications are shown in Table 1.

Professor Mitchell noticed that the *Ilex*-fruitstones were larger than the fruitstones of modern *Ilex aquifolium*, and considers the species identification tentative. Fruitstones of *Ilex aquifolium* have frequently been identified from Eemian deposits in Western Europe; however, the material may need a reconsideration.

Table 1. Macrofossils identified by G. F. Mitchell. The sample marked "top" is loose debris collected in 1967. The samples at 0–18 cm were dug out in 1967, those at 34–133 cm are from the core.

Depth, cm	from to	top	0 2	2 6	6 10	10 14	14 18	34 40	52 58	65 70	70 75	86 93	104 110	122 126	130 133
Volume, ml	–	–	110	200	200	200	200	104	104	87	87	121	104	69	52
Pollen zone	–	–	5	5	4b	4b	4b	4b	4b	4ab	4a	4a	34a	3	2
<i>Ajuga</i> cf. <i>reptans</i> nutlets		1	.	5	.	.	.	.	.
<i>Alisma</i> cf. <i>plant.-aquat.</i> embryos		2	.
<i>Carex</i> sp. a trigonous nuts, some with utricles, small		15	.	21	8	105	38	.	.	.	.	2	2	.	.
<i>Carex</i> sp. b biconvex nuts		33	c	200	2	175	23	.	.	.	.	.	.	.	.
<i>Carex</i> sp. c biconvex nuts, small		5	2	.	.	.	.	.	.
<i>Carex</i> sp. d trigonous nuts		3	.	1	.	.	.	.
<i>Carpinus betulus</i> fruits		15	.	4	.	.	.	.	.	.	.	.	2	.	.
<i>Corylus avellana</i> nuts		23	.	1	2	.	.	.	.	.	.	8	22	.	.
Cruciferae damaged seed		1	.	.	.	.	.	.	.	.	.
Gramineae caryopses		2	.	.	.	1
<i>Ilex</i> cf. <i>aquifolium</i> fruit-stones		3	.	1	.	1	13	1	1	.	.	.	.	.	.
<i>Lycopus europaeus</i> nutlets		1	1	10	.	.	.
<i>Mentha</i> sp. nutlets		1	.	.	.	1	.	.
<i>Potamogeton</i> sp. damaged fruitstone		1	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Quercus</i> sp. acorns and cupules		1	.	89	.	.	.
<i>Ranunculus sceleratus</i> achenes		5	.	1	1	1	.	.	2
<i>Rubus</i> cf. <i>idaeus</i> drupelets		9	.	1	3	1	2	.	.	.	.	.	.	.	2
<i>Tilia</i> sp. fruit segments		140	.	15	10	120	116	88	80	127	18	.	.	.	.
Umbelliferae small carpels		2
Buds and scales		9	2	102	16	.	.
Deciduous leaf debris		.	1	2	.	50	c	1	.	.	.	.	.	.	.
Monocot. debris		.	.	2	.	.	.	.	.	.	.	.	.	.	.
Stem nodes		1	.	.	.	.	2	2	.	.	.
<i>Cenococcum</i>		1	.	1	75	2	.	.	.	.	.	.	.	.	.
Arthropoda		.	.	1	.	.	.	.	.	.	.	.	.	.	1
Vermes		1	.	.	.	.	.	.

A few whole fruits of *Tilia cordata* and a few fruits and fruit stems of *Tilia platyphyllos* (at 34–75 cm) were noticed by the author.

Pollen analysis

Pollen preservation. Two kinds of pollen corrosion occurred, the thinning and the perforation types described by Havinga (1967). Both kinds occurred in the sandy layers (D and E), but they are not easily distinguished in all cases. Specimens indeterminate due to corrosion were rare. The numbers of grains with perforated exines was noted, they include the grains thinned so much that parts of the exine were removed. Percentage frequencies of specimens with perforated exines are shown in Plate 12.

It is difficult to say how corrosion may have influenced the pollen spectra. All taxa were nearly equally attacked in the layers E and D except for *Dryopteris*, the frequencies of which may be somewhat too low there.

The *Corylus* pollen grains were particularly severely attacked in layer C and the lower part of layer B, which contain a *Corylus* pollen maximum. It is not likely that the *Corylus* pollen frequencies are significantly too low there.

Tilia and *Corylus* have equally high frequencies of corroded grains in layer B, and their relative frequencies can hardly have been changed greatly by selective corrosion.

The low frequencies of corroded specimens noticeable in layer A are presumably due to a more acid depositional environment.

The original pollen diagram. A pollen diagram based on the tree pollen sum is shown in Plate 13. Only the most important non-tree pollen curves are shown.

The pollen spectra from the lowermost sandy layers are confusing. The three lowermost pollen spectra appear to be younger than those above them, and the spectrum at 118 cm is older than those above and beneath it. Spectra which appear to be in a correct sequence are connected by curves and the others are indicated by horizontal bars. The curves are similar to those known from early Eemian deposits. The corresponding silhouettes are white in the pollen diagrams. Black silhouettes are shown above the disturbed levels.

The inversions of the original sequence in the sandy layers were definitely not due to the coring operation, but it is not possible to say whether the layers were disturbed in situ or whether older pollen-bearing material was transported into the hollow at various times.

It can be assumed that the total tree pollen deposition varied greatly

because trees with a high or with a low pollen productivity dominated at various times. A curve for the ratio of the tree pollen sum to the sum of the corrected tree pollen values (see below) is shown on the diagram. This curve indicates true variations in the pollen deposition. The figures vary from about 1 to about 4, and changes in the non-tree pollen frequencies calculated as percentages of the tree pollen sum cannot be assumed to show true changes in their pollen deposition.

The tree pollen sums are about 500 in each sample, after correction. The numbers of tree pollen actually counted thus vary from about 500 to about 2000.

Local pollen assemblage zones and age of the deposit. Due to the smallness of the hollow at Egersund the tree canopy could cover it, and the tree pollen assemblages can be assumed to be of mainly local origin. The sequence is therefore divided into local pollen assemblage zones which are indicated by numbers on the pollen diagram. The local pollen assemblage zones are compared to the Eemian regional pollen assemblage zones in Denmark in Table 2.

An equivalent of the early-Eemian *Betula* regional p.a.z. is missing at Egersund. The *Betula-Pinus-Ulmus*, the *Quercus-Fraxinus*, and the *Corylus-Quercus* local p.a.z. resemble the Eemian *Betula-Pinus-Ulmus*, *Quercus-Fraxinus* and *Quercus-Corylus-Alnus* regional p.a.z. in Denmark with the following exceptions.

(1) *Fraxinus* is more frequent in the *Quercus-Fraxinus* local p.a.z. at Egersund (24 %) than in the corresponding regional p.a.z. (8 %).

Table 2. Eemian regional pollen assemblage zones in Denmark and the corresponding local pollen assemblage zones at Egersund.

Regional pollen assemblage zones	Local pollen assemblage zones
<i>Pinus</i> (E 7)	
<i>Picea-Pinus-Alnus</i> (E 6)	
<i>Picea-Carpinus-Alnus</i> (E 5)	(<i>Tilia-Carpinus</i> (5))
<i>Quercus-Corylus-Alnus</i> (E 4)	<i>Tilia</i> (4b) <i>Corylus-Quercus</i> (4a)
<i>Quercus-Fraxinus</i> (E 3)	<i>Quercus-Fraxinus</i> (3)
<i>Betula-Pinus-Ulmus</i> (E 2)	<i>Betula-Pinus-Ulmus</i> (2)
<i>Betula</i> (E 1)	

(2) *Corylus* is more frequent and *Quercus* less frequent in the local *Corylus-Quercus* p.a.z. than in the *Quercus-Corylus-Alnus* regional p.a.z.

(3) *Alnus* has low frequencies at Egersund.

The *Tilia* local p.a.z. is equivalent to the *Tilia-Corylus-Alnus* p.a.z. at Kollund, also situated at Flensborg Fjord 13 km southwest of Egersund (p. 00), but is not recorded further north in Denmark. The *Tilia* pollen frequency at Kollund is 20 % of the tree pollen (including *Corylus*). *Tilia* pollen is very rare at all other Danish Eemian sites including central South Jylland (Agerskov, Andersen unpublished, Fig. 1) and the *Tilia* pollen fre-

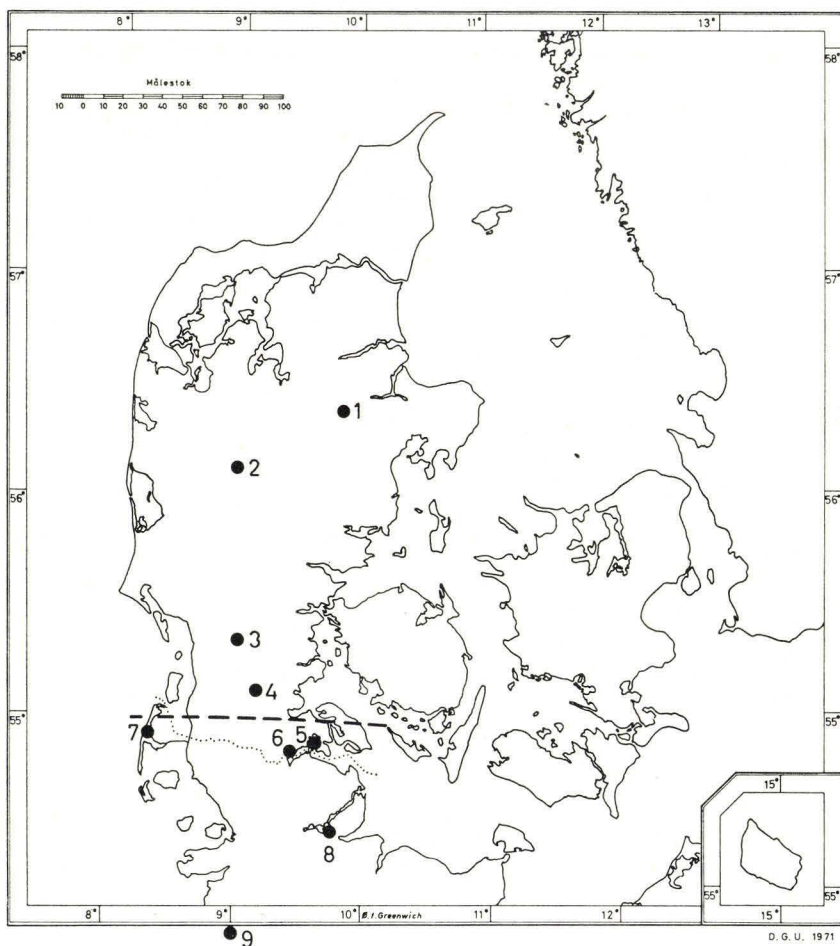


Fig. 1. Map of Denmark showing Eemian sites mentioned in the text. 1. Hollerup. 2. Herning. 3. Hygum Nymark. 4. Agerskov. 5. Egersund. 6. Kollund. 7. Westerland. 8. Loopstedt. 9. Burg.

quency is less than 10 % in the Eemian pollen diagram from Westerland on Sylt, northwesternmost Germany, published by Averdieck (1967, Fig. 1). *Tilia* pollen is frequent in other Eemian diagrams from northernmost Germany. The one closest to Denmark is Loopstedt near Schleswig (Schütrumpf 1967, Fig. 1) with 19 % *Tilia* pollen (tree pollen, including *Corylus*).

The *Tilia* pollen grains at Egersund nearly all belong to *T. cordata*. However, at 76 cm, at the transition from the *Corylus* p.a.z. about one fifth of the *Tilia* grains belong to *T. platyphyllos*.

The *Tilia-Carpinus* local p.a.z. at Egersund is transitional to the *Picea-Carpinus-Alnus* regional p.a.z., which follows after the *Tilia-Corylus-Alnus* p.a.z. at Kollund and the North German sites mentioned above, and equivalents of the Eemian *Picea-Carpinus-Alnus*, *Picea-Pinus-Alnus* and *Pinus* regional p.a.z. are missing at Egersund.

The sequence of local pollen assemblage zones at Egersund are sufficiently similar to the Eemian regional pollen assemblage zones to show that the deposit belongs to a part of the Eemian. It is unknown whether a *Betula* p.a.z. occurs at a lower level, but due to the coarseness of the lowermost deposit it is suggested that the soils were very unstable at that time, and it is possible that the hollow was still filled by dead ice at the time of the *Betula* p.a.z. It is also unknown whether the peat deposition continued throughout the Eemian. Deposits corresponding to the youngest Eemian regional pollen assemblage zones may have been removed by glacial erosion in the Weichselian or by wave action in the Holocene.

The higher *Fraxinus*- and *Corylus*-frequencies in the pollen assemblages at Egersund and the rareness of *Alnus* and *Picea* compared to the regional Eemian pollen assemblages as noticed above can be explained by the fact that only tree populations restricted to the nearest vicinity of the site are recorded. The presence of a *Tilia* assemblage zone at Egersund and at Kollund and its absence further to the north show that the northern limit of dense *Tilia* populations occurred somewhat north of these sites in the Eemian (see Fig. 1).

The re-calculated pollen diagram. The pollen assemblages in the interglacial deposit at Egersund are clearly enough predominantly influenced by tree communities which grew at the site. The low *Alnus* pollen frequencies indicate that no marginal forest developed, and that the site was surrounded immediately by high ground forest.

As the tree canopy could extend over the hollow, vertical tree pollen transport predominated, and pollen transported laterally (extra-local and regional, Janssen 1967) was insignificant in accordance with the experiences from surface samples from forests (Andersen 1970, 1973). The pollen

percentages thus can be transformed to crown area percentages after the method described in Andersen (1.c.). Such a re-calculated pollen diagram is shown in Plate 14.

Corylus formed a canopy and was fully illuminated in the *Quercus-Corylus* p.a.z. and this tree was presumably shaded in the *Tilia* and the *Tilia-Carpinus* p.a.z. Hence, *Corylus* was a large pollen producer in the former and a low pollen producer in the latter zones in accordance with Andersen (1970). The black silhouette on the pollen diagram indicates frequencies divided by 4, and the white silhouette indicates percentages with *Corylus* unchanged and calculated outside the tree pollen total. The black silhouette presumably illustrates the crown coverage of *Corylus* in the *Corylus* zone, and the white silhouette shows its areal participation in the *Tilia* and the *Tilia-Carpinus* p.a.z.

Tree frequencies of less than about 10 % may be due to the presence of pollen of extra-local or regional derivation, and in such cases it is not possible to say whether the tree was present locally with scattered specimens or not. The presence of macrofossils indicate local presence in some instances where the pollen representation is low (*Carpinus* in 3, *Quercus* in 4 a, and *Corylus* in 4 b and 5).

The variations in total tree pollen deposition are eliminated when the tree pollen counts are corrected, and changes in the non-tree percentages based on the sum of corrected tree pollen indicate true changes in deposition. The percentages do not, however, indicate the areal participation of these plants because the pollen frequency depends greatly on the distance from the sampling spot and because their pollen productivity may vary. They can hardly be interpreted in other terms than local presence or absence.

Pollen of anemophilous shrubs and herbs present in low frequencies may have originated from non-local populations because such pollen is produced in large quantities, whereas even low frequencies of entomophilous plants are likely to indicate their presence near the site at the time of deposition.

Plants represented with frequencies less than 0.5 % are indicated by crosses.

Curves for the various shrubs are shown separately in Plate 14. The herbaceous plants are grouped in categories such as "forest", "open ground", "uncertain", "wet ground" and "aquatics" according to their ecological significance. Curves for the various herbaceous plants are shown in Plate 15 together with curves for *Pediastrum* and redeposited Tertiary pollen.

The vegetational succession at Egersund

The re-calculated pollen diagram is divided into 5 vegetational phases. Their borders are at the same levels as the pollen assemblage zone borders, and the vegetational phases have the same numbers. It should be noticed that whereas the pollen assemblage zones merely signify levels with various characteristic pollen mixtures, the vegetational phases record intervals with various tree communities on the land surface. The shrubs and herbaceous plants occurring near or within the hollow depended on the amount of light which penetrated the tree canopy. Their presence or absence accordingly reflects the denseness of the tree cover around and over the hollow.

(*Betula* phase). A vegetational phase corresponding to the *Betula* regional p.a.z. is unfortunately not represented. *Betula* forest rich in *Juniperus* and with abundant herbaceous plants initiated the Eemian interglacial succession elsewhere in Denmark.

Betula-Pinus-Ulmus phase (2). *Betula*, *Pinus* and *Ulmus* constituted 20–40 % each, and *Fraxinus* and *Quercus* were present each with 10–20 % of the crown cover. *Juniperus*, *Viburnum*, *Salix* and *Hedera* were present, and herbaceous plants were abundant. Macrofossils of *Ranunculus sceleratus*, *Rubus* and Umbelliferae are recorded.

Pinus, *Betula* and *Ulmus* apparently grew in a mixed forest. *Fraxinus* and *Quercus* had immigrated but failed to expand. The tree canopy was open and allowed sufficient light for the growth of the shrubs and the herbaceous plants. *Viburnum*, *Salix*, *Hedera*, *Selaginella*, Gramineae, Umbelliferae, *Dryopteris*, *Glyceria*, *Alisma* and *Typha* are likely to have been present just around or in the hollow and there are many scattered records of terrestrial plants. *Artemisia*, *Selaginella*, *Saxifraga*, *Rumex*, *Ophioglossum* and the Chenopodiaceae are relics from a periglacial vegetation, and *Ulmus*, *Viburnum*, *Urtica* and *Humulus* suggest a fertile soil, whereas *Pteridium* indicates acid soil somewhere in the vicinity. The hollow contained a pond with *Callitriche*, *Ranunculus*, *Nymphoides*, *Lemna* and *Pediastrum*.

A slight amount of redeposited Tertiary pollen occurs (Plate 15). The few *Ilex* pollen grains may also have been redeposited, and *Ilex* probably did not immigrate till later as at other Eemian sites in Denmark (Andersen 1969).

Several plants typical of a temperate climate are recorded, and *Hedera* indicates oceanic conditions. Mull or hydro-mull (cp. Lafond 1952) presumably predominated near the site. *Pinus* and *Ulmus* had invaded an open *Betula* forest, but none of these trees attained full population density. It is possible that soil instability due to the melting of buried ice masses still

prevented the establishment of dense forest at that time. The phase is essentially protocentric in Iversen's sense (1958, cp. Andersen 1964, 1969). *Fraxinus* phase (3). *Fraxinus* expanded at the cost of *Betula*, *Pinus* and *Ulmus*, and constituted up to 70 % of the tree cover, and *Quercus* increased somewhat (20 %). *Populus* is represented, but there were few shrubs and herbaceous plants. The tree cover was apparently dense and the tree-crowns covered the hollow. *Hedera* had sufficient light to climb to the tree tops and flowered abundantly there. *Alisma* macrofossils are recorded.

Fraxinus was more successful than *Quercus* at this site and a damp soil too wet for *Quercus* is suggested. Hydro-mull thus prevailed around the hollow, and the dense *Fraxinus* forest suggests stable soil. The *Fraxinus* phase is transitional to Iversen's mesocratic stage.

Corylus phase (4a). *Corylus* expanded and attained up to 80 % of the tree cover. *Fraxinus* and *Quercus* decreased, but there is a low *Quercus* peak (20 %) in the middle of the phase. *Corylus* and *Quercus* are also represented by macrofossils. *Betula*, *Pinus*, *Ulmus*, *Fraxinus*, *Carpinus*, *Alnus*, *Taxus* and *Acer* are represented with low frequencies. *Carpinus* fruits are recorded, and *Acer* was probably present locally too, but the other trees mentioned are so scarcely represented that local presence cannot be claimed. There was no *Alnus* forest around the hollow, and the *Corylus* canopy extended over it. Shrubs and herbaceous plants were very scarce. There are a few records of shade tolerant forest herbs such as *Oxalis* and *Sanicula*, and there are macrofossils of *Lycopus*, *Mentha* and *Ranunculus sceleratus*.

The *Corylus* forest was thus very dense and the light was so scarce that the other trees could not rejuvenate. The *Corylus*-dominance was interrupted by a *Quercus* expansion, but this stage was short and *Quercus* was again suppressed by *Corylus*.

Hydro-mull probably prevailed, and the *Corylus* phase is mesocratic.

Tilia phase (4b). *Tilia* expanded rapidly and dominated the forest (up to 90 %). The *Tilia* pollen is mostly *Tilia cordata*. As mentioned above *Tilia platyphyllos* pollen is present at the transition from the *Corylus* phase and macrofossils of the species occur. *Tilia cordata* apparently was competitively superior to *T. platyphyllos*. *Corylus* nuts are recorded, and *Corylus* probably formed an understorey. The pollen productivity of *Corylus* was accordingly low, and the white silhouette on the pollen diagram probably shows its crown coverage truthfully. The curve exhibits three peaks in the *Tilia* phase (20–40 %). The other trees were very scarce.

There is a *Salix* peak; otherwise the shrubs are scarcely represented. There are 2 low *Ilex* peaks, and *Ilex* fruitstones are frequent at a level which cor-

responds to the uppermost peak on the pollen curve. The *Hedera* curve has 2 low peaks, and *Viscum* occurs scatteredly. The upland herbaceous plants were scarce. *Polypodium* is the most frequent one. The curve for wet ground plants shows 2 peaks. The lower peak comprises *Dryopteris*, *Carex* and *Typha*, and the upper one includes *Carex* and *Osmunda*. *Carex* fruits are abundant at a level corresponding to the uppermost peak on the pollen curve. Macrofossils of *Rubus*, *Ajuga*, *Lycopus*, *Mentha* and *Ranunculus sceleratus* are also recorded.

There were no aquatic plants, and the high frequencies of *Salix* and the wet ground plants suggest that these plants grew on the peat.

The *Tilia* forest was apparently dense and strongly shading. The variations in the frequencies of *Corylus* and several of the shrubs and herbaceous plants suggest slight variations in the light intensity under the trees. Hydro-mull or mull probably still prevailed. The appearance of *Osmunda* suggests slightly more acid conditions in the late part of the phase. The *Tilia* phase is essentially mesocratic.

Tilia-Carpinus phase (5). *Tilia* decreased to 40–50 %, *Carpinus* increased to about 20 % and *Corylus* to 40–50 %. *Carpinus* and *Corylus* definitely occurred in the forest around the site because macrofossils are present. *Betula* and *Fraxinus* also increase (up to about 10 %) and may have occurred near the hollow. *Hedera* increased slightly too, and *Calluna* and *Frangula* are represented. *Thelypteris dryopteris* appeared, and *Dryopteris*, *Carex*, *Osmunda*, *Sphagnum* and *Lysimachia* occurred on the wet ground. *Carex* nuts are abundant.

The tree cover was apparently not very dense. *Betula*, *Frangula*, *Calluna*, *Thelypteris dryopteris*, *Osmunda* and *Sphagnum* suggest acid conditions. The soil apparently changed into acid mull or mor, and acid water flushed the hollow. Traces of acidification appeared already in the late part of the *Tilia* phase, and the mull apparently degraded into a more acid soil. *Carpinus* tolerates acidity better than *Tilia* and occurs on a wider range of soils than *Tilia* to-day (Ellenberg 1963). Thus the replacement of *Tilia* by *Carpinus* was apparently promoted by soil degradation. A transition to the oligocratic stage (Andersen 1964 and later) is indicated.

Population dynamics at Egersund

A simplified pollen diagram is shown in Fig. 2, where bars indicate the vertical extension of peaks on the pollen curves suggestive of local presence of the various plants. Particularly high tree frequencies are indicated with black bars, peaks for other plants with white bars.

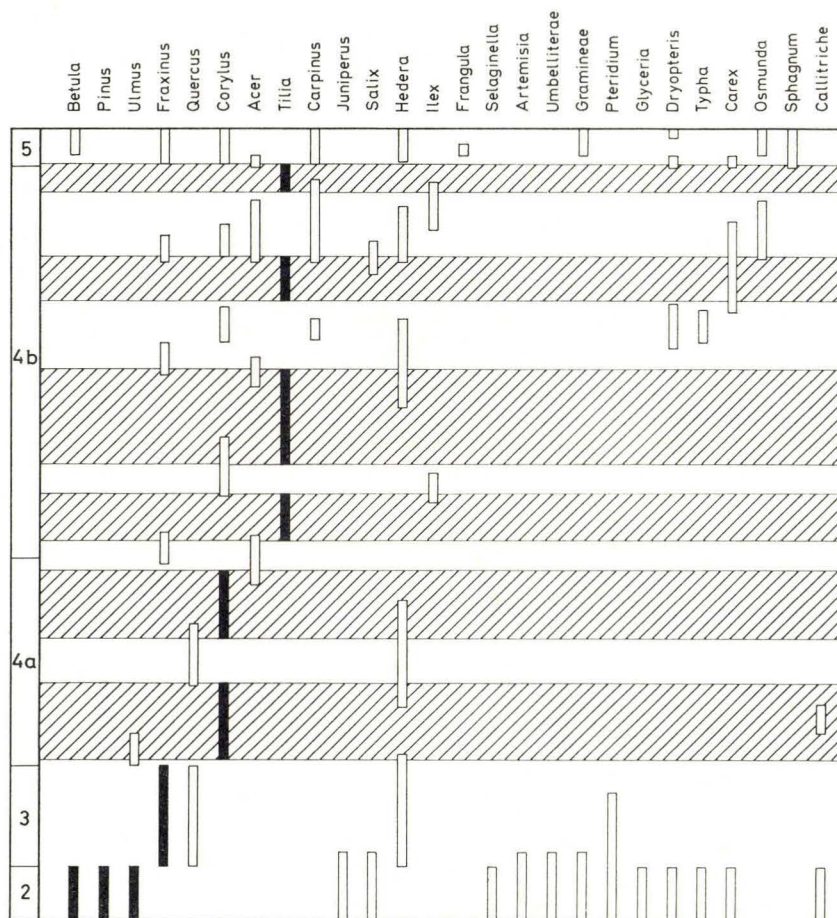


Fig. 2. Diagram showing the vertical extension of pollen and spore maxima. The black bars indicate the dominant plants. Shading indicates stages with a dense tree cover.

Fig. 2 illustrates changes in the density of the tree cover with the non-dominant plants particularly frequent in the stages with a more open tree cover. 6 stages with dense and 7 stages with open tree cover can be distinguished (shaded or white in Fig. 2).

The *Betula-Pinus-Ulmus* phase (2) had many shrubs and herbaceous plants, and the competition pressure was low probably because unstable soil prevented the establishment of a dense tree cover, as mentioned above. The change to the *Fraxinus* phase (3) can be explained as a result of soil stabilization. *Fraxinus* established itself at the cost of *Betula*, *Pinus* and *Ulmus*, and the illumination under the trees apparently decreased somewhat. Only *Quercus* and *Hedera* were frequent.

The *Corylus* phase (4 a) contained 2 stages with dense tree cover and an intermediate somewhat more open stage with low peaks of *Quercus* and *Hedera*.

There was apparently a slightly more open stage again between the *Corylus* and the *Tilia* phases (4 a and 4 b), with low peaks for *Fraxinus* and *Acer*. The *Tilia* phase (4 b) contained 4 dense stages with intermediate more open stages. The following plants had low peaks in the open stages: *Corylus* and *Ilex* (first), *Fraxinus*, *Corylus*, *Acer*, *Carpinus*, *Hedera*, *Dryopteris*, *Typha* (second), *Fraxinus*, *Corylus*, *Acer*, *Carpinus*, *Salix*, *Hedera*, *Ilex*, *Carex*, *Osmunda* (third).

The *Tilia-Carpinus* phase (5), was open again with low peaks for *Betula*, *Fraxinus*, *Corylus*, *Acer*, *Carpinus*, *Hedera*, *Frangula*, Gramineae, *Dryopteris*, *Carex*, *Osmunda* and *Sphagnum*.

3 tree species dominated the forest in the early *Betula-Pinus-Ulmus* phase, but only one tree species was superior in each of the successive vegetational phases at Egersund, in turn *Fraxinus*, *Corylus* and *Tilia*. Each of these tree species was superior to its predecessor and replaced it entirely. Whereas the *Fraxinus* expansion was delayed by soil instability, *Corylus* and *Tilia*, on the other hand, expanded soon after their appearance.

No time factor is known at Egersund (cp. Watts 1973), however, the steeply rising curves for *Fraxinus*, *Corylus* and *Tilia* suggest very rapid mass expansions. Hence it is possible that trees of a uniform age predominated in the various forest stages.

If mass expansion resulted in stands of uniform age, as suggested above, the alternation of dense and open stages in the *Corylus* and *Tilia* phases at Egersund probably reflect alternating generations, each of which reached a mature and then a weakening senescent stage. Mature stands of uniform age are endangered by storm catastrophes even in deciduous forest, as recent events in northern Europe have shown us, and large windthrows may occur in the primeval forests of southeast Europe (Fröhlich 1954). We may have to envisage that cyclic regeneration may be normal in primeval forests at least in limited areas.

Müller (1974) recently estimated the duration of the *Corylus* and the *Tilia*-zones to 2150–2350 years. This figure would allow about 350–400 years for each of the 6 *Tilia* and *Corylus* generations at Egersund, a maximum age, which is not unlikely.

The Eemian vegetational and landscape development

The Eemian regional pollen diagrams leave us without information as to whether the various species were mixed in a uniform vegetation cover or

Table 3. Pollen assemblage zones and vegetational differentiation in the Eemian in Denmark. The double lines indicate the transitions to strongly acid soil.

Regional pollen assemblage zone	Vegetational differentiation			
	dry	moist	wet	
<i>Pinus</i>	<i>Pinus</i>	<i>Pinus</i> ⁴⁾	<i>Calluna</i> ⁴⁾	telocra- cratic
<i>Pinus-Picea-Alnus</i>	<i>Pinus</i>	<i>Picea</i> ⁴⁾	<i>Alnus</i> ⁴⁾	oligo- cratic
<i>Picea-Carpinus-Alnus</i>	<i>Picea</i>	<i>Carpinus</i> ³⁾ ⁴⁾	<i>Alnus-Fraxinus-Taxus</i> ³⁾	
<i>Quercus-Corylus-Alnus</i> / <i>Tilia-Corylus-Alnus</i>	<i>Quercus</i>	<i>Corylus</i> / <i>Tilia</i> ¹⁾	<i>Alnus-Fraxinus-Taxus</i> ³⁾	meso- cratic
<i>Quercus-Corylus-Alnus</i>	<i>Quercus</i> ³⁾	<i>Corylus</i> ¹⁾	<i>Alnus-Fraxinus-Taxus</i> ³⁾	
<i>Quercus-Fraxinus</i>	<i>Quercus</i>	<i>Fraxinus</i> ¹⁾	<i>Fraxinus</i>	
<i>Betula-Pinus-Ulmus</i>	<i>Betula, Pinus, Ulmus</i> ¹⁾			proto- cratic
<i>Betula</i>	<i>Betula</i>			

¹⁾ represented at Egersund

²⁾ represented at Hygum Nymark (p. 65)

³⁾ represented at Kollund (p. 65)

⁴⁾ represented at Burg (p. 67)

whether a mosaic of various vegetation types occurred. The succession from Egersund gives a more precise picture, because communities on a single soil type are recorded. When the Egersund succession is compared with the other information available, a more differentiated picture of the Eemian vegetational development can be obtained. A survey is shown in Table 3.

Betula regional p.a.z.

The *Betula* regional p.a.z. had only one dominant, *Betula*, and it can be assumed that this tree predominated on all soil types.

Betula-Pinus-Ulmus regional p.a.z.

The succession from Egersund shows that *Betula*, *Pinus* and *Ulmus* formed a mixed forest community. These trees are also recorded in the regional pollen diagrams and there was apparently no vegetational differentiation.

Quercus-Fraxinus regional p.a.z.

Fraxinus predominated on the moist soil at Egersund and *Quercus* was probably restricted to the drier sites.

Quercus-Corylus-Alnus regional p.a.z.

Corylus replaced *Fraxinus* on the moist soil at Egersund, and *Quercus* was of restricted importance. *Quercus* probably tended to prevail on the better drained sites. At Hygum Nymark, near Rødding in central Jylland, a site not yet fully investigated (Fig. 1), the following corrected tree pollen spectrum was recorded.

<i>Quercus</i>	<i>Ulmus</i>	<i>Corylus</i>	<i>Pinus</i>	<i>Betula</i>	<i>Alnus</i>
79 %	3 %	6 %	5 %	7 %	0.4 %

Thelypteris dryopteris is recorded at 9 %, and no other herbaceous plants were represented. The spectrum shows a pure *Quercus* forest on an acid soil, probably acid mull.

Alnus and *Taxus* expanded simultaneously with *Corylus* in the regional pollen diagrams. These trees were not associated with *Quercus* and *Corylus*. A pollen spectrum from Kollund mentioned below suggests that these trees were associated with *Fraxinus* on the wet sites.

Quercus-Corylus-Alnus or Tilia-Corylus-Alnus regional p.a.z.

Quercus presumably still prevailed on the better drained and acid soils. *Tilia* replaced *Corylus* on the moist and fertile sites in southernmost Denmark and northern Germany, and pure *Tilia* forest with some *Corylus* dominated on the moist soil. A sample from the *Tilia-Corylus-Alnus* pollen assemblage recorded at Kollund not far from Egersund (Fig. 1) by Jessen and Milthers (1928) was re-analyzed, and a re-calculated treepollen spectrum is shown below.

<i>Quercus</i>	<i>Carpinus</i>	<i>Ulmus</i>	<i>Tilia</i>	<i>Corylus</i>	<i>Fraxinus</i>	<i>Taxus</i>	<i>Alnus</i>	<i>Pinus</i>	<i>Betula</i>
4 %	1 %	3 %	28 %	15 %	12 %	15 %	19 %	1 %	1 %

This spectrum has less *Tilia* and more *Fraxinus*, *Taxus* and *Alnus* than Egersund. *Fraxinus* and *Taxus* thus apparently were associated with *Alnus* on wet soil. Godwin (1956) mentioned mass occurrences of *Taxus* stumps in East Anglian fen peats from the Holocene, and *Taxus* remains are frequently recorded in Holocene peats in northwestern Germany (Firbas 1949, Averdick 1971).

The record from Egersund shows that the moist soils were still favourable in the *Quercus-Tilia-Alnus* regional p.a.z. Traces of acidification occur near the top of the zone.

Tilia platyphyllos was frequent at the beginning of the *Tilia* phase at Egersund, but this species was soon replaced entirely by *T. cordata*. Fruits of *Tilia platyphyllos* are recorded at 5 sites further north in Jylland, in-

cluding Herning (Fig. 1), and those of *T. cordata* at 4 (Hartz 1909, Jessen and Milthers 1928). *Tilia platyphyllos* was thus present during the *Tilia* expansion stage at Egersund and colonized far to the north together with *T. cordata*. Little is known about the ability of *Tilia platyphyllos* to compete with *T. cordata* under natural conditions to-day; however, *T. cordata* was superior in competition with *T. platyphyllos* at Egersund. The lack of a *Tilia* mass expansion further north in Jylland is puzzling. *Tilia* pollen occurs there at very low frequencies just before the transition to the *Picea-Carpinus-Alnus* regional p.a.z. (Plate 11), and it is likely that the oligotrophication which became prominent at that time (Andersen 1964 and later) prevented a *Tilia* mass expansion.

Picea-Carpinus-Alnus regional p.a.z.

Picea and *Carpinus* became dominant in the regional pollen diagrams from Denmark and North Germany, and the *Tilia-Carpinus* vegetational phase at Egersund is probably transitional to a *Carpinus* phase. A new re-calculated tree pollen spectrum from the *Carpinus-Alnus* pollen assemblage of Jessen and Milthers (1928) at the near-by Kollund site is shown below.

<i>Picea</i>	<i>Quercus</i>	<i>Ulmus</i>	<i>Tilia</i>	<i>Corylus</i>	<i>Carpinus</i>	<i>Fraxinus</i>	<i>Taxus</i>	<i>Alnus</i>	<i>Pinus</i>	<i>Betula</i>
4 %	2 %	2 %	5 %	4 %	47 %	6 %	8 %	20 %	1 %	2 %

If compared with the spectrum from Kollund above, it can be seen that *Carpinus* had replaced *Tilia* on the moist ground and that the *Fraxinus-Alnus-Taxus* forest on wet ground was rather unchanged.

Picea was absent at Kollund and Egersund, and *Picea* thus apparently was restricted to the driest sites, *Carpinus* prevailed on the moist sites, and *Alnus*, *Fraxinus* and *Taxus* on the wettest ground.

It was earlier assumed (Andersen l.c.) that the general oligotrophication notable in the *Picea-Carpinus-Alnus* regional p.a.z. was promoted by the expansion of *Picea* on the upland soils. The sequence from Egersund has shown that the low-lying moist soils became acid by a selfinduced process, which promoted the expansion of *Carpinus*. Only the *Alnus-Fraxinus-Taxus* forest on the wet ground was unaffected.

Pinus-Picea-Alnus regional p.a.z.

The *Pinus-Picea-Alnus* regional p.a.z. is known only from lake sites in Denmark. Dücker and Menke (1970) mention an Eemian hydro-mor from

Burg in Dithmarschen (Fig. 1) with an interesting local succession from a *Carpinus-Alnus* phase to a *Picea-Carpinus-Alnus* phase. *Picea* thus replaced *Carpinus* on the moist sites. *Pinus* became increasingly common in the regional pollen diagrams and probably replaced *Picea* on the drier soils. The soils thus became increasingly acid and poor. *Fraxinus* and *Taxus* decreased, but *Alnus* forest was still preserved on the wettest sites flushed by ground-water.

Pinus regional p.a.z.

The *Picea-Carpinus-Alnus* phase in the hydro-mor at Burg mentioned above was replaced by a *Pinus-Calluna* phase. *Picea* and *Alnus* disappeared in the regional pollen diagrams, and *Pinus* and *Calluna* apparently prevailed.

Conclusion

The studies reviewed above allow a more detailed picture of the Eemian vegetational development.

The vegetation in the *Betula* and the *Betula-Pinus-Ulmus* pollen assemblage zones was essentially protocratic in Iversen's sense. The forest was still of a pioneer character, no dense tree cover had developed and open-ground plant communities were frequent. The *Quercus-Fraxinus* pollen assemblage zones had a denser tree cover and initiated the mesocratic stage of the Eemian. The vegetation of the *Quercus-Corylus-Alnus* and the *Quercus-Tilia-Alnus* pollen assemblage zones was essentially mesocratic with a dense tree cover and mull soils; however, the occurrence of *Pteridium* spores in the *Betula-Pinus-Ulmus* and the *Quercus-Fraxinus* pollen assemblage zones (cp. Andersen 1969) and *Thelypteris dryopteris* at Rødding (p. 65) indicate initial acidification of the better drained soils at an early time.

Acidification of the well drained and the moist soils became prominent in the *Picea-Carpinus-Alnus* pollen assemblage zone, and an acidophilous vegetation characteristic of open habitats with *Pinus*, *Betula*, *Populus*, *Ilex*, *Juniperus*, *Pteridium* and *Calluna* became increasingly common, emphasizing the transition to the oligocratic stage (Andersen 1964 and later). The wettest habitats with *Alnus-Fraxinus-Taxus* vegetation were less affected. Progressive mor accumulation led to the dominance of *Pinus* and *Picea* in the *Pinus-Picea-Alnus* pollen assemblage zone, and *Fraxinus* and *Taxus* disappeared on the wet habitats, where only *Alnus* remained. *Pinus* and *Calluna* finally became dominant in the *Pinus* pollen assemblage zone, where the disappearance of *Ilex*, *Pteridium* and *Osmunda* indicates the transition to the telocratic stage (cp. Andersen 1969).

Soil maturation thus profoundly affected the Eemian vegetational development even on fertile soils, and it appears that this process was self-induced and progressed without climatic influence until near the end of the Eemian, where climatic change promoted an expansion of heath vegetation poor in trees (cp. Andersen 1957), the telocratic stage in Iversen's cycle.

Acknowledgements. The peat at Egersund was discovered in 1935 by Mr. Waldemar Nielsen, Egersund, who sent a sample to the Geological Survey of Denmark. Later, Mr. Nielsen assisted the author in re-locating the site. Mr. Jørgen Schmidt, Broager, collected a sample in 1949 and sent it to the Geological Survey. The visit by swim divers was made possible through the courtesy of inspector O. Crumlin Petersen, the National Museum in Copenhagen. The coring was carried out by Drs. E. Streif and H. Merkt, Hannover, with equipment loaned from the Bundesanstalt für Bodenforschung by permission from Professor G. Lüttig, Vice-President. Professor G. F. Mitchell, Dublin, kindly identified the macrofossils from Egersund. The author wishes to express his gratitude for interest shown and help offered by the persons mentioned above.

Dansk sammendrag

Fortolkningen af pollendiagrammer fra Eem-Interglacialtidens søaflejringer vanskeliggøres dels ved det manglende kendskab til vegetationens reelle sammensætning, dels ved det utilstrækkelige kendskab til dennes uddifferentiering i plantesamfund. Den første mangel kan afhjælpes ved en korrektion af pollendiagrammerne, den anden ved undersøgelse af ganske små mosehuller, hvor kun den omgivende vegetation er repræsenteret. Et sådant lille mosehul i Flensborg Fjord ud for Egersund er undersøgt. Her findes en succession af birke-fyrre-elmekov, askeskov, hasselskov, lindeskov og lindeskov. Lindeskov fra Eem-Interglacialtid er i Danmark kun påvist ved Egersund og ved Kollund, som blev undersøgt af Jessen og Milthers (1928), og nordgrænsen for lindeskov har forløbet i det sydligste Jylland, mens der længere nordpå kun har været spredte lindeforekomster. På grundlag af pollenanalyser fra Egersund og andre lignende forekomster er det muligt at opnå et billede af skovens sammensætning og jordbundsudviklingen på henholdsvis tør, fugtig og våd bund i Eem-Interglacialtiden (Table 3).

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Biostratigraphic studies in Late Weichselian sediments near Böllingsö

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Stockmarr, Jens: Biostratigraphic studies in Late Weichselian sediments near Böllingsö. *Danm. geol. Unders., Årbog 1974*, pp. 71–89, pls. 8–10. København, 18. september 1975.

Three pollen diagrams, two fruit and seed diagrams and 18 radiocarbon datings have been carried out on Late Weichselian gyttja and peat layers, 1½ km from the former outlet from the lake Böllingsö. Although some radiocarbon datings give an age of more than 12,000 B.P., the sediments can not be accepted as having this age. The explanation is that Bölling peat was rebedded at this locality in the Allerød period. This explanation should not be applied to Böllingsö, where the Bölling period layers are incontrovertible. The upper Younger Dryas sediments also contain rebedded older material in great amount. The diagrams cover the period from probably late Older Dryas to Pre-Boreal.

The first description of the profile at the Böllingsö Canal was made by Johs. Iversen, Alfred Andersen and Harald Krog in 1946. The canal had recently been dredged, and a 35 m long section was drawn and described very precisely. Samples were taken for pollen analysis and a preliminary pollen diagram from the transition Younger Dryas-Preboreal was made by Iversen.

In 1952 radiocarbon dating was made possible, and a new excavation in the side of the canal was investigated by Harald Krog and Alfred Andersen. This time a series of pollen samples were taken, and a diagram with radiocarbon datings was made by Harald Krog (Böllingsö Canal 1 in this article (Fig. 3)). In 1958 a boring was made by Harald Krog approximately 5 m from the diagram to collect samples for more radiocarbon datings (in brackets in diagram 1 (Fig. 3)). Because of two datings of Bölling age at the bottom of the profile, Iversen interpreted the lowermost part of the diagram as possibly belonging to the Bölling period.

On the basis of this assumption a new excavation was made in 1971. The

participants were F. W. Shotton, G. Russel Coope and Peter Osborne, from the University of Birmingham, and Johs. Iversen, Harald Krog and Jens Stockmarr from the Geological Survey of Denmark. The purpose was to collect material from the periods Bölling, Older Dryas and Alleröd for entomological studies in Great Britain, and palynological studies in Denmark. Unfortunately the palynological studies and the radiocarbon dating showed that no Bölling sediments at all were found, and even the Older Dryas sediments are debatable.

Geology

The site is placed approximately 1½ km west of the outlet from Böllingsö, the type locality for the Bölling period (Iversen 1942, 1954). Fig. 1 shows the location of the site in central Jutland. To the north-east, the glacial disturbance is of Weichselian age, while it is still not confirmed whether the Weichselian ice reached the sediments to the south-west. Between lies the meltwater valley with the Böllingsö on the water divide and with Funder river running southwards and Karup river running westwards. In early Postglacial time a great part of the valley was covered by a lake. Later a Sphagnum bog developed, and the lake only continued to exist in the central part of the valley, as Böllingsö, until the late 19th century, when the uppermost part of Karup river was straightened and dredged and got the name Böllingsö Canal. Böllingsö was reclaimed, the bog was drained and has in recent times been almost totally cut away.

In 1971 a trench in the Late Weichselian sediments was excavated with a bulldozer, and Plate 8 shows the section on the north side, approximately 1½ m high. The number of meters in Plate 8 refer to a basic point which has been used during all excavations at the site. The vertical arrows point to the lowest organic layer, which is underlain by grey sharp sands. Because of the high ground water level, it was not possible to expose the peat all through the section.

In Plate 9 is seen a compiled profile with datings inserted. The lower gyttja and peat layer from 30 to 53 cm consists of a coarse drift gyttja with twigs at the bottom, and of moss peat at the top. This is the organic layer which in Plate 8 is shown with vertical arrows. Above, separated by more or less thin sand layers, are found two other organic layers from 86 to 90 cm and from 97 to 101 cm. The layers are separated in two bands to the west while in the rest of the section they are almost fused (particularly clearly in Plate 8 between 20 and 25 metres where these layers are the only exposed organic layers). Then follows brooksand with a lot of thin organic

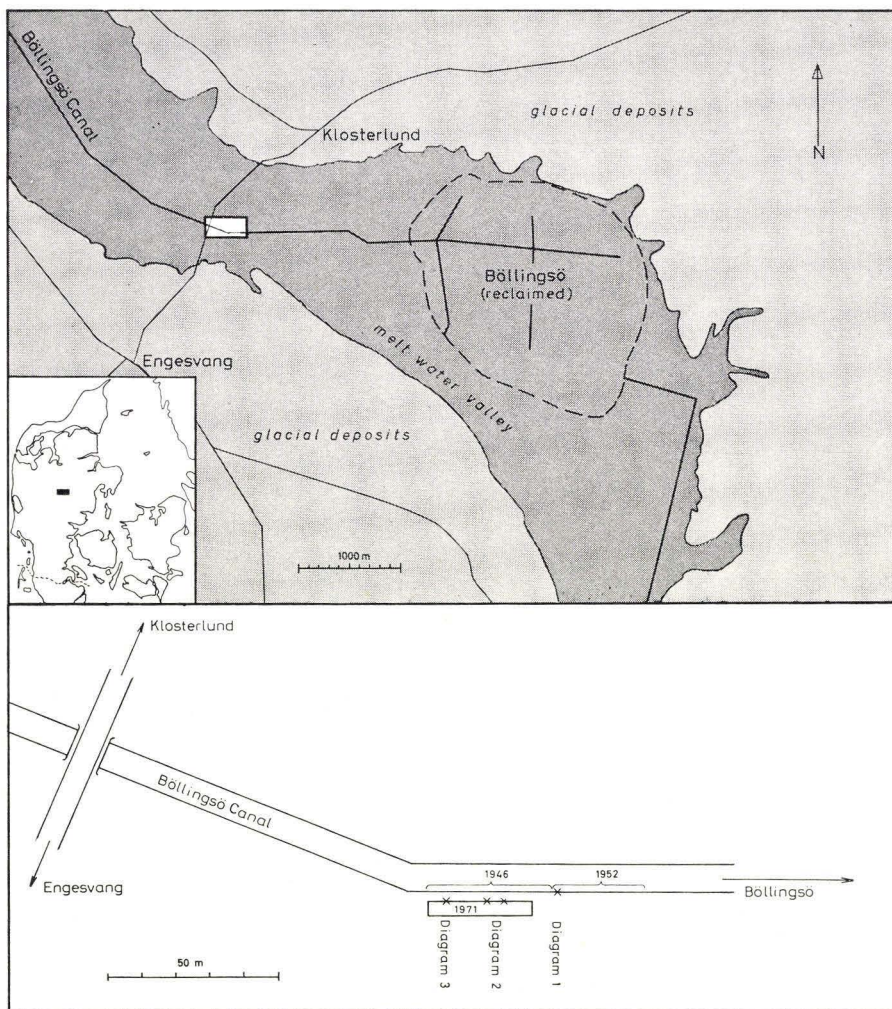


Fig. 1. Location of the site in Jutland. Excavations took place in 1946, 1952 and 1971. Diagram 1 is from the 1952 excavation while diagram 2 and 3 are from 1971. Diagram 2 is composed of 2 profiles within a distance of 5 metres.

bands consisting of drifted material, and above the whole section follows an algae gyttja (not seen in Plate 9).

Starting from the bottom in diagram 2 (Fig. 4), the first sediment is grey sand with drifted material (mainly moss leaves, and twigs in the upper part). From 19 cm is found a coarse drift and detritus gyttja which at about 30 cm changes to a moss peat with gyttja. The sand layer at 38 cm is the same as the more than 30 cm thick sand layer above the lower peat

in the west end of the section (between K 1904 and diagram 3 in Plate 8). The layer from 38 to 53 cm is the same as the two organic layers which are almost fused lying between 20 and 25 metres in Plate 8. The layers consist of mixed plant material with some sand and are often somewhat laminated. Somewhere (i.a. where K 1904 was taken) the layer consisted of almost pure moss. Above follows yellow sand with organic bands and with diffuse organic material near the top. From 112 cm follows a soft greenish algae gyttja with a structure like bakers yeast.

The same sediment sequence can be found in diagram 1 (Fig. 3), while in diagram 3 (Fig. 5) it is somewhat different. Corresponding to the lower gyttja and peat in diagram 2 (19–38 cm), is here found a peat with very little gyttja. The main component in this peat is *Cyperaceae* leaves and, above this, almost pure moss.

Radiocarbon datings

18 datings have been made at the Carbon-14 Dating Laboratory, Copenhagen, under the supervision of Henrik Tauber (see Table 1). The age calculations are based on a half-life for radiocarbon of 5570 years.

Table 1. Radiocarbon datings.

Number	Years B.P.	Material	Location
K 110	10,970±300	noncalcareous gyttja ÷ fine detritus	diagram 1, 50 cm
K 111	10,500±350	noncalcareous gyttja	diagram 1, 98 cm
K 112	11,900±360	moss peat ÷ fine detritus	not in diagrams
K 833	10,590±160	moss peat	diagram 1, (28 cm)
K 834	12,140±150	gyttja with small twigs	diagram 1, (1 cm)
K 844	12,320±160	gyttja with small twigs	diagram 1, (3 cm)
K 845	10,570±160	moss peat	diagram 1, (30 cm)
K 1900	11,970±160	fine detritus from sand, mainly moss leaves	diagram 2, 4 cm
K 1901	12,510±140	fine detritus from drift gyttja	diagram 2, 20 cm
K 1902	11,090±130	fine detritus from peat	diagram 3, 11 cm
K 1903	10,400±130	fine detritus from moss peat	diagram 3, 23 cm
K 1904	11,190±130	fine detritus from peat	Plate 8, 33.5 m
K 1922	9,310±130	Betula twig	diagram 2, 112 cm
K 1973	11,880±140	fine detritus from sand, mainly moss leaves	diagram 2, 10 cm
K 1974	10,450±160	pure moss	diagram 3, 21 cm
K 2000	11,970±200	twigs from drift gyttja	diagram 2, 20 cm
K 2002	11,550±160	twigs from drift gyttja	diagram 2, 24 cm
K 2003	10,250±200	pure moss	diagram 3, 17 cm

The samples K 110 – K 112 have been published by Anderson, Levi & Tauber and by Iversen in 1953 without correction for the Suess-effect.

K 833 – K 845 derive from the boring made approximately 5 m from diagram 1 by Harald Krog in 1958. According to the description they can be equated with diagram 1 and are shown in brackets at the approximate level.

It is not possible to place K 112 stratigraphically because it is situated more than 20 m east of diagram 1, but on the basis of the old section it is supposed to belong to the two fused organic layers. K 1904 is taken in the lower of these two layers at 33.5 m (Plate 8). This dating, $11,190 \pm 130$ B.P., is very important as the sample is taken in the section above diagram 3 (see Plate 8) where more samples are found to be 800 years younger.

K 1901 and K 2000 are from two different fractions of the same sample.

The samples K 1973 – K 2003 have been treated with KOH to dissolve any secondarily deposited humates.

Methods

The diagrams are called Böllingsö Canal 1, 2 and 3, pollen diagram (Fig. 3–5), and 2 and 3, fruit and seed diagram (Fig. 6), where the numbers refer to their location given in Fig. 1 and Plate 8.

The lowermost 31 cm in diagram 1 (Fig. 3) were taken with a Hiller sampler, while the rest of the samples were taken in the section just behind.

Pollen diagram 2 (Fig. 4) is also a composite diagram. The lowermost 26 cm were taken in a barrel and these samples could also be used for radiocarbon datings and fruit and seed analysis (fruit and seed diagram 2 (Fig. 6)). Up to 40 cm the samples were taken in the open section just behind the barrel, and here no macrosamples were taken. All these samples were taken at about 19 m (Plate 8), while the samples from 40 to 105 cm were taken in the open section at 15 m. The uppermost few samples were taken 20 m away from the others and are only given to make the comparison with diagram 1 complete. There is a gap in time between the samples above and below 105 cm. It should be mentioned that the zero points for the depth are arbitrarily chosen in each profile. Plate 9 has its own zero point.

The pollen samples have been treated with potassium hydroxide, hydrofluoric acid and acetolysis, and were transferred to silicone oil. The calculation sum is a total, unreduced sum, and only aquatics and rebedded tertiary and interglacial pollen grains have been excluded. Approximately 500 grains have been counted per sample, except for those with a high proportion of *Cyperaceae*, where more than 1000 grains were counted. The rebedded

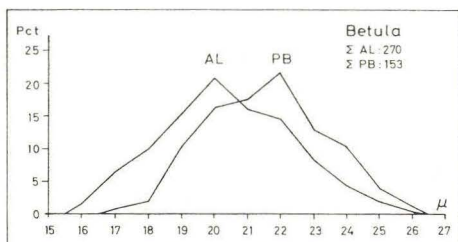


Fig. 2. Size distribution of *Betula* pollen in 5 added analyses from Alleröd (AL) and 2 added analyses from Preboreal (PB). The calculation sum is given to the right. The arithmetic mean for the Alleröd distribution is 20.4 microns while it is 21.6 microns for the Pre-Boreal distribution. The difference is statistically significant. The Alleröd curve is supposed to represent mainly *Betula nana* and the Pre-Boreal curve *Betula pubescens* type.

pollen has not been used for correction of the curves. The zonation is given in accordance with Knud Jessen (1935) and Iversen (1942). The pollen diagrams are very local and are dominated by the *Cyperaceae*.

A list of pollen types which are omitted in the pollen diagrams is given in Table 2.

Betula pollen grains have been measured in some pollen samples. Measurements from 5 Alleröd peat samples have been added, and the size distribution is demonstrated in Fig. 2 (AL), where it is compared with the size distribution of *Betula* pollen grains from the Preboreal transition from sand to algae gyttja (PB). There is a small, but statistically significant difference between the two curves, though it need not prove a difference in species. The very close position of the two peaks is due to the mounting medium, silicone oil (Berglund & Digerfeldt 1970), and in this connection it must also be mentioned that the material has been treated with hydrofluoric acid. The Preboreal *Betula* pollen must be mainly *Betula pubescens* type, while the *Betula* pollen from Alleröd is probably dominated by *Betula nana*. This is also in agreement with the fruit and seed diagrams, where all *Betula* fruits are referred to *Betula nana*, though not all had their wings well preserved. In the macro-fossil samples were also found 20 catkin scales and one leaf from Alleröd, one catkin scale from the supposed Older Dryas and one leaf from early Younger Dryas, all from *Betula nana*.

The fruit and seed samples have been treated with diluted nitric acid for one or more days and then sieved on an 18 (1.0 mm) and a 35 (0.5 mm) mesh sieve. The diagrams are percentage diagrams and the sums are given to the right. All fruits and seeds are included in the sum, but a few are omitted. 8 samples from below diagram 2 have also been examined but only 25 seeds of *Cyperaceae* and one *Potamogeton filiformis* fruitstone were found.

Older Dryas, pollen zone I c

The Older Dryas is probably only represented in diagram 2. In the pollen diagram no clear difference can be seen between Alleröd and Older Dryas, and only the small *Helianthemum oelandicum* maximum suggests the presence of Older Dryas. The high *Betula* values are difficult to interpret, as it was expected that even *Betula nana* had low values in Older Dryas. In the fruit and seed diagram a marked change is seen from a vegetation of different distigmate *Carex* spp. with *Potentilla palustris*, *Empetrum nigrum* and *Carex* cf. *rostrata* to a more varied flora dominated by *Carex* cf. *rostrata*, distigmate *Carex* spp., *Empetrum nigrum* and *Potentilla palustris*. The two datings $11,970 \pm 160$ B.P. (K 1900) and $11,880 \pm 140$ B.P. (K 1973) at the transition to Alleröd are probably reliable, but both the standard error and the possibility of contamination with older material (compare with the Alleröd datings, see below) makes it possible that the samples were deposited in early Alleröd.

Alleröd, pollen zone II

6 datings have been carried out on supposed Alleröd material. The first two were made in 1963 from the bottom of the gyttja in the boring near diagram 1, and gave $12,320 \pm 160$ B.P. (K 844) and $12,140 \pm 150$ B.P. (K 834). Then in 1972 a dating was made on the lowermost part of the coarse drift gyttja, in diagram 2. The dating was made on the fine detritus fraction and gave $12,510 \pm 140$ B.P. (K 1901). As it did not fit in with the pollen diagram a new dating was made, but this time on twigs from the coarse fraction of the same sample. This dating gave $11,970 \pm 200$ B.P. (K 2000), distinctly younger than the first one, and it was decided to trust neither this one, nor the three datings of Bölling age. The next dating from diagram 2 was $11,550 \pm 160$ B.P. (K 2002) also made on twigs, and also this one may be a little too old. The last dating was made on fine detritus from the upper Alleröd moss peat in diagram 3, and should give a fully reliable dating, $11,090 \pm 130$ B.P. (K 1902), shortly before the climatic deterioration.

The pollen curves are very smooth during the Alleröd period and the cool period (II b) which is found in other pollen diagrams (i.e. Krog 1954) can not be shown here. It is characteristic that *Populus*, *Juniperus*, *Hippophaë* and *Helianthemum oelandicum* reach their maximum values in early Alleröd or just before (*Helianthemum*). It must be emphasized that the lower limitation for the Alleröd zone is only given on the basis of the fruit and seed diagram 2 and other explanations for the change in this diagram may be found. But the changes in the fruit and seed diagram 2 are very

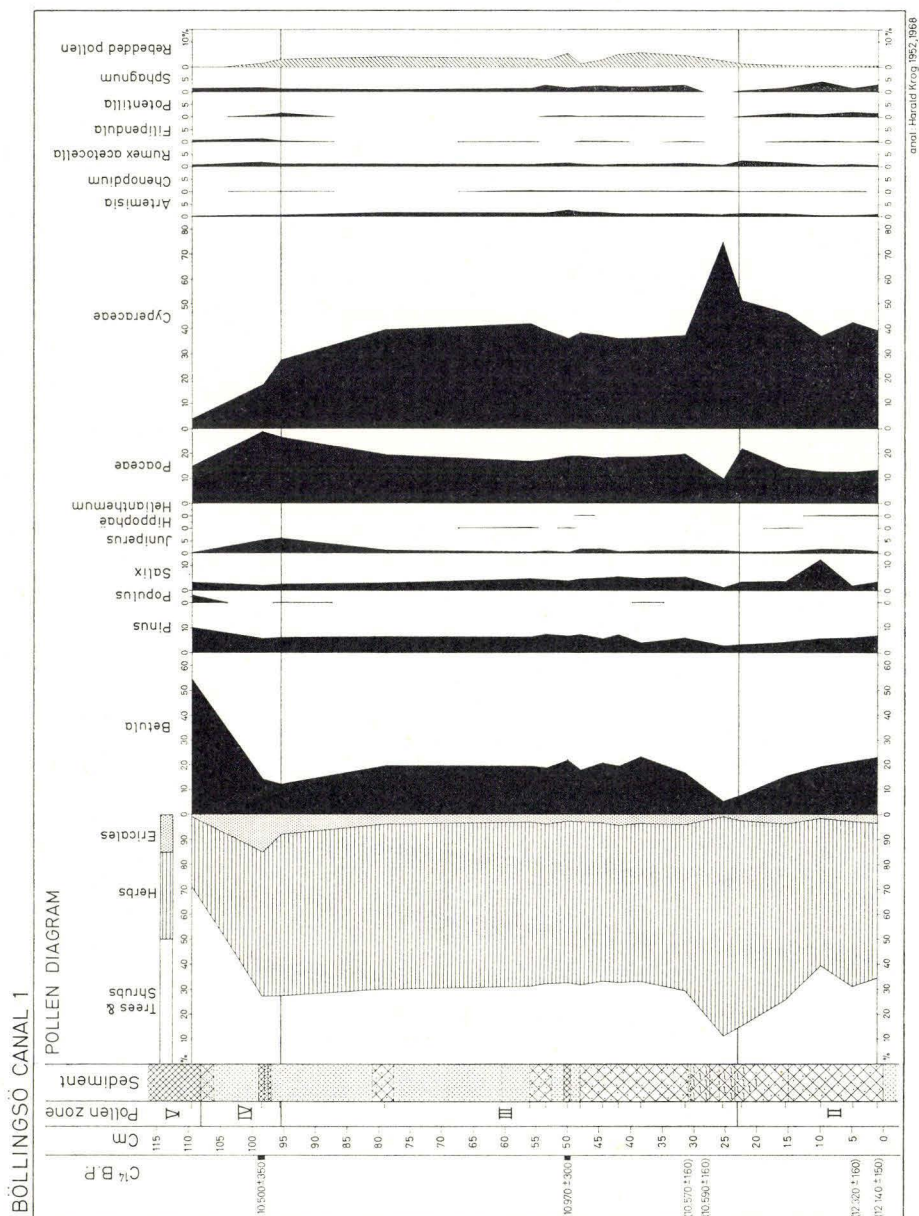


Fig. 3. Pollen diagram 1, a percentage diagram based on a total unreduced sum (appr. 500 grains per sample). The radiocarbon datings in brackets are from a boring appr. 5 m from the diagram. Because of the radiocarbon dating reversion, the pollen in the samples from 31 to 95 cm is expected to contain quite a lot of rebedded older pollen (mainly of Allerød age).

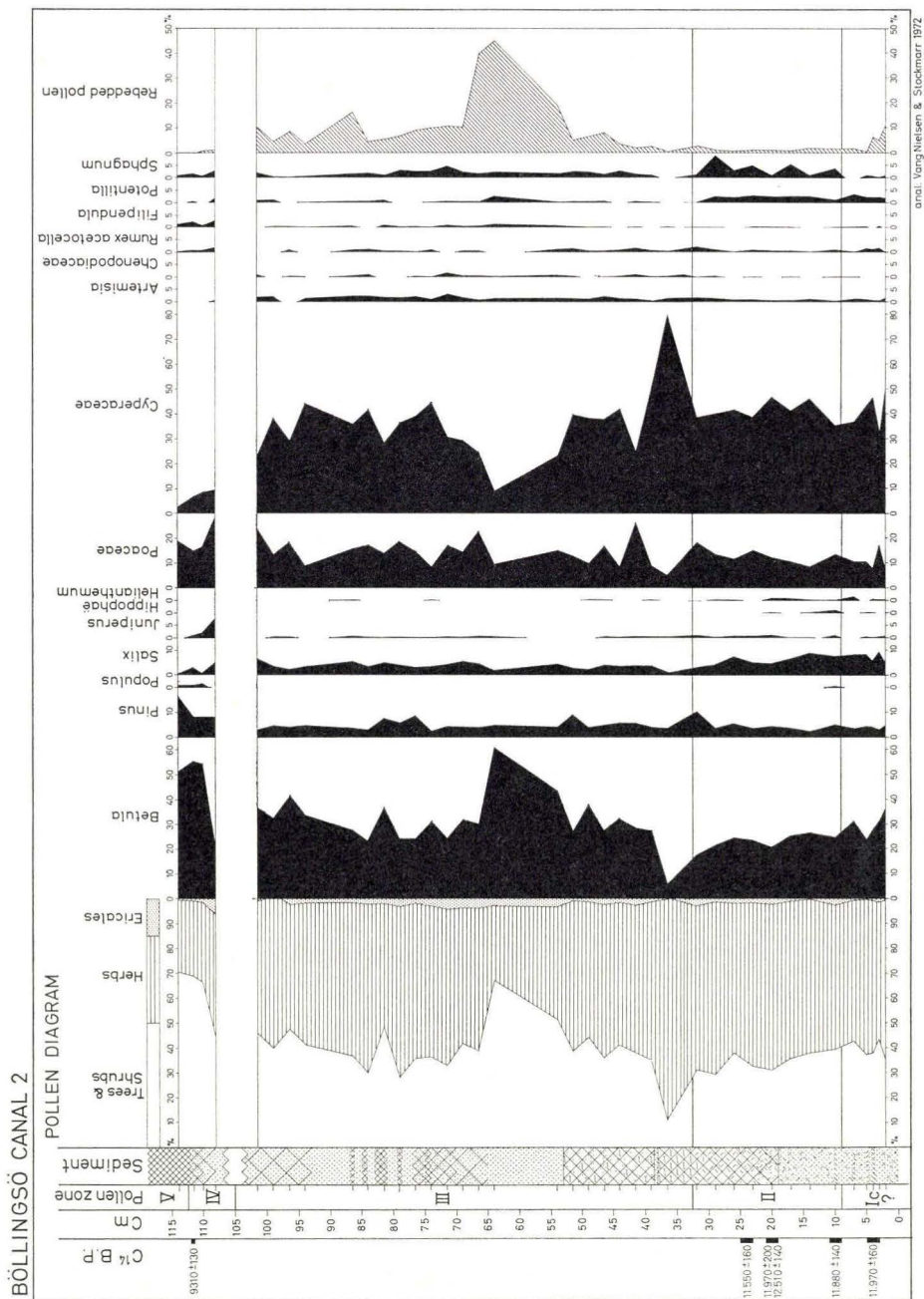


Fig. 4. Pollen diagram 2, a percentage diagram based on a total unreduced sum (app. 500 grains per sample). The samples from 39 to 103 cm are thought to contain quite a lot of rebedded older material (mainly of Alleröd age) (compare Fig. 3). The two datings at 20 cm are from the same sample, but from two different fractions. They are too old in relation to the datings below and the samples are expected to be dominated by rebedded Bölling material.

remarkable and a climatic explanation seems probable. The expansion or immigration of *Empetrum*, *Arctostaphylos* and distigmate *Carex* at the expense of tristigmate *Carex* (probably all *Carex rostrata*) and the immigration of all the aquatics is striking.

The diagrams demonstrate a mixture of different plant communities. The valley slopes were probably covered with a *Betula nana* – *Cyperaceae* – *Empetrum nigrum*-heath with *Juniperus communis* and *Hippophaë rhamnoides*. *Arctostaphylos uva-ursi*, *Arctostaphylos alpina*, *Stellaria graminea*, *Gymnocarpium dryopteris*, *Campanula*, *Lycopodium annotinum*, *Astragalus alpinus*, *Plantago major*, *Plantago media* and probably some *Cyperaceae*, *Poaceae* and *Tubuliflorae* may have grown in sheltered areas. That the vegetation was not fully closed is seen from the occurrence of *Equisetum*, *Artemisia*, *Chenopodiaceae*, *Rumex acetosella*, *Thalictrum* and also, in early Alleröd, *Helianthemum oelandicum*. Rare types such as *Selaginella selaginelloides*, *Dryas octopetala* and *Plantago maritima* are also examples of this open vegetation type. The latter plants are almost indifferent as regards temperature and they were more common in the light open vegetation of the Dryas periods, than in Alleröd.

The vegetation on the lower part of the slopes is often richer in more demanding species than the upper slope because of outbursting springs, together with the high insolation on south to west exposed slopes. On such slopes an open *Salix* scrub may have grown. *Pteridium aquilinum*, cf. *Anemone* and *Urtica* cf. *dioeca* (only one grain of each) could be due to contamination.

In the valley was found a poor sedge fen dominated by *Carex* cf. *rostrata*, other *Carex* species, *Potentilla palustris* and *Sphagnum*, with small amounts of *Caltha palustris*, *Menyanthes trifoliata* and *Montia lamprosperma*. *Empetrum nigrum* may also have grown in drier parts of the fen. Other plants such as *Butomus umbellatus* (one grain in early Alleröd, first Danish find, Plate 9), *Filipendula ulmaria*, *Tofieldia* cf. *calyculata*, and *Typha latifolia* may have grown either near the transition from fen to valley slope or near the river which must have been running from Böllingsö. In the river may have grown *Batrachium* cf. *aquatile*, *Hippurus vulgaris*, *Potamogeton alpinus* (one fruitstone), *Potamogeton filiformis* and *Potamogeton vaginatus*, though some of them may rather have been brought in by the water from Böllingsö, from where some of them are known. *Potamogeton vaginatus* has earlier been found as a fossil in Denmark by dr. Tilo Nötzold, DDR, in samples from Alleröd in Böllingsö (unpublished). *Potamogeton filiformis* has been determined from Böllingsö by Inger Brandt (1954). *Potamogeton alpinus* has not been found in Late Weichselian sediments in Jutland before, but is known from Zealand. *Potamogeton alpinus*

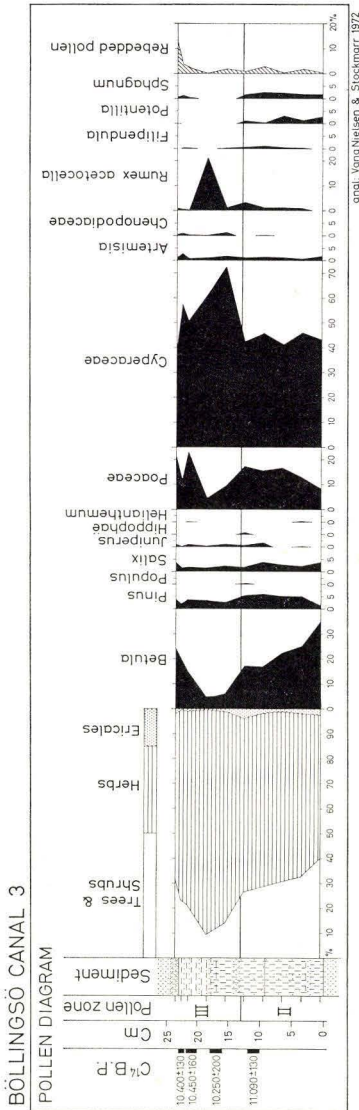


Fig. 5. Pollen diagram 3, a percentage diagram based on a total unreduced sum (app. 500 grains per sample). Only the topmost sample may be dominated by rebedded older material.

and *P. filiformis* are today found throughout Scandinavia, the latter often in brackish water. *Potamogeton vaginatus* is only known from brackish water in Bottenviken and a few lakes near the coast (Hultén). The *Potamogeton* fruitstones are illustrated in Plate 10.

Concerning the climate and environment of the Alleröd period, it is interesting to compare the recent distribution of *Arctostaphylos alpina* with

Typha latifolia (diagram 1, 1 and 5 cm) and *Butomus* (diagram 2, 14 cm) (Hultén 1971). The former is represented by 25 seeds in the samples, the latter two by 2 pollen tetrads and one pollen grain (Plate 9). One grain from *Butomus* has earlier been found by Berglund (1966) from early Preboreal in Blekinge, Sweden. *Typha latifolia* is not found today above the 14°C isotherm for July (Hultén, 1971). *Butomus* follows *Typha latifolia*, but is also known, in a sterile form, from a few localities in the north between the 13° and 14°C isotherm for July. *Arctostaphylos alpina* is almost only found in areas with a temperature below 13°–14°C in July, because it is shaded away by the forest in areas with higher temperatures. In Alleröd, with a temperature above 14°C in July and no shading trees, both plants could live in the same area in their respective biotopes.

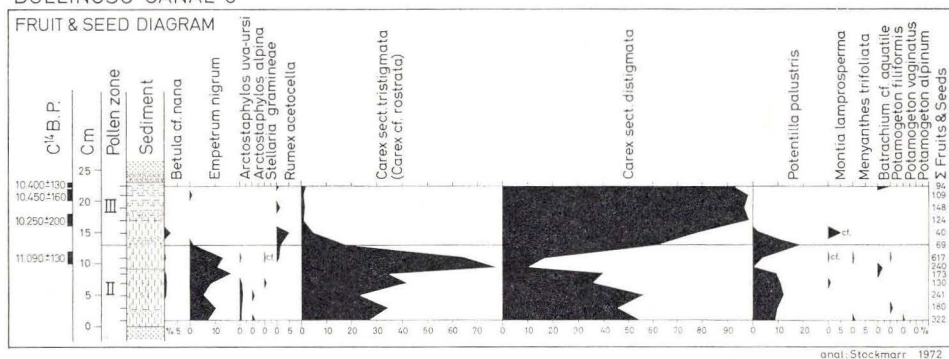
Younger Dryas, pollen zone III

While the lower limit for Alleröd is somewhat dubious, the upper one is absolutely clear, both in the pollen diagrams and in fruit and seed diagram 3. Suddenly the distigmate *Carex* species spread and the majority of the other plants receded. This is specially clear for *Betula*, *Empetrum*, *Filipendula*, *Poaceae*, *Potentilla* and *Sphagnum*. But the Heliophytes from Alleröd kept their position and may even have conquered a greater area. These plants were *Artemisia*, *Chenopodiaceae*, *Rumex acetosella* and *Thalictrum*. Plants like *Armeria maritima*, *Chamaenerion angustifolium*, *Dryas octopetala*, *Saxifraga* spp. and *Selaginella selaginoides* were uncommon in Alleröd, but spread in Younger Dryas. The few pollen grains of *Helianthemum oelandicum* and *Hippophaë rhamnoides* may be rebedded pollen from Older Dryas or early Alleröd. Two pollen grains from *Pleurospermum austriacum* (new in Jutland) were found in diagram 2 and 3 at the upper end of the *Cyperaceae* maximum. Their value as winter temperature indicators has already been described by Iversen (1954).

There are 6 datings from Younger Dryas in the diagrams, and of these 4 are from the upper end of the *Cyperaceae* maximum and one from the maximum itself. 5 of the 6 datings are made on moss peat or pure moss and should thus be fully reliable. Together they date the upper part of the *Cyperaceae* maximum to 10,400–10,500 B.P. This makes the older part of the Younger Dryas very thin, and the possibility of a hiatus cannot be denied.

Above the *Cyperaceae* maximum and until the transition to Preboreal, or in Plate 8, from the tip of the vertical arrows and to the top of the sands, gyttja with sand, sand with gyttja and pure sand are found; these

BÖLLINGSÖ CANAL 3



BÖLLINGSÖ CANAL 2

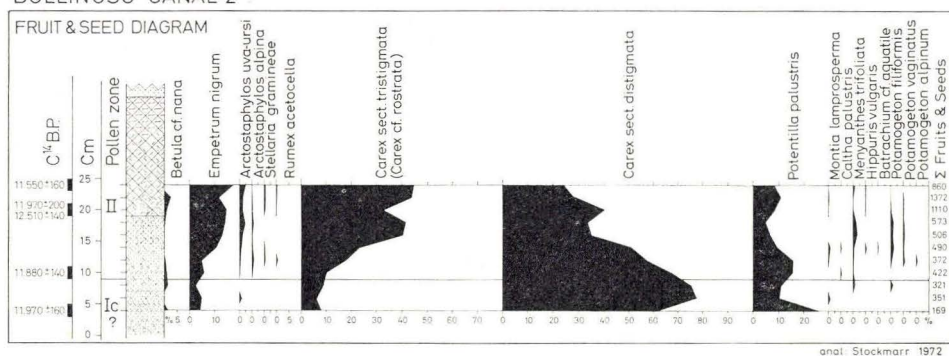


Fig. 6. Fruit and seed diagram 2 and 3, percentage diagrams, based on a total sum (to the right). Sieves with 0.5 and 1.0 mm meshes have been used. Diagram 2 corresponds to the lower part of pollen diagram 2 (Fig. 4) and diagram 3 corresponds to pollen diagram 3 (Fig. 5).

must all have been very quickly deposited and must be looked upon as a mixture of some primary sediment and rebedded Alleröd and older material. This situation is also elucidated by the radiocarbon dating at 50 cm in diagram 1, $10,970 \pm 300$ B.P. (K 110) and the dating mentioned above (K 1904) $11,190 \pm 130$ B.P. Both datings are from samples overlying younger material, and so the upper part of the Younger Dryas in the diagrams must be looked upon with some scepticism. The dated layer at 50 cm in diagram 1 is the same as the thin layer at 86 cm in diagram 2. The layer is indicated by two horizontal arrows in Plate 8. A dating made in Cambridge of a sample taken between diagram 1 and 2 in the same layer, gives an age of $10,340 \pm 240$ B.P. (Birm. 354, Shotton & Williams 1973). This dating seems to give the true age of the layer. So this sample must have been almost pure primary sediment, while the sample from diagram 1 must have contained quite a lot of rebedded older material.

In diagram 1 the pollen analyses were only made on samples from more or less pure gyttja layers, and the curves are steady but with rebedded material. In diagram 2, however, all layers have been analysed and a much higher proportion of rebedded pollen grains are found, and so the pollen curves are fuzzy.

From the pollen curves and the radiocarbon datings it is supposed that the uppermost part of the lower organic layer (shown with vertical arrows in Plate 8), which contains the *Cyperaceae* maximum (pollen diagram 1, 23–30 cm, pollen diagram 2, 33–38 cm and pollen diagram 3, 13–23 cm) is the only layer dominated by primarily sedimented Younger Dryas pollen grains. The rest of the pollen curves from Younger Dryas are dominated by pollen grains of an Alleröd age or older.

The dominating plant community in the upper part of Younger Dryas probably was a light open *Betula nana* – *Empetrum nigrum* – *Poacea* – heath with many light plants of which a few were associated with moist ground. Pollen grains of the following light plants have been found, and are supposed to be mainly primary: *Equisetum*, *Lycopodium annotinum*, *Huperzia Selago*, *Botrychium*, *Selaginella*, *Gymnocarpium*, *Armeria maritima*, *Artemisia*, *Parnassia*, *Polygonum convolvulus*, *Rumex acetosella*, *Saxifraga aizoides*, *Saxifraga hirculus* and *Sedum*. *Plantago lanceolata* (3 grains) must for the moment be looked upon as rebedded interglacial pollen. *Ephedra distachya* type (2 grains), *Ephedra strobilacea* type (2 grains) and one undetermined *Ephedra* grain have been found in Younger Dryas. All *Ephedra* were found in organic layers, and two of them, one of each species, were found in the lower part of Younger Dryas with the *Cyperaceae* maximum.

The moist and wet ground was dominated by a *Carex* community with *Sphagnum* and *Parnassia* (one grain, also known from Younger Dryas in Scania (Berglund & Digerfeldt 1970)), and at the transition between the wet ground and the heath a *Salix* scrub with *Chamaenerion angustifolium* and *Oxyria* may have grown. *Polemonium cf. coerulum* (one grain) may have been associated with this community. H. Krog has found both this grain and another from Younger Dryas in southern Jutland (unpublished). Two finds of *Polemonium* are known from Scania (Berglund 1971) from Older Dryas and Preboreal respectively.

Preboreal, pollen zone IV

The transition from Younger Dryas to Preboreal, the *Juniperus* maximum, is found in diagram 1, while the late Preboreal is also found in diagram 2. The dating in diagram 1, 10,500 ± 350 B.P. (K 111) is made on gyttja,

and it may be a little too old in comparison with other datings, probably due to a content of older rebedded material. The transition is typical and matches very well the development in Böllingsö (Iversen 1954). First comes the rise of *Juniperus*, *Potentilla* and *Poaceae*, then follow *Empetrum* and *Filipendula* and finally comes the rise of *Betula pubescens* type followed by *Populus*.

At the end of the Preboreal, where the sediment changes to the algae gyttja, a *Betula* twig in diagram 2 has been dated to $9,310 \pm 130$ B.P. (K 1922).

Conclusion

After the sedimentation of the Older Dryas pure sharp sands in the Bölling valley the water began to be more quiet and some plant remains began to sediment together with the sand. Some of the plant remains derived from older reworked peat or gyttja layers in the vicinity. This development went on during the early Alleröd, and more and more organic material was sedimented, until detritus gyttja and peat began to form during upper Alleröd and Younger Dryas. These layers are shown on Plate 8 by the vertical arrows and on Plate 9 up to 53 cm.

In late Younger Dryas a renewed vigorous water stream broke up older sediment elsewhere, mixed the material and redeposited it as organic bands and sand. This is the main part of the section (Plate 8), from the vertical arrow's points and to the topmost dark algae gyttja. In Plate 9 these layers cover the profile from 53 cm and to the top. In the central part of the section (Plate 8) the thick redeposited peat and gyttja layers are only separated from the lower primary peat by a 1 cm thick sand layer (see Plate 8, 19 m and Fig. 4, 38 cm).

The topmost few centimetres of sand contain only very little rebedded pollen and are of Preboreal age.

Though we did not find what we expected, i.e. the Older Dryas developed as peat, the old problems about the stratigraphy at the canal seem to have been solved in outline. It should still be possible elsewhere in the area to find a part of the Bölling peat which was eroded in early Alleröd time and later.

Acknowledgements. Harald Krog handed diagram 1 over to me and was very helpful during the excavation and in later discussion. C. Vang Nielsen analysed the main part of pollen diagrams 2 and 3. Henrik Tauber provided the radiocarbon datings, and Kirsten Andersen has made the working drawings. My sincere thanks are due to them.

Table 2. List of pollen types which are omitted in the pollen diagrams
 Pollen zone III is, in this list only, divided in III a and III b. III a represents the primary peat with the *Cyperaceae* maximum, while III b represents the rest of Younger Dryas.

Pollen zones	I c ?	II	III a	III b	IV
Total amount of pollen grains counted	2287	9804	10763	15314	3515
<i>Equisetum</i> spp.	5	8	6	28	37
<i>Diphasium complanatum</i>	.	1	.	.	.
<i>Huperzia Selago</i>	.	.	.	1	.
<i>Lycopodium</i> spp.	.	.	.	2	.
— <i>annotinum</i>	.	2	.	4	.
<i>Botrychium</i> spp.	.	.	1	2	1
<i>Dryopteris</i> spp.	2	2	4	6	11
<i>Polypodium vulgare</i>	.	.	.	1	.
<i>Pteridium aquilinum</i>	.	1	.	.	.
<i>Gymnocarpium dryopteris</i>	1	16	3	14	3
<i>Selaginella selaginoides</i>	.	2	.	9	1
<i>Ephedra</i> sp.	.	.	.	1	.
— <i>distachya</i>	.	.	1	1	.
— <i>strobilacea</i>	.	.	1	1	.
<i>Armeria maritima</i>	.	.	1	6	1
<i>Butomus umbellatus</i>	.	1	.	.	.
<i>Tofieldia</i> spp.	1	6	.	.	.
<i>Campanula</i> spp.	.	2	.	1	1
<i>Caryophyllaceae</i> spp.	1	18	24	65	8
<i>Cerastium</i> type	4	15	9	4	.
<i>Dianthus</i> type	.	.	1	.	.
<i>Chamaenerion angustifolium</i>	.	1	.	8	4
<i>Potamogeton</i> spp.	.	1	2	6	5
<i>Brassicaceae</i> spp.	5	8	6	26	2
<i>Galium</i> spp.	1	15	3	10	9
cf. <i>Gentiana</i> sp.	.	.	.	1	.
<i>Hippuris vulgaris</i>	.	1	.	.	.
<i>Asteraceae</i>					
sectio <i>Liguliflorae</i> spp.	3	3	1	4	6
sectio <i>Tubuliflorae</i> spp.	2	29	28	67	19
<i>Myrriophyllum alterniflorum</i>	.	.	.	.	1
— <i>spicatum</i>	.	.	.	2	11
<i>Oxyria digyna</i>	.	.	.	3	.
<i>Polygonum aviculare</i>	.	1	.	.	.
— <i>convolvulus</i>	.	.	.	1	.
<i>Rumex acetosa</i>	.	.	.	1	.
<i>Fabaceae</i> spp.	2	9	2	21	.
<i>Astragalus</i> cf. <i>alpinus</i>	1	6	1	2	.
<i>Parnassia palustris</i>	.	.	.	1	.

(Cont. on next page)

Pollen zones	I c ?	II	III a	III b	IV
<i>Saxifraga</i> spp.	1	1	2	1	.
— <i>aizoides</i>	.	.	.	1	.
— <i>hirculus</i>	.	.	.	1	.
<i>Plantago lanceolata</i>	.	.	.	3	.
— <i>major</i>	.	1	2	.	.
— <i>maritima</i>	.	1	.	.	.
— <i>media</i>	.	1	.	.	.
<i>Polemonium coeruleum</i>	.	.	.	1	.
<i>Ranunculaceae</i> spp.	5	12	49*)	20	4
cf. <i>Anemone</i> sp.	.	1	.	.	.
<i>Caltha palustris</i>	.	16	7	8	.
<i>Thalictrum</i> spp.	5	21	13	32	.
<i>Rosaceae</i> spp.	.	2	3	9	.
<i>Dryas octopetala</i>	.	2	.	.	.
<i>Rubus</i> sp.	.	.	.	1	.
<i>Schrophulariaceae</i> spp.	.	2	1	.	.
<i>Sedum</i> sp.	.	.	.	1	.
<i>Solanum dulcamara</i>	.	.	.	1	.
<i>Sparganium</i> type	.	1	.	3	.
<i>Typha latifolia</i>	.	2	.	.	.
<i>Ulmus</i> spp.	.	.	.	.	2
<i>Apiaceae</i> spp.	1	17	2	18	2
<i>Pleurospermum austriacum</i>	.	.	2	.	.
<i>Urtica</i> cf. <i>dioeca</i>	1	1	.	3	13

*) 37 pollen grains in one sample.

Dansk sammendrag

Hvor Engesvang-Kragelund vejen krydser Bøllingsø Kanalen (Karup å's øvre løb) (Fig. 1), blev der i 1971 foretaget en udgravning med det formål at undersøge en tørvestrøbe, der i 1963 var C^{14} -dateret til Bølling alder. Et pollendiagram analyseret af Harald Krog (Fig. 3) viste imidlertid kun tegn på en kuldeperiode.

To nye profiler er blevet pollen- og frøanalyseret (Fig. 4-6). Desuden er der C^{14} -dateret 11 prøver, så det totale antal nu når op på 18. Flere af C^{14} -dateringerne viser sig at være foretaget på omlejet materiale. Ved diagram 3 fra den dybtliggende tørv (se Plate 8) er der dateret tre prøver, der alle giver ca. 10,300 før 1950, mens prøven K 1904, der er taget i tørvestriben over diagram 3, giver $11,190 \pm 130$ før 1950. Der må her være tale om en driftstrøbe bestående af hovedsagelig Allerød materiale aflejret i den yngste del af Yngre Dryas. Denne forklaring kan udstrækkes til hele det brede tørve- og gytjelag på Plate 8. Kun den nederste tørv (vist med pile) kan anses for at ligge på primært leje, og selv denne indeholder sekundært aflejret materiale i den nedre del.

Diagrammerne og profilvæggen tolkes således, at det dybestliggende sand formentlig er af Ældre Dryas alder. Herover følger Allerød sand, drift- og grovdegrit gytje samt tørv. Den øvre del af tørven er af Yngre Dryas alder. Det er det øverste af denne aflejring, der er vist med lodrette pile på Plate 8. I sen Yngre Dryas har stærkt strømmende vand igen aflejret ældre organisk materiale og sand i store mængder. Også i Præboreal tid er der aflejret sand, men dette sand har kun et ringe indhold af sekundært organisk materiale. Sedimentet skifter herefter til en grønlig algegytje.

Aflejringen, der formodes at være af Ældre Dryas alder, er karakteriseret ved den stærke dominans af frø af *Carex sectio distigmata* (Fig. 6). Zonegrænsen er sat hovedsagelig p. g. a. den voldsomme ændring af frø sammensætningen, og er derfor ikke særlig sikker. *Betula* kurven er lige så høj som i Allerød, formentlig fordi det i begge zoner drejer sig om lokal *Betula nana* (Fig. 2).

I Allerød har vegetationen været domineret af en *Betula nana*-*Cyperaceae*-*Empetrum nigrum* hede på højere bund, mens den fugtige dalbund har været domineret af *Carex cf. rostrata*, *Potentilla palustris*, *Sphagnum* og *Empetrum nigrum*.

Yngre Dryas har været vinterkold, hvilket bl. a. ses af fundet af 2 pollen-korn af *Pleurospermum austriacum*. Denne zones primære aflejringer viser en stærk dominans af *Carex sectio distigmata*. I den øvre del af Yngre Dryas er det sekundære materiale så dominerende, at det er vanskeligt at udtale sig om vegetationens udseende.

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Cykliske klimavariationer de sidste 7500 år påvist ved undersøgelser af højmoser og marine transgressionsfaser

Bent Aaby

Aaby, Bent: Cykliske klimavariationer de sidste 7500 år påvist ved undersøgelser af højmoser og marine transgressionsfaser. *Danm. geol. Unders., Årbog 1974*, pp. 91–104, København, 18. september 1975.

Recent investigations in Holocene Danish raised bogs show cyclic climatic variations with a periodicity at about 260 years during the last 5500 years. The shore line displacement in Southern Scandinavia, which is mainly influenced by eustatic sea level variations, shows a periodicity of 520 years, and the cyclic climate variation can be traced back to 7500 B.P. This result, showing a periodicity in climatic variations for most of the Holocene may tentatively be used for predicting the natural long-term trend of the future climate (cf. summary).

Højmosen er en særlig mosetype, hvis overflade hvælver sig urglasformet over det omgivende terræn. Som følge heraf påvirkes den ikke af mineraljordens relativt næringsrige grundvand, men har helt sin egen vandbalance. Al væde tilføres fra atmosfæren som regn eller sne, og fugtighedsforholdene på mosen bestemmes bl.a. af nedbør, temperatur og fordampning. Som følge heraf er højmosen meget fintfølsomme overfor variationer i de meteorologiske forhold. En ændring af klimaet kan derfor bevirke, at mosens fugtighedsforhold forandres, hvilket kan registreres som en variation i tørvens nedbrydningsgrad (humificeringsgrad), plantesammensætning m.m. Højmosen kommer derved til at fungere som en levende klimamåler, der tillige indeholder en mængde oplysninger om tidligere klimasvingninger. Dog kan ikke alle klimatiske variationstyper registreres i vore højmoser. En ændring til mindre nedbør eller højere middeltemperatur vil bevirke at fugtigheden på moseoverfladen aftager, og nydannet tørv bliver mere nedbrudt og fremtræder mørkere end tidligere. Den samme tendens i tørvedannelsen kan være resultatet af en naturlig udvikling under konstante klimatiske forhold, idet ny tørv vil dannes i et stadigt tørrere miljø, fordi afstanden til vandspejlet øges. Det er derfor vanskeligt at skelne om en udvikling til mørkere tørvedannelse er naturlig eller skyldes en klimaændring. Den modsatte udvikling, til dannelse af lysere tørv kan derimod generelt tilskrives klimaet. Hvilke af

de klimatiske parametre, der ændres, er vanskeligt at afgøre, fordi en forøgelse af fugtighedsforholdene på mosen både kan forårsages af større nedbør, og af en temperatursænkning, eller en kombination af disse. Det er således klimaændringer til koldere og/eller mere nedbørsrige forhold end i den umiddelbart foregående periode, der registreres ved undersøgelserne. Det er vanskeligt at vurdere, hvor markante eller omfattende disse tidligere klimaændringer har været. Derfor kan der normalt ikke foretages en sammenligning mellem flere på hinanden følgende klimavariationer.

Den levende højmoses overflade består ofte af en mosaik af relativt tørre tuer og fugtige høljer. Generelle ændringer i mosens fugtighedsforhold vil medføre, at dette strukturmønster ændres, således at tuernes areal forøges i

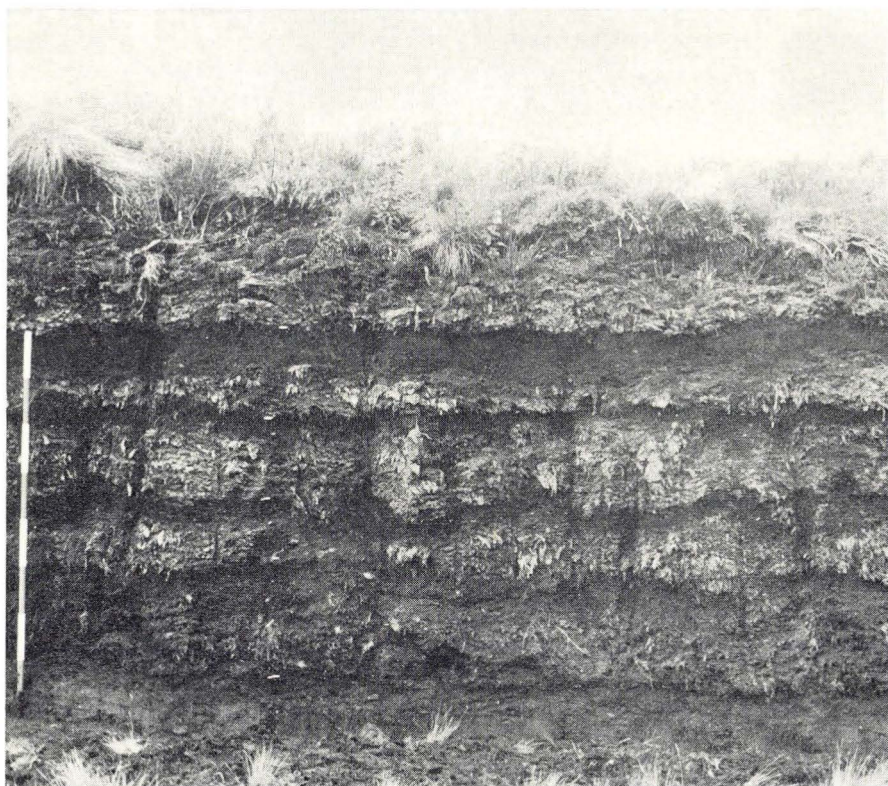


Fig. 1. Tørrevæg i Fuglsø Mose. Højmosen er opbygget af mørke og lyse tørvelag, der kan følges over lange strækninger. En ændring fra stærkt til svagt humificeret tørv er klimatisk betinget.

Part of a more than 100 m long peat section in the raised bog Fuglsø Mose. The bog contains dark and light peat layers, which are general for the section. A change from more to less humified peat indicates a shift in climate.

tørre perioder og formindskes i fugtige. I åbne tørveprofiler kan det direkte iagttages, hvorledes tuernes og hølernes arealfordeling har varieret i tidens løb. Ved omhyggelig analyse af en tørvevægs opbygning er det muligt at skelne mellem tilfældige lokalt betingede humificeringsvariationer og mere generelle ændringer. Kun forandringer fra stærkt til svagt humificeret tørv, der kan påvises flere steder i en profilvæg eller følges over længere strækninger må antages at afspejle klimaændringer. Det er dateringer af niveauer, hvor der sker sådanne ændringer, der indgår i undersøgelserne.

Profilopmåling og materialeindsamling er foretaget af B. Aaby, A. Andersen, H. Bahnson og H. Krog. Tørvens humificeringsgrad er bestemt af H. Bahnson, hvoraf resultaterne fra Fuglsø Mose tidligere er publiceret (Bahnson 1968). Bearbejdelsen af materialet fra Draved Mose er udført af B. Aaby. H. Tauber har foretaget C-14 dateringerne.

Alle i artiklen nævnte dateringer er angivet i kalibrerede kalenderår.

Lokalitetsbeskrivelser og undersøgelsesresultater

Draved Mose

Draved Mose har en størrelse på ca. 340 ha og ligger i Sønderjylland mellem Tønder og Løgumkloster. Undersøgelser af højmosens vækstdynamik og udvikling er foretaget i et 30 m langt tørveprofil i mosens centrale del. Som led i dette arbejde er der et enkelt sted udtaget en lodret serie tørveprøver, hvor bl.a. humificeringsgraden er bestemt, og hvorfra der foreligger ialt 54 C-14 dateringer jævnt fordelt i profilsøjlen. På grundlag af disse dateringer er der beregnet en højde/alder kurve som glidende middeltal af 5 på hinanden følgende dateringer. Denne kurve (Aaby og Tauber 1975, fig. 3) er anvendt til aldersbestemmelse af de i profilet klimatisk betingede humificeringsændringer (se tabel 1). På fig. 3 er angivet profilsøjlen humificeringsværdier og rhizopodindholdet i tørv. De nævnte rhizopoder er fugtighedsindikatorer; deres hyppighed tiltager med stigende fugtighed, men hæmmes under ekstremt våde forhold (Harnish i Grospietsch 1965). Det fremgår af figuren, at rhizopodernes antal i de fleste tilfælde tiltager, når humificeringsgraden falder og aftager, når tørv har en tiltagende omsætningsgrad. Humificeringskurvens relative ændringer afspejler således variationer i mosens fugtighedsforhold på dannelsesetidspunktet og kan derfor direkte anvendes til at fastslå niveauerne for de klimatisk bestemte forandringer. Rhizopodhyppigheden er udregnet på basis af den korregerede træpollensum, idet S. T. Andersens (1970) korrektionsfaktorer er anvendt.

Det omtalte profil er forstyrret foroven og dækker perioden ca. 5500 år f.Kr. til ca. 1200 år e.Kr. For at undersøge mosens senere udvikling er der i 1973 foretaget en mindre udgravning i den levende del af højmosen. Her

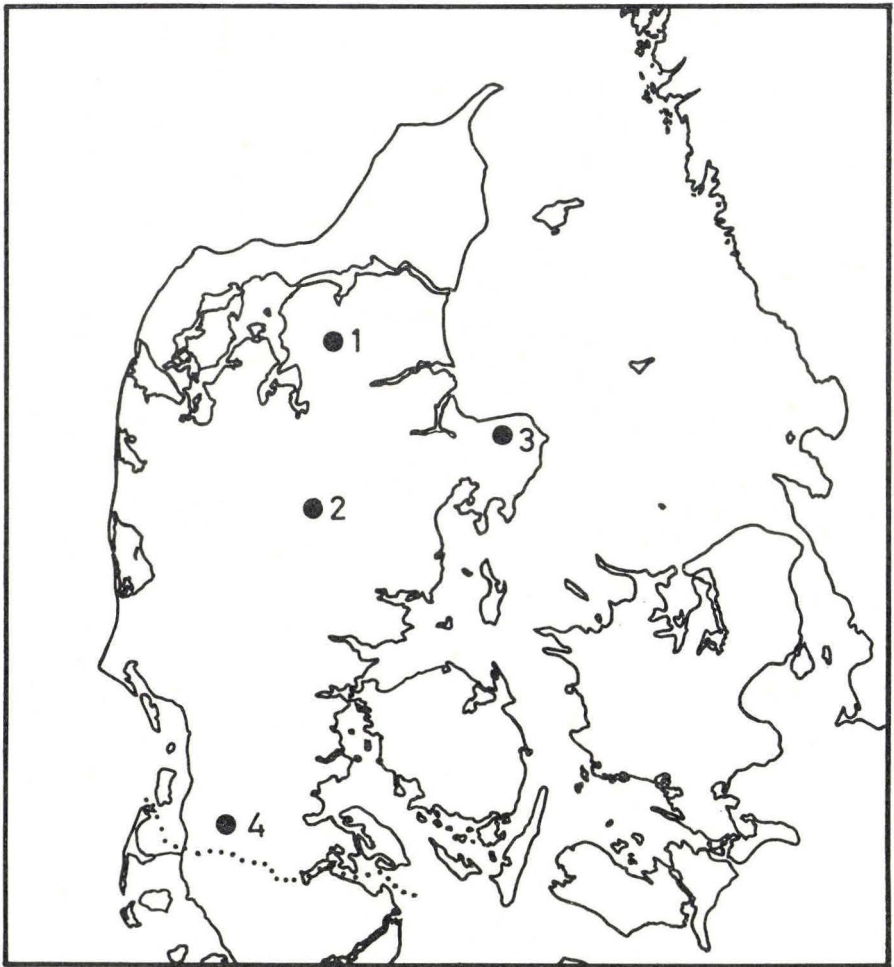


Fig. 2. Undersøgte danske højmoser (*Location map*). 1: Store Borremose, 2: Bølling Mose, 3: Fuglsø Mose, 4: Draved Mose.

er opmålt en 3,20 m lang og ca. 1 m høj profilvæg, der gennemskærer en tue og en hølje. Humificeringsbestemmelser er foretaget i en lodret søjle gennem tuen, og dateringer af markante fugtighedsændringer er foretaget både i tue og hølje. Resultaterne fremgår af tabel 1.

Fuglsø Mose

Højmosen ligger i den nordlige del af Djursland ca. 20 km NØ for Auning og er på ca. 330 ha. Der er udført omfattende undersøgelser af de mørke og

DRAVED MOSE profil 1959

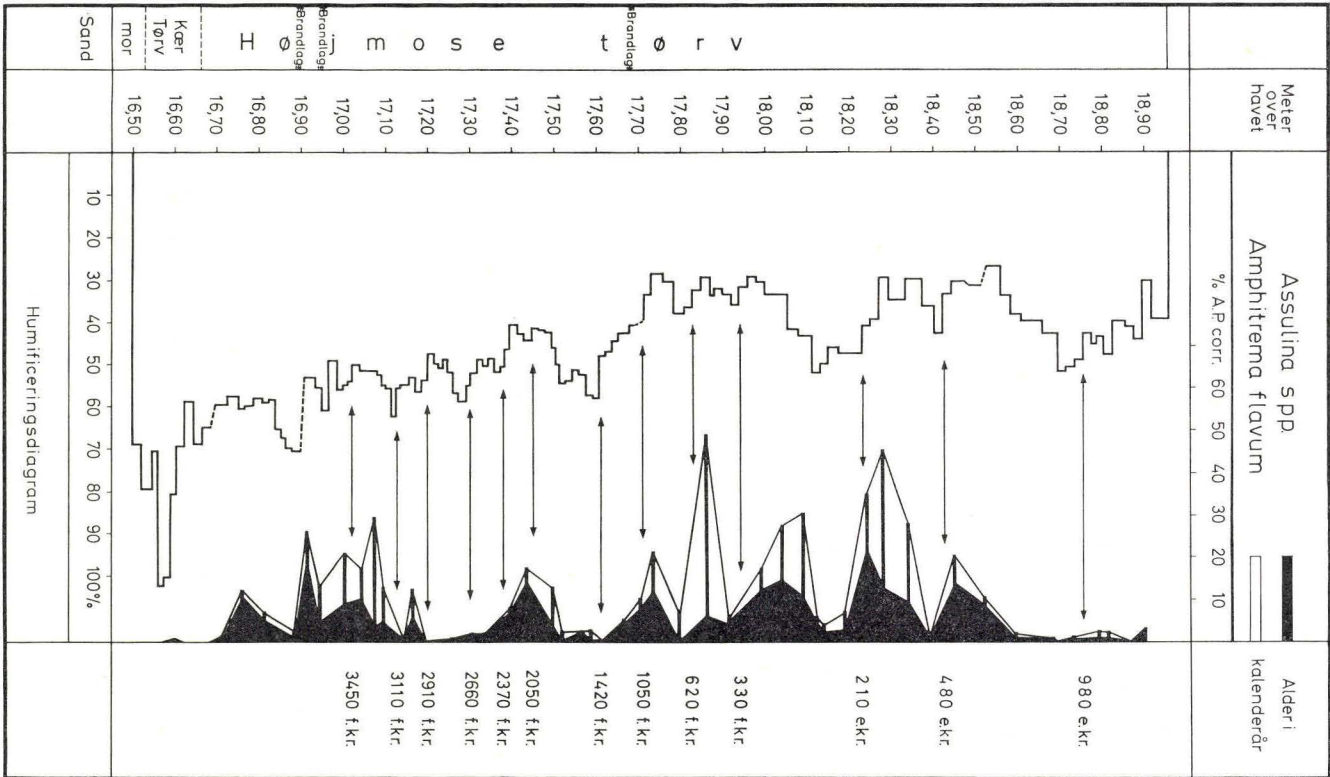


Fig. 3. DRAVED MOSE profil 1959. Humificeringsgrad og rhizopodindhold i en lodret tørvessøjle, hvori der er foretaget 54 C-14 dateringer. De vandrette linier viser niveauer, hvor humificeringsgraden aftager. Disse humificeringsændringer er generelle for hele tørveprofilet.

DRAVED MOSE section 1959. Degree of humification and the content of rhizopods in the peat column from where 54 radiocarbon dates are available. The horizontal lines indicates levels with decreasing humification degrees, which are assumed to reflect climate variations. The changes in colour at the indicated levels are general for the peat section.

lyse tørvelag, mosen er opbygget af (se fig. 1). Humificeringsændringerne er meget tydelige og kan følges over store strækninger. H. Bahnson har bestemt humificeringsgraden flere steder i mosen, og tidspunkterne for de tydeligste ændringer fra mørk til lys tørv er dateret ved C-14 metoden (Bahnson 1968, 1972). Resultaterne er vist i tabel 2.

Bølling Mose

Den oprindeligt ca. 200 ha store mose ligger ca. 10 km V for Silkeborg i Midtjylland. To tørrevægge er opmålt. I det 92 m lange "skelprofil 1" findes to markante horisonter, hvor stærkt humificeret højmosetørv overlejres af svagere omsat tørv. Begge niveauer er C-14 dateret til henholdsvis ca. 560 år f.Kr. og ca. 470 år e.Kr.

"Skelprofil 2" ligger ca. 90 m SV for skelprofil 1, og i den 10 m lange profilvæg er en tydelig humificeringsgrænse dateret til ca. 1020 e.Kr. (se tabel 2).

Store Borremose

Mosen har en størrelse på ca. 200 ha og ligger ca. 4 km SØ for Aars i Himmerland. I den centrale del af mosen er der foretaget opmåling af den øverste del af et 5,5 m langt tørveprofil. Ca. 2 m oppe i tørvén fandtes i hele profilets længde et markant skifte i tørvéns humificeringsgrad, som er dateret til ca. 420 år e.Kr. (se tabel 2).

Påvisning af klimavariationer ved højmosundersøgelser

Højmosers opbygning af mørke og lyse tørvelag blev tidligt betragtet som klimatisk betinget, men deres datering var i forrige århundrede og i begyndelsen af dette meget usikker. Først med svenskeren E. Granlunds banebrydende undersøgelser (1932) fik man på grundlag af arkæologisk materiale en omtrentlig angivelse af alderen på de forskellige "rekurrensytor" (RY), d.v.s. de generelle ændringer fra stærkt til svagt omsat tørv. Efter indførelsen af C-14 dateringsmetoden har det været muligt at få en nøjagtigere aldersangivelse. I dag er en del RY'er aldersbestemt i forskellige europæiske højmoser, hvoraf navnlig dateringerne fra åbne profiler må betragtes som pålidelige. Generelt er de danske dateringer i god overensstemmelse med resultater fra bl.a. tyske undersøgelser (Overbeck et al. 1957).

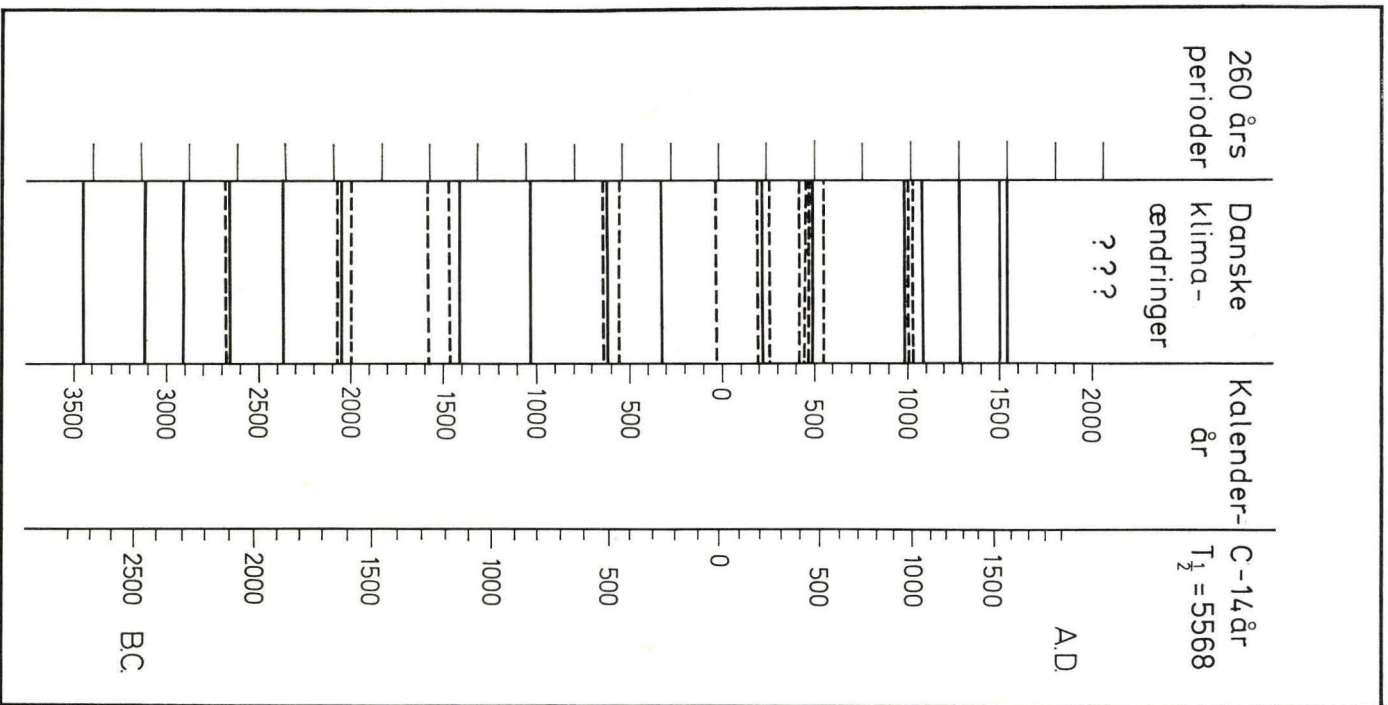


Fig. 4. Påviste danske klimaændringer. Fuldt optrukne linier viser resultater fra Draved Mose; stiplede linier er fra andre højmoser. Klimaændringerne er cykliske med en periodelængde på normalt 260 år.

Radiocarbon dated climatic record from Denmark. The full lines indicate the date of change in climate reflected in Draved Mose. Results from other bogs are shown as dotted lines. At the figure a periodicity of 260 years is given together with calendar years and conventional radiocarbon years. The past climatic changes are cyclic, showing a periodicity of normally 260 years.

Før en nærmere analyse af de foreliggende resultater kan foretages, har det været nødvendigt at omregne C-14 dateringerne til kalenderår, idet længden af et C-14 år har varieret i tidens løb afhængig af C-14 koncentrationen i atmosfæren. Dateringerne er kalibreret efter den amerikanske *Pinus aristata* træring kronologi (Damon et al. 1973). Både de konventionelle og de kalibrerede dateringer er angivet i tabel 1 og 2.

Alderen på de til dato undersøgte klimatiske betingede humificeringsændringer er angivet på fig. 4, hvor dateringerne fra Draved Mose er vist med fuldt optrukket linie, og resultaterne fra de øvrige danske højmoser er tegnet med stiplet linie. Flere dateringer er næsten samtidige, hvilket betyder, at den samme klimaændring kan påvises i flere moser. Således er klimaændringen ca. 500 år e.Kr. afspejlet i Draved Mose, Bølling Mose, Store Borremose og to forskellige steder i Fuglsø Mose.

Den sidste klimavariation, der kan påvises i vore højmoser, er dateret til første halvdel af det 16. århundrede, netop begyndelsen af den såkaldte "lille istid". Det var en ret kold periode, som varede til midten af forrige århundrede. Også de to tidligere påviste klimaændringer i slutningen af det 10. århundrede og 13. århundrede har vi belæg for (Lamb 1966, Bergthorsson 1969, LaMarche 1974, Dansgaard et al. 1975). Da vi således ved, at de yngre påviste ændringer afspejler virkelige variationer i klimaet, må det også antages, at de ældre registreringer gør det samme.

Registreringerne af de fortidige klimaændringer har ikke en tilfældig fordeling, men grupperer sig efter et mønster. Der er ca. 260 år mellem de yngre dateringer, og også de ældre dateringer kan indpasses i denne periodicitet, undtaget omkring 1500 f.Kr., hvor 2 resultater afviger noget. Periodiciteten på 260 år er dog ikke helt generel. Enkelte gange er der den dobbelte afstand, 520 år, mellem klimaregistreringerne. Dette kan skyldes, at der faktisk ingen klimaændringer har været i de pågældende perioder, som kunne reflekteres i de danske højmoser, muligvis på grund af interferens med et andet af klimaets svingningsmønstre, hvis periode er kortere eller længere end 260 år. Det er også tænkeligt, at materialet endnu er så sparsomt, at ændringerne ikke er påvist.

Resultaterne af disse højmoseundersøgelser er i god overensstemmelse med nye undersøgelser over variationer i forholdet mellem iltisotoperne O-18 og O-16 i borekerner fra Grønlands indlandsis (Dansgaard et al. 1975). Disse undersøgelser viser, at forholdet mellem iltisotoperne, der er temperaturafhængigt, bl.a. har varieret med en periodelængde på ca. 250 år de sidste 1400 år.

I Danmark er klimavariationer undersøgt ca. 5500 år tilbage i tiden. Ældre klimasvingninger kan ikke påvises i højmoser, fordi denne mosetype sjældent er ret meget ældre.

Påvisning af klimavariationer ved havniveauundersøgelser

For at følge klimavariationer længere tilbage i tiden er det nødvendigt at undersøge andet materiale, der ligeledes formodes at afspejle generelle klimaændringer.

Havets eustatiske bevægelser afspejler klimavariationer. I relativt kolde perioder bindes vand som is ved polerne, og verdenshavets niveau sænkes. Stiger temperaturen igen en tid, så smelter isen, og havniveauet vil stige.

Den mest pålidelige publicerede undersøgelse over strandlinieforskydninger i Skandinavien er fra Blekinge i Sydsverige. På grundlag af stratigrafiske undersøgelser i et antal kystlokaliteter og 50 C-14 dateringer fra disse, har det været muligt at konstruere en kurve for strandlinieforskydningen i *Littorina* tiden (fig. 5) (Berglund 1971).

Undersøgelser over landjordens isostatiske bevægelser i nyere tid viser, at hævningsen er næsten konstant, idet der dog sker en svag aftagen i hævningsstakten med tiden (Bergsten 1954, Andrews 1968). Hvis det antages, at landhævningsen har haft samme mønster i *Littorina* tiden som i nyere tid, vil der under konstante ydre forhold ske en regression af havet. Det samme

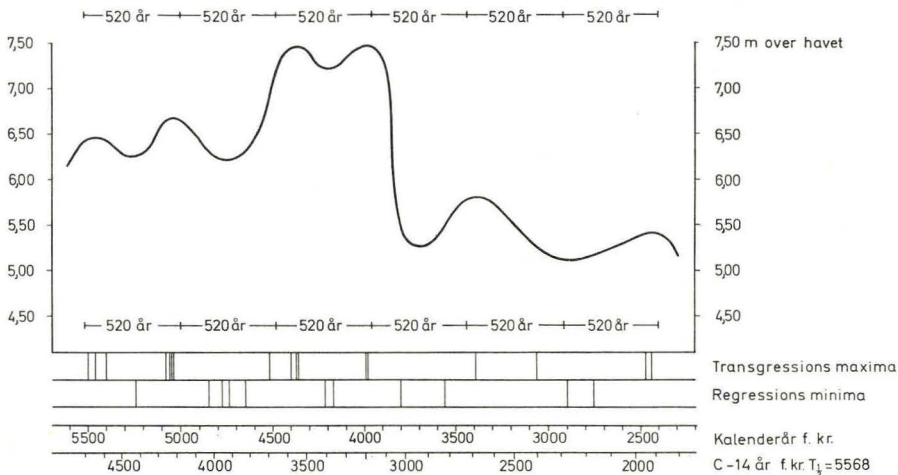


Fig. 5. Kurve visende strandlinieforskydninger i *Littorina* tid i Blekinge. Ifølge personlig information (Berglund 1975) er kurven ændret lidt i forhold til den tidligere publicerede (Berglund 1971). De C-14 daterede transgressionsmaxima og regressionsminima fra forskellige lokaliteter, som kurven er baseret på er ligeledes angivet.

Curve showing shore displacement during *Littorina* time s. str. in Blekinge, S. E. Sweden. According to personal information (Berglund 1975), the curve is slightly changed since first published (Berglund 1971). The radiocarbon dated transgression maxima and regression minima from different localities which the curve is based on are indicated together with calendar years and conventional radiocarbon years. The shore displacement curve shows cyclic variations with a periodicity of normally 520 years.

vil ske, når klimaet ændres til køligere forhold. Den modsatte tendens, en transgression, vil i Blekinge området kun ske ved en reel stigning af verdenshavet. Det er derfor kun transgressionsfaser, der med sikkerhed er forårsaget af en klimaændring.

Det fremgår af kurven for strandlinieforskydningen, at transgressionsfaserne generelt har været periodiske med ca. 520 år mellem hver ny fase. Det er netop dobbelt så lang en periode, som kan påvises ved højmosundersøgelserne.

Endnu før C-14 dateringer var til rådighed antydede Bennema (1954), at de hollandske transgressionsfaser var cykliske med en 525 års periodicitet. En antydning som i dag sandsynliggøres af undersøgelserne fra Blekinge.

Klimavariationer i senglacial tid

En kalibrering af C-14 dateringer efter træring kronologier kan i øjeblikket foretages til ca. 5500 år f.Kr. Det er derfor ikke muligt direkte at få tilnærmede kalenderårsangivelser af ældre C-14 dateringer. Undersøgelser (Tauber 1970) viser dog, at i senglacial tid og tidlig postglacial tid er længden af et konventionelt C-14 år meget nær et kalenderårs længde.

De to mest markante temperaturfald i senglacial tid sker på overgangen fra chronozonerne: Bølling til Ældre Dryas og Allerød til Yngre Dryas og er C-14 dateret til henholdsvis ca. 10000 år f.Kr. og ca. 9000 år f.Kr. (Mangerud et al. 1974). Der er således ca. 1000 år mellem disse tydelige klimaændringer; netop den dobbelte eller 4-dobbelte længde af de påviste postglaciale perioder. Også mindre klimaændringer kendes fra senglacial tid, men disse er endnu ikke pålideligt dateret.

Diskussion

Højmoser reflekterer fortidens klima, men ikke alle variationer kan påvises ved undersøgelser af tørvestrukturen. Efter en ændring til mere fugtige forhold, skal mosen have tid til at reagere på de nye tilstande inden en ny klimaforandring kan registreres og skelnes fra den foregående ændring. Højmosen kan derfor ikke registrere de mange forskellige kortidsvariationer, vi ved klimaet har undergået. Kun variationer med en større frekvens og med en rimelig stor amplitude vil kunne spores i tørvedannelsen. Mosen fungerer derfor som et biologisk "low pass" filter, hvor klimasvingninger med kortere frekvenser end sandsynligvis 150–200 år, normalt ikke registreres, idet variationen på 260 år er den korteste markante svingning, som kan

Tabel 1. Dateringsliste for niveauer med markante humificeringsændringer der kan tillægges klimatisk værdi.

Lokalitet	C-14 år m o.havet (T ½ = 5568)			C-14 år før 1950		Kalenderår	
*) Draved Mose, profil 1959	18,74	970	A.D.	980	B.P.	980	A.D.
	18,41	460	»	1490	»	480	»
	18,22	210	»	1740	»	210	»
	17,95	260	B.C.	2210	»	330	B.C.
	17,84	570	»	2520	»	620	»
	17,71	830	»	2780	»	1040	»
	17,61	1120	»	3070	»	1420	»
	17,46	1610	»	3560	»	2050	»
	17,38	1870	»	3820	»	2370	»
	17,30	2100	»	4050	»	2660	»
	17,19	2290	»	4240	»	2910	»
	17,13	2450	»	4400	»	3110	»
	17,01	2780	»	4730	»	3500	»
**) Draved Mose, profil 1973, tue	cm under overflade						
	34,0	1530	A.D.	420	B.P.	1500	A.D.
	52,0	1280	»	670	»	1280	»
	67,0	1060	»	890	»	1080	»
	profil 1973, højle	25,0	1560±100	»	390	»	1540

*) Dateringerne beregnet på grundlag af kurve for glidende middeltal af 5 på hinanden følgende C-14 dateringer (Aaby og Tauber 1975, fig. 3).

The dates calculated from curve constructed as sliding means of 5 successive radiocarbon dates (Aaby and Tauber 1975, fig. 3).

*²⁸) Dateringerne beregnet ved interpolation. I profilet er 4 niveauer C-14 dateret (Aaby og Tauber 1975).

The dates are calculated by interpolation. In the section 4 levels have been radiocarbon dated (Aaby and Tauber 1975).

påvises. Højmoserne reflekterer derfor generelle langtidsvariationer i fortidens klima.

De eustatiske havbevægelser udviser også en vis træghed i relation til klimaforandringer og kommer derfor ligeledes til at reflektere generelle klimatendenser. Den korteste påviste klimasvingning har periodelængden ca. 520 år i *Littorina* tid.

Klimaets variationsmønster, som det afspejler sig i højmoserne og strandforskydningen, viser således, at nogle af de mest markante langtidssvingninger har haft en periodelængde på ca. 260 år eller et multiplum deraf gennem det meste af Holocæn tid.

Tabel 2. Dateringsliste for niveauer med markante humificeringsændringer der kan tillægges klimatisk værdi.

Lokalitet	K-prøve nr.	C-14 år			C-14 år	
		(T ½ = 5568)			før 1950	Kalenderår
Fuglsø Mose, profil 420	1225	530±100	A.D.		1420	555 A.D.
»	»	1226	1170±110 B.C.		3120	1470 B.C.
»	»	1227	1630±110 B.C.		3580	2065 B.C.
»	»	1228	2050±120 B.C.	2100 B.C.		
»	»	1229	2140±120 B.C.		4050	2670 B.C.
»	Balkprofil	1270	990±100 A.D.		960	1010 A.D.
»	»	1271	460±100 A.D.		1490	480 A.D.
»	»	1272	190±100 A.D.		1760	190 A.D.
»	profil 729	1350	250±100 A.D.		1700	250 A.D.
»	»	1355	10±100 B.C.		1960	40 B.C.
»	»	1356	600±100 B.C.		2550	645 B.C.
»	»	1349	1260±100 B.C.		3210	1590 B.C.
»	»	1352	1580±100 B.C.		3530	2000 B.C.
Bølling Mose, skelprofil I	734	380±100	A.D.			
»	»	733	520±100 A.D.	450 A.D.	1500	470 A.D.
»	»	735	430±100 B.C.			
»	»	736	480±110 B.C.	450 B.C.	2400	560 B.C.
»	»	II 1147	990±100 A.D.			
»	»	1148	970±100 A.D.	980 A.D.	970	1020 A.D.
Store Borremose	732	400±100	A.D.			
»	»	731	350±100 A.D.	400 A.D.	1560	420 A.D.

Undersøgelser af klimaet de seneste århundreder viser, at udviklingen har været præget af ændringer med middellang frekvens (60–100 års perioder). Derfor kan en 260 års periodicitet ikke anvendes til forudsigelse af klimaudviklingen i nærmeste fremtid. Kun den naturlige langtids tendens kan antydes, idet der ikke tages hensyn til menneskets påvirkning af atmosfæren.

Den sidste registrering af klimaændringer i vore højmoser er dateret til begyndelsen af det 16. århundrede, og fra de ældste meteorologiske observationer (Manley 1958) ved vi, at der indtrådte et ret tydeligt temperaturfald midt i det 18. århundrede. Antages det, at klimaet således vil fortsætte med at variere som hidtil med en periodicitet på ca. 260 år, må vi forvente at den generelle udviklingstendens vil gå mod køligere forhold fra begyndelsen eller midten af næste århundrede. Men mange faktorer kan påvirke fremtidens klimaudvikling; således må det forventes at de menneskeskabte ændringer af atmosfærens sammensætning vil få øget meteorologisk betydning og disse påvirkninger kan fuldstændigt ændre den naturlige klimaudvikling.

Acknowledgements. Jeg er tak skyldig for megen hjælp og værdifulde diskussioner til Svend Th. Andersen, H. Bahnson, Björn E. Berglund, W. Dansgaard og H. Tauber.

English summary

In 4 Danish raised bogs 8 open sections have been investigated to establish dates of general changes in degree of humification of peat layers. It is assumed that the transition from strongly humified peat to less decomposed peat is caused by climatic changes. Using 79 radiocarbon dates, 32 climatic shifts have been dated. They fit into a periodicity of about 260 years for the last 5500 years.

Eustatic sea level variations also reflect past climatic changes. In Blekinge, southeast Sweden, a curve showing shore displacement during *Littorina* time s. str. has been established by 50 radiocarbon dates. The shore displacement is the final result of the independent eustatic and isostatic movements. The rate of isostatic uplift is supposed to be rather constant, therefore the trend of the curve may mainly be influenced by eustatic changes. The variations are cyclic, normally having a periodicity of about 520 years.

Not every shift in climate can be reflected in the peat structure. After a change to more wet conditions the bog needs some time to react on the new environmental condition, before another shift in climate can be separated from the previous variation. The raised bog therefore operates as a low pass filter. Also the variations in sea level do only reflect the general trend in climate.

The past climate as reflected in raised bogs and in the shore displacement shows that some of the most distinct long-term cyclic variations have had a periodicity of about 260 years, or a multiple of that during of the Holocene.

The climatic record for the last centuries is dominated by climatic changes of medium frequencies (60–100 years periods), therefore a 260 years periodicity cannot be used for predicting the climatic trend of the near future. Only the long-term natural trend is tentatively given. If it is supposed that the 260 years periodicity will continue, a new cycle beginning with general decreasing mean temperatures may appear in the first or middle part of the next century.

However, man-made pollution of the atmosphere surely will increase. This influence may completely change the natural trend in the future climate.

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The growth spiral in some planktonic foraminifera from the Eocene of Denmark

Arne Dinesen

Dinesen, Arne: The growth spiral in some planktonic foraminifera from the Eocene of Denmark. *Danm. geol. Unders., Årbog 1974*, pp. 105–138, pls. 3–7. København, 18. september 1975.

The individual growth pattern of the planktonic foraminifera *Globigerinatheka index* (Finlay) is extremely variable, and the taxonomical problems involved are very complex. The different morphotypes displayed by some Danish material of *G. index* are presented in this paper.

The growth spiral is analysed and compared with the spiral of other taxa referred to as *Globigerina* sp., *Globigerina* ex gr. *bulloides* d'Orbigny, and *Globigerina patagonica* Todd & Kniker. The appearance of the ultimate chamber is illustrated by graphs of its dimensions, absolutely and relatively. In many specimens the ultimate chamber is displaced from the 'normal' growth spiral. The growth lines representing length *versus* Breadth of the 'normal' growth spiral are constructed and statistically tested.

Some intervals of the Eocene "Plastic Clay" Group of Denmark contain rich faunas of planktonic foraminifera (Berggren, 1960, 1969; Dinesen, 1972). The taxonomic units involved are characterized by a wide phenotypic variation. Therefore, the result of a conventional break-down in "central types" could easily resemble that to which Drooger (1966, p. 41) alluded with the following comment: "Practically none of the described species and subspecies corresponds to what could have been Mendelian populations. They are no more than clusters and types from such populations, which often had a very wide variation".

In a study of the quantitative composition of the faunas the "transitional types" have to be included as well as the "central types". In order to provide a base for a useful discrimination, the application of biometric methods seems to be indispensable. Thereby the phenotypic variation in the samples can be mapped and compared from one sample to another.

The evaluation of the statistical results depends on the procedure applied during the selection of the samples. In previous biometric studies on planktonic foraminifera the statistical samples are selected according to different rules of procedure.

Scott (1966, 1967, 1970) and Lindenberg (1969), for instance, selected their statistical samples on the basis of a sharp and precise definition of an "experimental class". The experimental class of Scott (1966, p. 515) includes "all individuals within the family Globigerinidae Carpenter that possess more than one aperture", and that of Lindenberg (1969, p. 343) contains "all tests of the material investigated which had more than 3 and less than 5, more or less globular chambers in the last-formed whorl, and which had a coarsely cancellate surface and a distinct apertural lip". From a theoretical point of view the consideration of a single or a few characteristics, and not of the entire shell, may produce a statistical sample from which some parts of the infraspecific variation has been omitted, and/or it may produce a sample in which specimens with a heterogenous phyletic background have been pooled. The same conclusion is found in the following statement by Lindenberg (1969, p. 344): "Discrimination of sample populations is ambiguous with respect to its biologic, taxonomic and phyletic meaning."

On the other hand Berggren & Kurtén (1961) did not define any experimental class, but their samples were picked from supposedly Mendelian populations. Although a strong element of subjectivity is introduced by this type of statistical sample, it may be more suitable than a sample representing a well-defined experimental class when the actual purpose is to procure a taxonomic interpretation.

The procedure followed by Quilty (1969) apparently combined valuable elements from the studies mentioned above. Quilty studied samples selected from different groups of morphotypes, all of which were supposed to belong to a single species, and at least some of his groups were well-defined like experimental classes.

The present study is a preliminary attempt to make a comparison of some few species of Globigerinidae from the Danish Eocene. The eight samples investigated were selected from supposedly Mendelian populations without a precise definition of the experimental classes.

Data on the origin of the statistical samples

Sample 1 *Globigerinatheka index*, 50 (in part of the study only 49) specimens.

Locality: A marl pit about 0.3 km SW of the church of Søvind, East Jutland. Formation: Søvind Marl (Upper Eocene). Remarks: The rock sample consists of a sticky, light olive grey marl. It is the same sample as referred to as S-1-3 by Tank (1963) and Dinesen (1972).

Sample 2 *Globigerinatheka index*, 39 specimens.

Locality: A bore hole at Rodtenseje, about 1.2 km SE of the church of Odder, East Jutland. Formation: Søvind Marl (Upper Eocene). Remarks: The boring was made in 1972 by the Micropaleontological Department, Geological Institute, University of Aarhus. The rock sample (No. 35) consist of a sticky, light olive grey marl, and it was taken at a depth of 10.85–10.95 m below ground.

Sample 3 *Globigerinatheka index*, 50 specimens.

Locality: The Viborg No. 1 core hole (DGU File No. 66.318), about 1.5 km WSW of the cathedral of Viborg, Mid Jutland. Formation: Søvind Marl (Upper Eocene). Remarks: The core hole was drilled in 1939 by Danish American Prospecting Company. The rock sample (AD No. 143) consists of a sticky, light olive grey marl, and the depth is about 292 m below ground.

Sample 4 *Globigerinatheka index*, 50 specimens.

Locality: A borehole at Hesselho (DGU File No. 113.30), about 5 km NW of the church of Skovlund, West Jutland. Formation: Søvind Marl (Upper Eocene), as a floe in the Quaternary deposits. Remarks: The borehole was drilled in 1951 by the Geological Survey. The rock sample consist of a sticky, light olive grey marl, and the depth is 30 m below ground.

Sample 5 *Globigerina* sp., 50 specimens.

Locality: A marl pit at Toftum, about 1.5 km WNW of the church of Søvind, East Jutland. Formation: Søvind Marl (Upper Eocene). Remarks: The rock sample consists of a sticky, light olive grey marl.

Sample 6A *Globigerina* ex. gr. *bulloides*, 50 (in part of the study only 34) specimens.

Locality: A marl pit about 0.3 km SW of the church of Søvind, East Jutland. Formation: Søvind Marl (Upper Eocene). Remarks: The rock sample consists of a sticky, light olive grey marl. The sample is the same one as referred to as S-1-1 by Tank (1963) and Dinesen (1969), and it was collected about 6 m below sample S-1-3 (statistical sample 1).

Sample 6B *Globigerina* ex gr. *bulloides*, 50 specimens.

The specimens were picked from the same residue as sample 6A.

Sample 7 *Globigerina patagonica*, 50 (in part of the study only 49) specimens.

Locality: A clay pit about 800 m WSW of the church of Ulstrup, West Zealand. Formation: Røsnæs Clay (Lower Eocene). Remarks: The rock sample consists of a sticky, reddish brown, calcareous clay.

The localities of the eight samples are shown on the map, fig. 1.

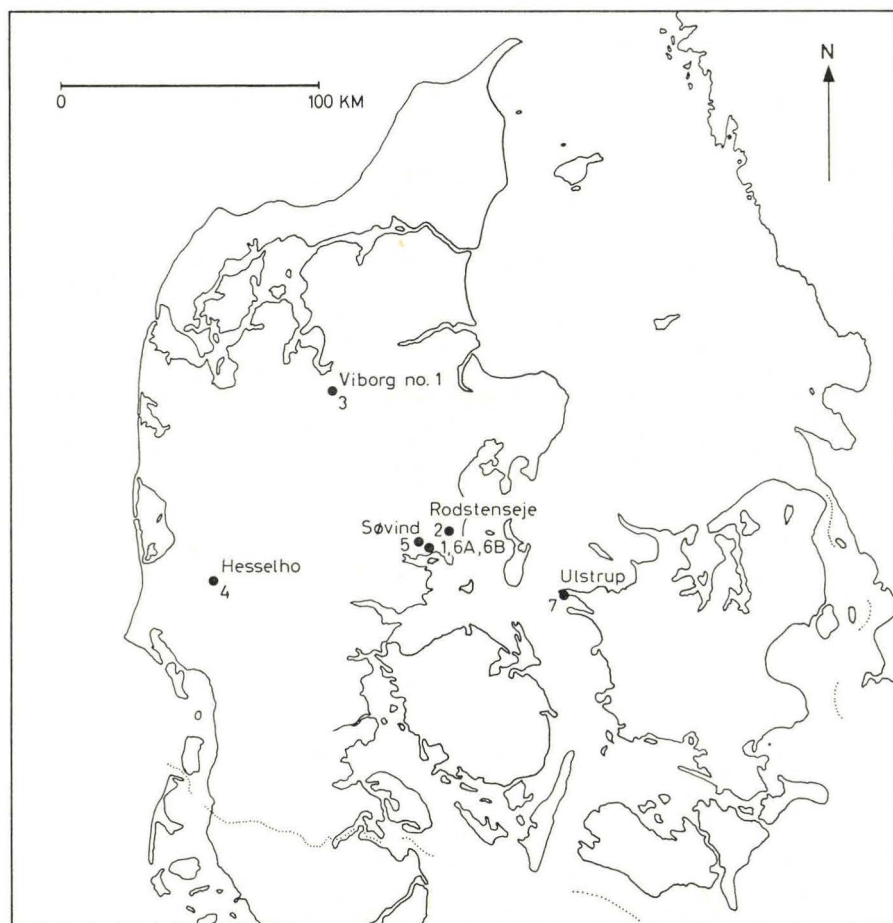


Fig. 1. Locality map. Localities of the samples 1–7 indicated.

Palaeontological notes

Globigerinatheka index (Finlay)

Pl. 3, figs. 1–8; pl. 4, figs. 1–7.

- 1939 *Globigerinoides index*; Finlay, pp. 125, 127, pl. 14, figs. 85–88.
- 1957b *Globigerapsis index* (Finlay); Bolli, p. 165, pl. 36, figs. 14a–18b.
- 1958 *Globigerinoides index* Finlay; Hornibrook, p. 34, pl. 1, figs. 11–14.
- 1959 *Globigerina ampliapertura* Bolli; Drooger & Batjes, p. 174, pl. 1, fig. 1.
- 1962 *Globigerapsis index* (Finlay); Blow & Banner, pl. 15, figs. G–H.
- 1962 *Globigerapsis tropicalis*; Blow & Banner, p. 124, pl. 15, figs. D–F.
- 1969 *Globigerapsis index* (Finlay); Berggren, p. 125, pl. 2, figs. 22–24.

- 1969 *Globigerapsis index* (Finlay); Blow, p. 330, pl. 27, figs. 1–2.
1969 *Globigerapsis tropicalis* Blow & Banner; Blow, p. 331, pl. 27, figs. 5–6.
1969 *Globigerapsis index* (Finlay); Quilty, p. 47, fig. 7, No. 42–48; text fig. 3.
1971 *Globigerinatheka (Globigerapsis) index index* (Finlay); Jenkins, p. 187, pl. 22, figs. 641–645.
1972 *Globigerinatheka index index* (Finlay); Bolli, p. 124, pl. 1, figs. 1–4, 6–7; text figs. 51–57, 63–64.
1972 *Globigerinatheka index tropicalis* (Blow); Bolli, p. 127, pl. 3, figs. 1–24, pl. 4, figs. 7–12; text figs. 58–60.

(For further synonyms: see the papers by Quilty, Jenkins and Bolli.)

Description. The material shows a wide phenotypic variation due to the representation of different ontogenetic stages and also due to the disturbances which often appear during the growth of the individuals.

In the majority of the specimens the growth ceased at a “*Globigerina*-like” stage with 3, 3½ or 4 chambers in the final whorl and with a single umbilical aperture from the ultimate chamber. As far as the sutures can be observed from the dorsal side the specimens with 3 chambers in the final whorl have 4 chambers per whorl in the initial stage of the growth.

In “4-chambered” specimens the ultimate chamber often has a characteristic flattened, beret-like form. Such a specimen is shown on pl. 3, fig. 1.

On the other hand there are relatively few specimens with 2 apertures from the ultimate chamber. In these specimens the aperture spanning over the penultimate chamber is normally the largest one. Almost all specimens with 2 apertures have 4 chambers in the whorl to which the ultimate chamber is added. Specimens with 3 apertures occur but they are very seldom and not represented in the statistical samples.

The ultimate chamber may be more or less reduced in size and dislocated out of the “normal” growth spiral in the “*Globigerina*-like” specimens as well as in the specimens with more than one aperture. In a few cases the specimens with two apertures have a small “bulla-like” chamber above one or both of the two apertures.

The frequencies of the different morphotypes represented in the statistical samples are recorded in table 1.

The preferred direction of coiling is dextral. The percentages of dextrally coiled specimens in sample 1–4 are 96 %, 97.4 %, 86.0 % and 82.0 % respectively.

The texture of the wall represents another variable feature, and the texture seems to be strongly dependent on the development and the thickness of the calcite crust (cp. Hemleben, 1969, fig. 4). In the specimen shown on pl. 3, fig. 2 the crust is lacking in parts of the ultimate chamber.

Table 1: The frequencies (in percentages) of the morphotypes of Globigerinatheka index in sample 1 - 4.

Sample	1	2	3	4
Number of specimens	50	39	50	50
A. 1 aperture, 3 chambers in the final whorl, ultimate chamber 'normal'	8.0	25.6	10.0	14.0
B. 1 aperture, 3½ chambers in the final whorl, ultimate chamber 'normal'	2.0	15.4	20.0	20.0
C. 1 aperture, 4 chambers in the final whorl, ultimate chamber 'normal'	26.0	30.8	40.0	30.0
D. 1 aperture, 4 chambers in the final whorl, ultimate chamber 'reduced'	38.0	12.8	28.0	16.0
E. 2 aperture, ultimate chamber 'normal'	2.0	2.6	0.0	0.0
F. 2 apertures, ultimate chamber more or less 'reduced'	22.0	12.8	2.0	20.0
G. 2 apertures, with a 'bulla-like' structure added to one or both of the 2 apertures	2.0	0.0	0.0	0.0

Remarks. According to Bolli (1972, p. 123) "all Middle to Late Eocene planktonic foraminifera that possess a trochospiral globigerinid stage whose umbilical area is covered by a final chamber with two or more sutural apertures which may or may not be covered by bullae" are now included in *Globigerinatheka* Brönnimann 1952, emended by Proto Decima & Bolli 1970.

Before this emendation was undertaken the specimens in which the sutural apertures are not covered by bullae were referred to the genus *Globigerapsis* Bolli, Loeblich & Tappan 1957. In the diagnosis of *Globigerapsis* it was stated by Bolli et al. (1957, p. 34) that the ultimate chamber is "embracing and covering the umbilical region of the early coil", and that the primary aperture is "interiomarginal, umbilical in the young stage, covered in the adult by an enveloping final chamber", that there are "two or more arched secondary apertures at the lower margin of the final chamber, at the contact with the sutures of the earlier whorl". Furthermore it was stated that "*Globigerapsis* . . . differs from *Globigerinatheka* Brönnimann in lacking the small angular bullae covering the secondary apertures. It differs from *Globigerinoides* Cushman in the absence of an umbilical primary aperture in the adult. *Globigerapsis* does not show the multiple apertures on the earlier chambers as does *Globigerinoides* and *Porticulusphaera*, new genus".

The different growth stages represented in a sample (436 specimens) of *Globigerapsis index* (Finlay) from the Upper Eocene of Western Australia were studied on a quantitative basis by Quilty (1969). Depending on the size and the position of the ultimate chamber, the presence or the absence of bulla(e), and the number of apertures, his material was grouped in 5 "genera" ("*Globigerina*", "*Globigerinoides*", "*Globigerapsis*", "*Globigerinita*" and "*Globigerinatheka*"). The statistical tests of Height versus Breadth in the "normal" growth spiral suggested that all the specimens belonged to a single population. This result gave occasion for Quilty to emphasize the importance of defining genera in terms of phylogeny and not only in terms of a set of morphological characters. Quilty considered the genera *Globigerinoides* and *Globigerinita* to represent monophyletic groups different from *Globigerapsis*, and *Globigerina* was supposed to be the ancestral root stock from which one of the lineages gave rise to *Globigerapsis*. Although Quilty observed another texture in the walls of the bullae of "*Globigerinita*" and "*Globigerinatheka*" than in the walls of the earlier parts of the shells and in the wall of the modified, ultimate chamber of "*Globigerapsis*", he did not attach any weight to the bulla as a specific character. The five "generically different" groups were considered to be biologically conspecific, and *Globigerinatheka* was named as one of the genera which "are probably all only

complex variants of populations belonging to species of previously defined genera and as such must be rejected".

Bolli (1972, p. 111), however, stated that "a bulla may vary from thin walled with fine pores, clearly contrasting with earlier chambers, to thick and coarsely pored, like preceeding chambers, the distinction between an umbilical bulla and a final chamber in the same position clearly rests on size alone", and he figured such a variation in *Globigerinatheka index tropicalis* (pl. 3) and in *G. subconglobata luterbacheri* (pl. 7). It was also stated by Bolli that neither the original definition of a bulla (given by Bolli, Loeblich & Tappan 1957, p. 13), nor the redefinition (given by Banner & Blow 1959, p. 26) include any "size limits or characteristics of the wall". Instead of suppressing *Globigerinatheka*, as done by Quilty, Bolli rejected *Globigerapsis* as the junior synonym of the two genera.

According to these quotations it seems to be fully justified to refer the present material to the genus *Globigerinatheka*, although several specimens have not passed the globigerinid stage, represented by the morphotypes A, B, C and D. The combined percentages of the morphotypes A–D are 74.0 % in sample 1, 84.6 % in sample 2, 98.0 % in sample 3, and 80.0 % in sample 4. A dominance of the globigerinid stage was also observed in the Australian sample examined by Quilty (1969), who stated that the ratio between "*Globigerina*", "*Globigerinoides*", "*Globigerapsis*", "*Globigerinita*" and "*Globigerinatheka*" is 49:9:10½:7:1, i.e. the globigerinid stage ("*Globigerina*") amounted to about 64 %. From the Middle Eocene Porangan stage of New Zealand Jenkins (1971) has reported on samples of *G. (G.) index index* where the specimens "lack the umbilical bulla and the multiple apertures", i.e. the globigerinid stage amounts to 100 %.

On the other hand the taxonomic interpretation at the species level is problematical due to the variation in the number of chambers per whorl and the variation in the coarseness of the wall texture exhibited by the present material. In a letter (dated April 14th 1964) Berggren expressed his opinion on specimens picked from the same residue as sample 1. According to Berggren some of these specimens with a relatively fine wall surface are close to *G. tropicalis* Blow, whereas some other specimens with a coarser wall surface are closer to *G. index* Finlay, but despite these similarities Berggren would not exclude the possibility that a "new form" could be represented. The presence of *G. index* was reported by Berggren (1969) in some other samples of the Søvind Marl from a locality at Moesgård Strand, East Jutland, and this determination was confirmed by Blow (1969).

The relationship between *G. index* and *G. tropicalis* is not finally settled. Blow (1969) still considered *G. tropicalis* as a separate species and figured an ideotype (pl. 27, figs. 5–6) looking quite different from the figured

hypotype of *G. index* (pl. 27, figs. 1–2); both specimens came from the same sample from Tanzania. Bolli (1972, p. 125) stated: "It is often difficult, however, to assign specimens of intermediate character to one of the two species". Jenkins (1971, p. 187) observed "a wide morphological variation from high- to low-spined tests with rough- and smooth-walled forms" in a sample of *G. (G.) index index* from the Middle Eocene Bortonian stage of New Zealand. *G. tropicalis* was suggested by Jenkins to be the "tropical equivalent" of *G. index index*, but he did not define how to discriminate the smoothwalled forms of *G. index* from *G. tropicalis*. The writer has examined 11 specimens of *G. index* from the Uppermost Eocene of New Zealand (sample S 136/887, Oamaru Diatomite, Jackson's Pad-dock, Oamaru), kindly put at my disposal by Dr. Hornibrook. As shown on pl. 4, figs. 6–7 these specimens have a rather smooth wall surface, not at all as rough as the holotype and the paratypes (refigured by Hornibrook (1958) and Jenkins (1971)).

The classification of the Danish material as shown in table 1 deviates in some respects from the classification of *G. index* used by Quilty (1969). "*Globigerina*" as defined by Quilty has only 3 chambers in the final whorl and corresponds to morphotype A. Quilty did not register any forms similar to the morphotypes B, C and D which are strongly represented in the Danish material. The "*Globigerinoides*" of Quilty corresponds to the present morphotype E from which there is a gradual transition to "*Globigerapsis*". The Danish specimens of the "*Globigerapsis*" type as well as of the "*Globigerinita*" type are included in morphotype F, because, as also observed by Bolli (1972), there is no sharp boundary between the bulla of "*Globigerinita*" and the ultimate chamber of "*Globigerapsis*". The single specimen of morphotype G in sample 1 may be considered as representing a transitional stage from "*Globigerapsis*" to the typical "*Globigerinatheka*". Almost all specimens of the morphotypes E, F and G have 4 chambers in the whorl to which the ultimate chamber (or bulla) is added, but the four "genera" with multiple apertures registered by Quilty have only 3 chambers in the corresponding whorl.

The holotype (a "*Globigerina*") and the paratypes ("*Globigerapsis*") of *G. index* as well as the New Zealand specimens in my collection are all "3-chambered" in the final whorl like Quilty's Australian material. It has not been possible to count the number of chambers in the initial part of the shells in the New Zealand material, but Quilty observed 4 chambers per whorl in the initial part of some glauconitic casts. In most of the Danish specimens the initial part of the shells is obscured. However, some of the specimens of morphotype A undoubtedly show a reduction from 4 to 3 chambers per whorl during growth, and a single specimen of morphotype

D shows a reduction from 5 to 4 chambers. Even a reduction from 5 in the initial part over 4 in a later stage to 3 in the final whorl has been observed in a specimen of morphotype F. One of the specimens figured as *G. (G.) index index* by Jenkins (1971, pl. 22, fig. 644) apparently has 4 chambers in the whorl to which the ultimate chamber with two apertures is added, but it still seems to be remarkable that 4 chambers in the final whorl are much more common in specimens in the Danish material than in specimens from Australia and New Zealand.

The holotype of *G. tropicalis* was described with 5 chambers per whorl in the first two whorls and with 3–4 chambers in the final whorl. Bolli (1957, pl. 36, figs. 14a–18b) figured specimens from Trinidad as *G. index*. Blow & Banner (1962) incorporated these specimens in the list of synonyms for *G. tropicalis*. Bolli (1972) accepted the “adult” specimens (fig. 14–15) as *G. index tropicalis*, but excluded the “juvenile” specimens (figs. 16–17) from his list of synonyms. Nevertheless the “juvenile” specimens are similar to the Danish morphotype C with 4 chambers in the final whorl. Some other specimens from Trinidad figured by Bolli (1972, pl. 3, figs. 7, 20) as *G. index tropicalis* unmistakably have 4 chambers in the whorl to which the ultimate chamber with two apertures is added. These few examples may indicate that an essential part of the Danish material is closer to the subspecies *tropicalis* when the number of chambers in the final whorl is taken in consideration.

It is very likely that the specimen figured by Drooger & Batjes (1959, pl. 1, fig. 1) as *Globigerina ampliapertura* from the Søvind Marl (sample Søvind-3, possibly from the same locality as the present sample 1) is identical with the specimens of morphotype C. However, Berggren (1969) registered *G. ampliapertura* in the same samples from Moesgård Strand in which he found *G. index*.

The very high percentage of dextrally coiled specimens is usual in both *tropicalis* and *index*.

It seems to be reasonable to consider the Danish material analyzed in this context as a single biological unit spanning from *Globigerinatheka index index* to *G. index tropicalis*.

Globigerina sp.

Pl. 5, figs. 1–3.

Description. The chambers are subspherical and moderately increasing in size during the growth of the shell. As the overlap of the chambers is moderate, the sutures are distinctly depressed, and the equatorial profile is

lobulate. In the initial part of the shell 5 chambers per whorl may be counted. In the younger stages a whorl is made up of 4 chambers per whorl, or more rarely of only 3 or $3\frac{1}{2}$. On the dorsal side a more or less distinct spire is developed, some specimens being convex, others more flattened. The relative size and the position of the ultimate chamber show some variation, and specimens with a strongly reduced ultimate chamber occur, although they are not very frequent. The aperture is relatively large and usually symmetrically arched. The shape and the size of the aperture are influenced by the size and the position of the chamber. The wall surface is covered by fine spines or pustules.

The percentage of dextrally coiled specimens in sample 5 is 96 %.

Remarks. The present species has not been identified. Some of the specimens appear to resemble *Globigerina ampliapertura* Bolli as illustrated by Bolli (1957a, pl. 22, figs. 5a–b; 1957b, pl. 36, figs. 8a–c), and some others to resemble *Globigerina* cf. *trilocularis* d'Orbigny as illustrated by Bolli (1957a, pl. 22, figs. 8a–c). After examination of some few of the specimens, professor Bolli has kindly informed me in a letter (dated July 19, 1974) that the Danish specimens “differ from *ampliapertura* in more delicate test walls, higher spire, more lobulate peripheral outline and in the aperture being situated more umbilical (in *ampliapertura* it has the tendency to become extraumbilical)”. Compared with *G.* cf. *trilocularis* the Danish specimens “seem to possess a higher spire and a more distinct, higher arched aperture”. Bolli suggests that the Danish specimens are “much closer to *Globigerina praebulloides* or *G. ouachitaensis ouachitaensis* as figured on plate 9, figures O–Q and H–K respectively in Eames et al., 1962”.

Some specimens of *G. ampliapertura* from Trinidad, sent by Prof. Bolli, confirm that the present species is a different one. The wall structure seems, however, not only to differ from the wall structure of *G. ampliapertura*, but also from the wall structure of *G. ouachitaensis* (s.l.) and of *G. praebulloides* (s.l.). The specimens of *G. ampliapertura* from Trinidad, received from professor Bolli, as well as the stereoscan illustrations of the same species given by Blow (1969, pl. 12, figs. 6, 9, 10) show well-developed inter-pore ridges. Well-developed ridges are also seen in *G. ouachitaensis* (s.l.) and *G. praebulloides* s.l.) according to Blow (1969). Although a certain variation in the character of the wall structure of these two “species” occurs, as discussed below under *G. ex gr. bulloides*, the variation can hardly embrace a wall structure as demonstrated by the present species.

Globigerina ex gr. *bulloides* d'Orbigny

Pl. 6, figs. 1–5; pl. 7, figs. 1–5.

Remarks. Several morphotypes are grouped under the preliminary term *G. ex gr. bulloides*, and the problem of whether or not the genetical background of the group is heterogeneous is unsettled. Some of the morphotypes can probably be referred to *Globigerina praebulloides* (s.l.), *G. ouachitaensis* (s.l.), *G. officinalis*, *G. angustiumbilitata* and *Globigerinita univava*, but many specimens show transitional features, and a discrimination has not been possible.

The variable phenotypic appearance is provoked by a variable number of chambers in the final whorl (4, 4½ or 5) and by the variation in the size, the shape and the position of the ultimate chamber. In some specimens the aperture is bordered by a more or less well-developed lip, whereas the size and the shape of the aperture depend on the relative position of the ultimate chamber.

Blow (1969, note to pl. 17, figs. 3, 4) stated that the type of wall structure and texture seen in *G. ouachitaensis* (s.l.) is not the same as that in *G. praebulloides* (s.l.). However, stereoscan illustrations of *G. praebulloides pseudociperoensis* (Blow, 1969, pl. 17, figs. 8, 9) are given in lesser magnification than the illustrations of *G. ouachitaensis ouachitaensis* (pl. 17, figs. 3, 4), and therefore the subjoined note of Blow, that "the pores are seen to be finer, more closely spaced and do not have so well-developed inter-pore ridges as compared to *G. ouachitaensis* (s.s.) and *G. ouachitaensis ciperoensis*" does not convince about the existence of any distinct difference in the type of the wall of *G. ouachitaensis* (s.l.) and *G. praebulloides* (s.l.).

The present material displays various types of wall structures. In some specimens the wall is pustulate, whereas some other specimens have more or less well-developed inter-pore ridges or a "crystalline" surface as if covered with a calcite crust. As more than one type of wall may be represented in one and the same specimen, and as long as the taxonomic value of these different types is unknown, I have preferred to lump the material in the "*bulloides*-group".

The percentages of dextrally coiled specimens in sample 6A and 6B respectively are 50 % and 58 %.

Globigerina patagonica Todd & Kniker

Pl. 5, figs. 4–9.

1952 *Globigerina patagonica*; Todd & Kniker, p. 26, pl. 4, fig. 32.

1960 *Globigerina yeguaensis* Weinzerl & Applin; Berggren, p. 73, pl. 2, figs. 1a–4c; pl. 3, figs. 1a–3c; pl. 4, figs. 1a–2c; pl. 8, figs. 1a–5c; text fig. 11.

1969 *Globigerina patagonica* Todd & Kniker; Berggren, p. 149, pl. 1, figs. 1–6.

Remarks. *Globigerina patagonica* was intensively studied by Berggren (1960) and Berggren & Kurtén (1961). The percentage of dextrally coiled specimens in sample 7 is 58 %.

Biometry

General remarks on the measurements

The individual growth met with in planktonic genera such as *Globigerina* and *Globigerinatheka* complicates the utilization of biometrical methods. Owing to the mutual arrangement of subglobular chambers it is difficult to define a precise site of an axis or a plane according to which a repeatable orientation of the shell can take place, and owing to the changes in the increase of the chamber size and the changes in the relative position of the chambers during the growth it is difficult to find quite adequate characteristics.

Berger (1969) stated that the 'basic building plan' of a Globigerinacean shell is controlled by the following three characteristics: (1) the ratio between successive chamber radii ('q-ratio'), (2) the angle of advance between the lines connecting the center of the test with two successive chamber midpoints ('a-angle') and (3) the ratio of the radius of a chamber to the distance between its midpoint and the one of the succeeding chamber ('overlap'), and these three characteristics were used by Berger for the construction of two-dimensional, geometric models. Whereas the constructed models have a constant number of chambers per whorl in the total shell, natural specimens very often show a decrease in the number of chambers per whorl during growth. For instance, the specimens figured by Blow & Banner (1962) as *Globigerina praebulloides praebulloides* (pl. IX, figs. O-Q), *G. praebulloides leroyi* (pl. IX, figs. R-T), *G. tripartita tapuriensis* (pl. X, figs. H-K), *G. ampliapertura ampliapertura* (pl. XI, figs. A-C), *G. ampliapertura euapertura* (pl. XI, figs. E-G) show a decrease from 5 or 4 chambers per whorl in the older part of the shell to 4 or 3 chambers per whorl in the younger part, and a similar pattern is observed in many specimens in the present material. On the other hand, an increase in the number of chambers per whorl during growth seems to be much more seldom, but an example is demonstrated by Blow (1969, p. 381, pl. 17, figs. 8-9) in his description and illustration of *G. praebulloides pseudociperoensis* with 4 chambers per whorl in the older part and 5 chambers in the final whorl. This difference between the models and the natural specimens can hardly be explained otherwise than by the fact that the constant values of the three characteristics applied for the construction of the models

do not match exactly with the natural growth. In fact, characteristics like the 'q-ratio', the 'a-angle' and the 'o-lap' may change during growth, and, if the characteristics are to be absolutely comparable, they have to be measured at identical stages of growth.

The 'p-ratio' studied statistically in several samples of globigerinid foraminifera by Scott (1966) and Lindenberg (1969) is similar to Berger's 'q-ratio', but p (or $\log p$) was calculated by means of the formula $Z_n = a \cdot p^{n-1}$ in which Z is n^{th} chamber, a is the first chamber, and p is the common ratio of a geometric series represented by the chambers. Scott calculated $\log p$ and the diameter of the penultimate chamber (D_{n-1}) from the diameter of the ultimate (D_n) and antepenultimate (D_{n-2}) chamber

($p = \sqrt[2]{\frac{D_n}{D_{n-2}}}$; $D_{n-1} = D_{n-2} \cdot p$). Lindenberg calculated $\log p$ and the diameters of the second (D_2) and the fourth (D_4 = the ultimate) chamber of the last-formed whorl from the diameter of the first (D_1) and the third

(D_3) chamber of this whorl ($p = \sqrt[2]{\frac{D_3}{D_1}}$; $D_2 = D_1 \cdot p$; $D_4 = D_3 \cdot p$).

The reason for Lindenberg to omit the ultimate chamber from the calculation of $\log p$ was that this chamber "quite often seemed to be irregularly shaped". The method used by Scott and Lindenberg allowed a comparison between the observed (O) and the calculated (or expected, E) diameter of a chamber, and different types of distributions were indicated from the curves representing $\log p$, O-E, and O-E irrespective of signs. Since the curves for $\log p$ were skewed in some of the samples analysed by Scott, and since the curves for O-E of the ultimate chamber did not always fit with a Poisson distribution, the instability of the 'p-ratio' seems to be clearly demonstrated by these two authors. Especially, the deviations of the plots for D_2 and D_4 from the expected regression line for $Z_n = a \cdot p^{n-1}$ as illustrated by Lindenberg (1969, p. 250, fig. 5), may serve to indicate the lack of stability of the 'p-ratio'.

By measuring the length and the breadth of the 'normal growth spiral' in *Globigerapsis index*, Quilty (1969) tried to find a comparable starting point for his studies. However, at the same time Quilty (p. 51) stated that "it is often difficult to decide whether or not the ultimate chamber is, or is not, a little displaced from the normal growth spiral". Furthermore, the problem is accentuated for this genus according to the description given by Blow & Banner (1962, p. 123), because even earlier chambers in *Globigerapsis* than the ultimate one may be displaced from the 'normal' growth spiral. Blow & Banner stated that "the early whorls of regularly enlarging, trochospirally coiled, *Globigerina*-like chambers are followed in the last whorl by chambers which abruptly start to enlarge very rapidly, become

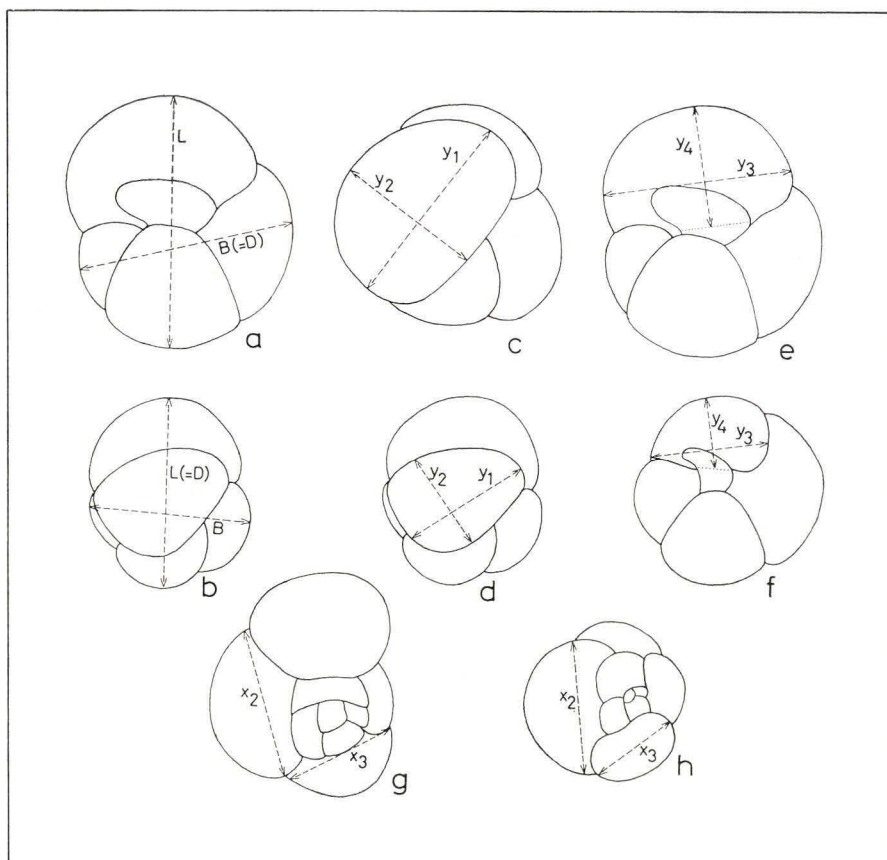


Fig. 2. Contour outlines with indication of the measured characteristics. a, c, e, g: specimen with the ultimate chamber included in the 'normal' growth spiral. b, d, f, h: specimen with the ultimate chamber displaced from the 'normal' growth spiral. a, e, f: ventral view, ultimate chamber 'northwards'. b, c, d: ventral view, penultimate chamber 'northwards'. g, h: dorsal view along the axis of the 'normal' growth spiral.

more ventrally extensive (more tightly coiled), and increasingly embrace the umbilicus of the earlier whorls".

In the present study the length and the breadth of the 'normal' growth spiral are analyzed by means of growth lines, following the method outlined by Quilty (1969), although these characteristics may have a restricted value as expressions for the 'basic shape'. The variability of the ultimate chamber and its relation to the 'normal' growth spiral are illustrated by some other methods.

The following characteristics are measured:

- L the maximum distance from the distal extremity of the ultimate chamber in the 'normal' growth spiral to the distal extremity of the antepenultimate chamber (modified from Quilty, 1969). Orientation of the shell: perpendicular to the axis of the 'normal' growth spiral, i.e. ventral view along the axis. See fig. 2a, b.
- B The maximum distance from the distal extremity of the penultimate chamber in the 'normal' growth spiral to the distal extremity of the ante- antepenultimate chamber (in specimens where this chamber is visible from the ventral side) *or* to the angle between the antepenultimate and the ultimate chambers (in specimens with 3 chambers in the last whorl) (modified from Quilty, 1969). Orientation of the shell: as for L. See fig. 2a, b.
- D the diameter of the shell exclusive of the ultimate chamber. D is equal to B in specimens with a 'normal' growth throughout, and D is equal to L in specimens with a more less reduced ultimate chamber. See fig. 2a, b.
- x_2 the largest diameter visible on the penultimate chamber (equal to Scott, 1970). Orientation of the shell: perpendicular to the axis of the 'normal' growth spiral, i.e. dorsal view along the axis. See fig. 2g, h.
- x_3 the largest diameter visible on the antepenultimate chamber (equal to Scott, 1970). Orientation of the shell: as for x_2 . See fig. 2g, h.
- y_1 the maximum diameter of the ultimate chamber measured parallel to the width of the (primary) aperture. Orientation of the shell: perpendicular to the axis of a spire in which the penultimate chamber is considered as the ultimate one, i.e. ventral view, neglecting the ultimate chamber even if not reduced in size. See fig. 2c, d.
- y_2 the maximum diameter of the ultimate chamber measured normal to y_1 . Orientation of the shell: as for y_1 . See fig. 2c, d.
- y_3 the maximum diameter of the ultimate chamber measured parallel to the width of the (primary) aperture. Orientation of the shell: perpendicular to the axis of a spire in which the ultimate chamber is considered as belonging to the 'normal' growth spiral even if reduced in size, i.e. ventral view, including the ultimate chamber even if reduced in size. See fig. 2e, f.
- y_4 the maximum diameter of the ultimate chamber measured normal to y_3 , i.e. the distance from a line through the junctions of the (primary) apertural rim with the ante-antepenultimate and the penultimate chamber *or* from a line through the junctions of the (primary) apertural rim with the antepenultimate and the penultimate chambers to the distal point of the ultimate chamber. Orientation of the shell: as for y_3 . See fig. 2e, f.

The measurements were undertaken in a binocular microscope (magnifications: objective 8x, ocular 10x) by means of an ocular scale, the units of which are 0.0135 mm. The error of the readings may amount to ± 0.5 unit.

The ultimate chamber and its relation to the 'normal' growth spiral

The phenotypic appearance of the individuals is strongly influenced by the relation between the ultimate chamber and the preceding part of the shell. The ultimate chamber displays a wide variation with respect to its relative size and position in the samples 1, 2, 3, and 4 (*Globigerinatheka index*) as

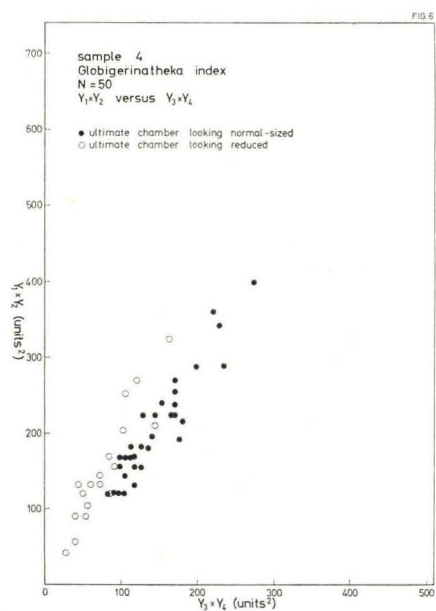
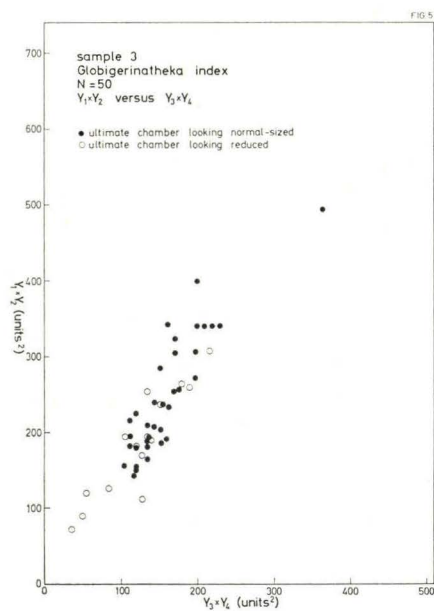
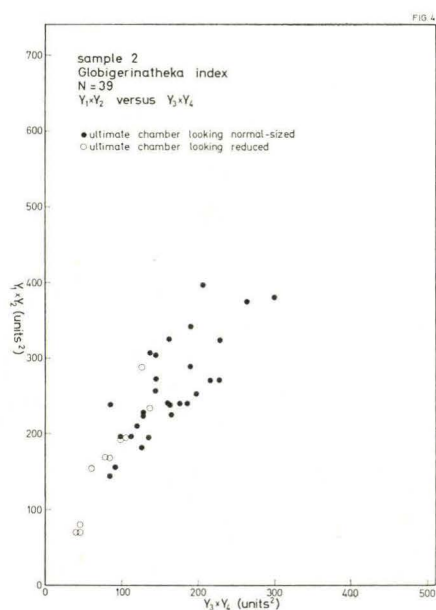
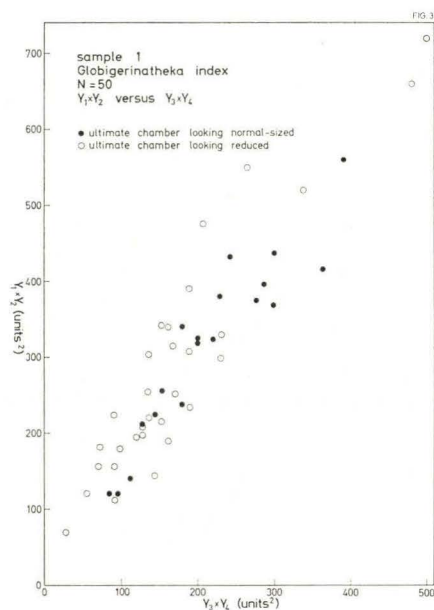
well as in the samples 6A and 6B (*Globigerina* ex gr. *bulloides*). On the other hand, in the samples 5 (*Globigerina* sp.) and 7 (*Globigerina patagonica*) the ultimate chamber is – with only a few exceptions – included in the ‘normal’ growth spiral. The following graphs (figs. 3–34) may serve to illustrate the variability observed in the 8 samples.

The first set of graphs (figs. 3–10) demonstrates the variation in the absolute size of the ultimate chamber. The graphs show the rectangle in which the ultimate chamber can be inscribed when the shell is oriented with the penultimate chamber turned ‘northwards’ ($y_1 \cdot y_2$) as a function of the rectangle in which the ultimate chamber can be inscribed with this chamber turned ‘northwards’ ($y_3 \cdot y_4$). The plots will approximately reflect to what extent the ultimate chamber is inflated. Because the dimension y_4 will often be small compared with the dimension y_2 in specimens with distinctly reduced and displaced ultimate chambers, the ratio $y_1 \cdot y_2 : y_3 \cdot y_4$ will normally give relatively high values in such specimens.

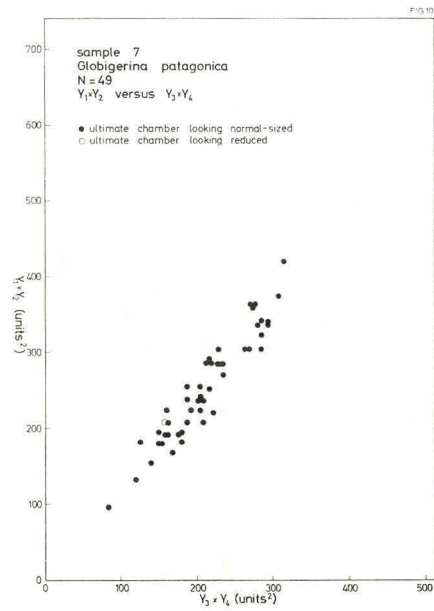
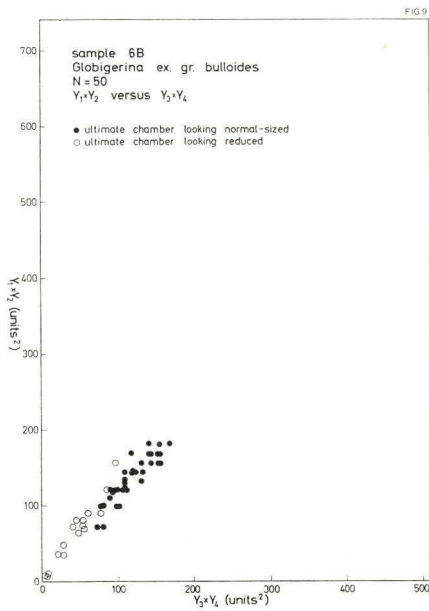
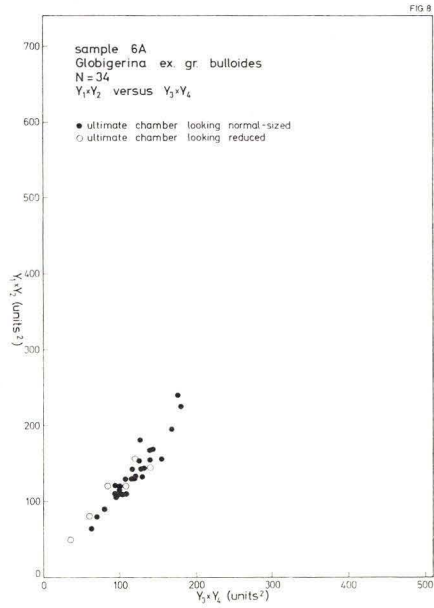
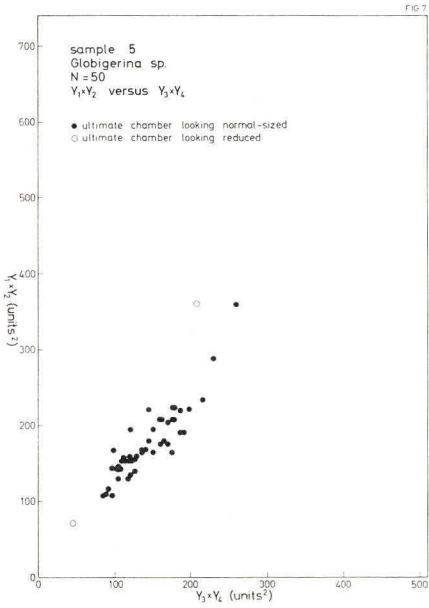
The relation between the dimension y_4 of the ultimate chamber and the preceding part of the shell is illustrated by the next set of graphs (figs. 11–18). The dimension y_4 as a function of D tends to have a linear distribution in samples 5 and 7, whereas the other samples are characterized by more scattered plots. In almost all the cases in which the ultimate chamber was judged to be excluded from the ‘normal’ growth spiral, the specimens have a low ratio $y_4 : D$, but there is a gradual transition between the specimens with respectively a normal-sized and a reduced ultimate chamber (cp. the statement by Quilty cited p. 118 on the ultimate chamber).

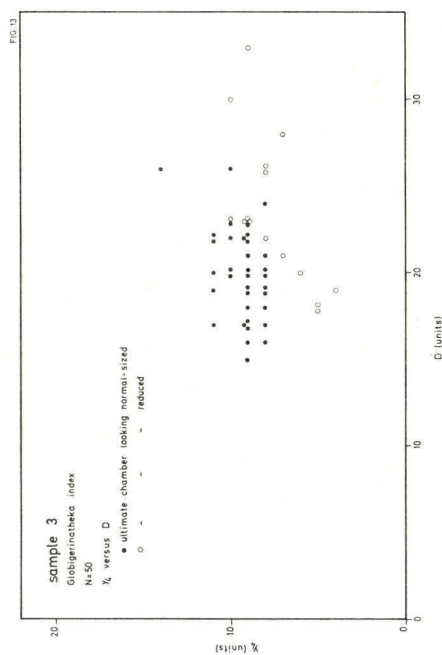
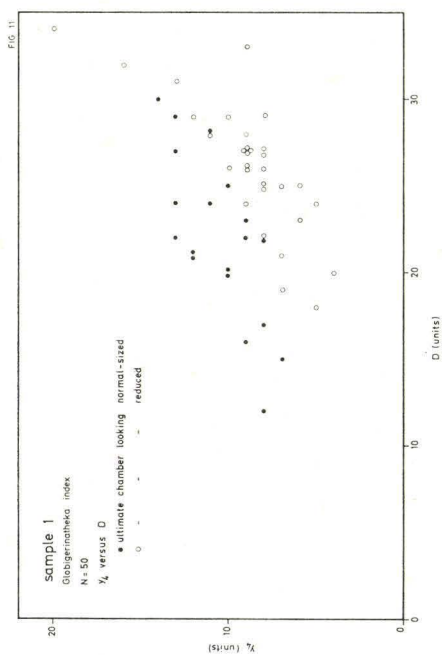
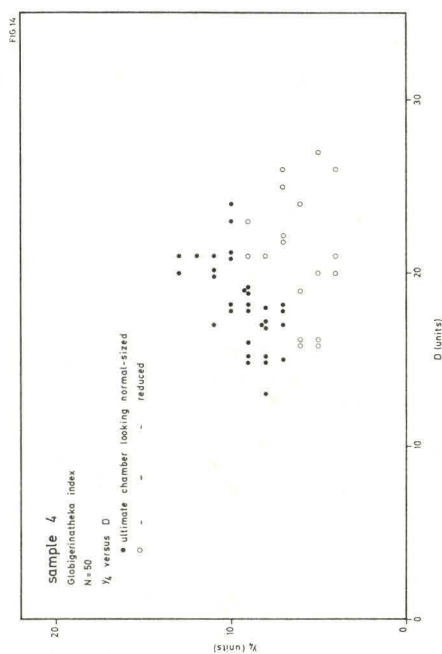
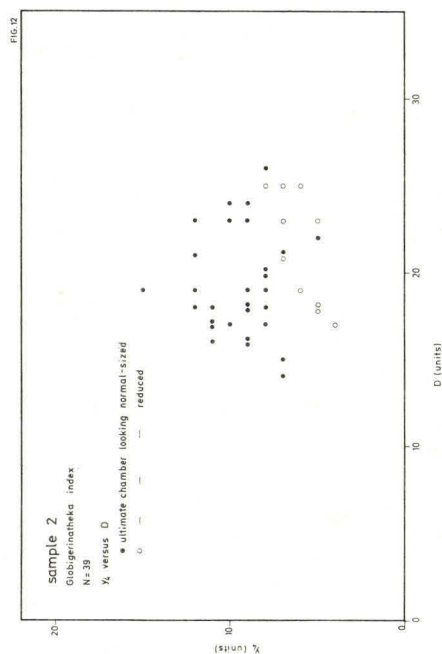
In their studies on the rate of chamber expansion mentioned p. 118 Scott (1966) and Lindenberg (1969) measured the chamber diameters from the dorsal side before calculating $\log p$. In the present study the diameter of the ultimate chamber was measured from the ventral side (y_3) and p' is defined as $\sqrt[2]{\frac{y_3}{x_3}}$. The graphs (figs. 19–26) illustrate the distribution of $\log p'$. When the sum functions are studied by means of probability paper the plots do not follow a straight line as expected if the distribution were normal. The skew distribution seems to be very pronounced in the samples 1, 2, 3, 4, 6A and 6B.

The specimens of *Globigerina* sp. and *G. patagonica* studied respectively in samples 5 and 7 are characterized by a relatively regular growth. This is well demonstrated by the graphs (figs. 27–34) of the observed diameter of the penultimate chamber ($O_{x_2} = x_2$) minus the expected diameter of the same chamber $E_{x_2} = p' \cdot x_3$). The mean figure for $O_{x_2} - E_{x_2}$ is close to zero in samples 5 and 7, whereas the means of the other six samples are definitely displaced to the positive side.



Figs. 3–10. The dimensions of the ultimate chamber. Ordinate ($y_1 \cdot y_2$, see fig. 2): with ultimate chamber 'northwards'. Absciss ($y_3 \cdot y_4$, see fig. 2): with penultimate chamber 'northwards'.





Figs. 11–18. The height (y_4 , see fig. 2) of the ultimate chamber versus the diameter (D, see fig. 2) of the preceding part of the shell.

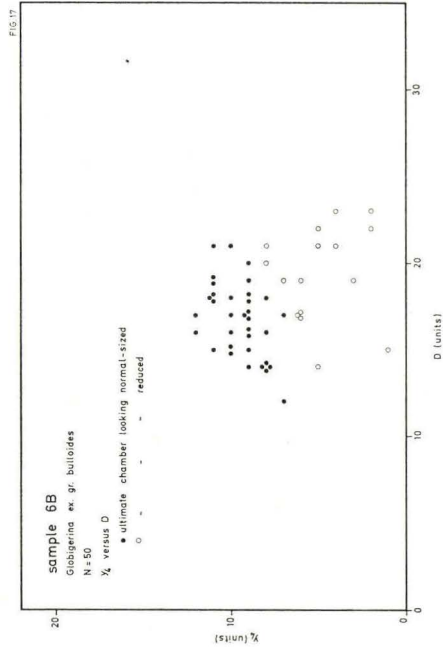
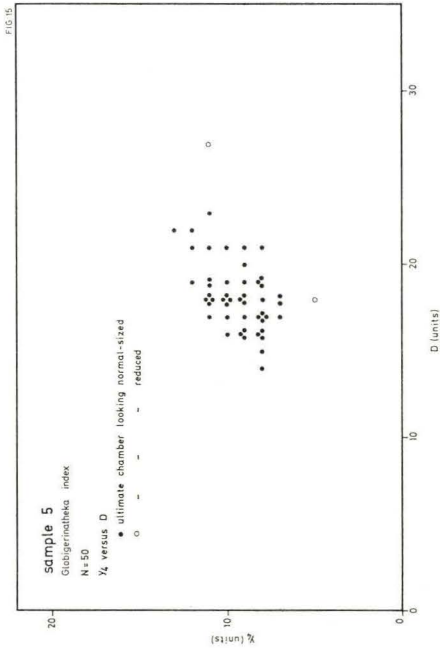
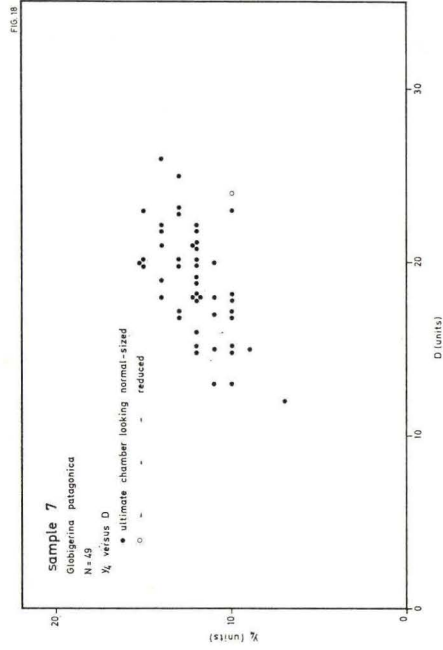
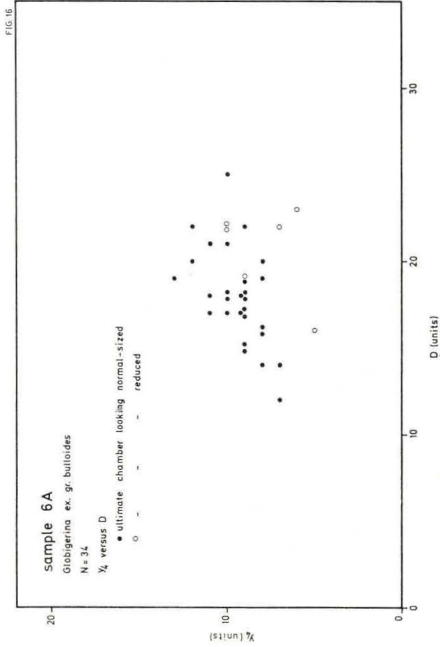


FIG. 20

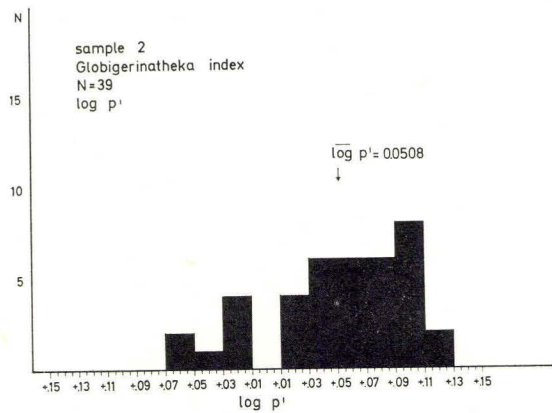


FIG. 22

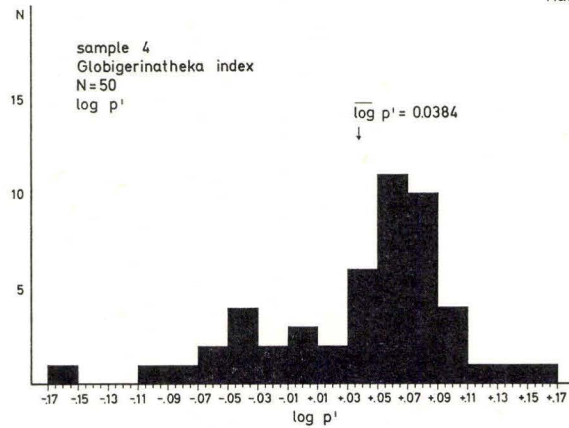


FIG. 19

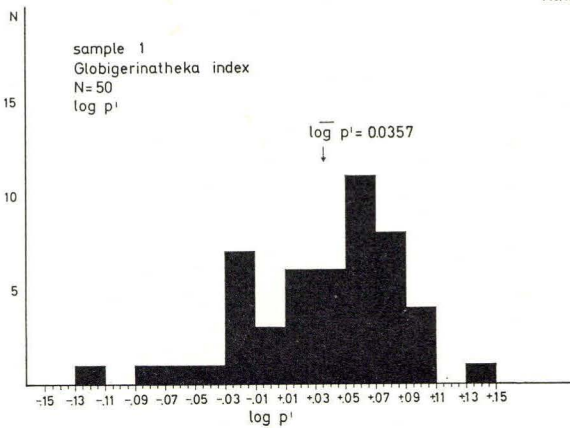
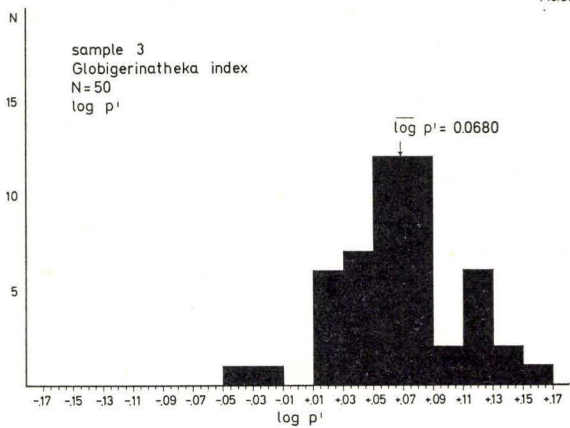


FIG. 21



Figs. 19-26. The distribution of the rate of chamber expansion as expressed by log p' values (see text p. 121 for explanation).

FIG. 24

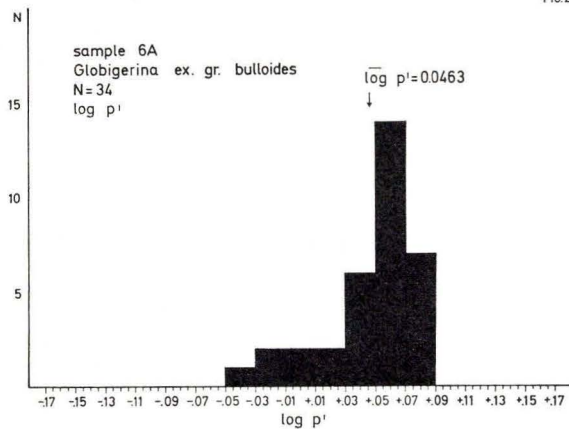


FIG. 26

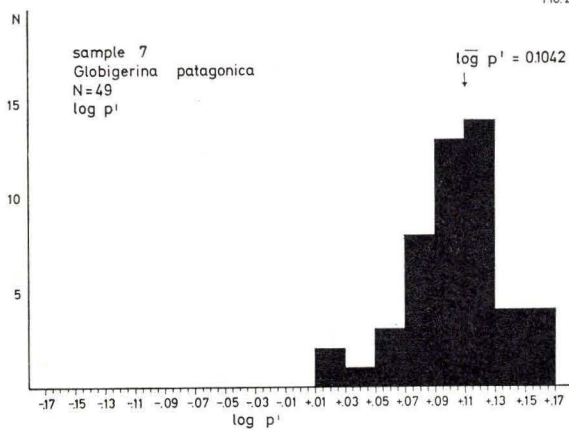


FIG. 23

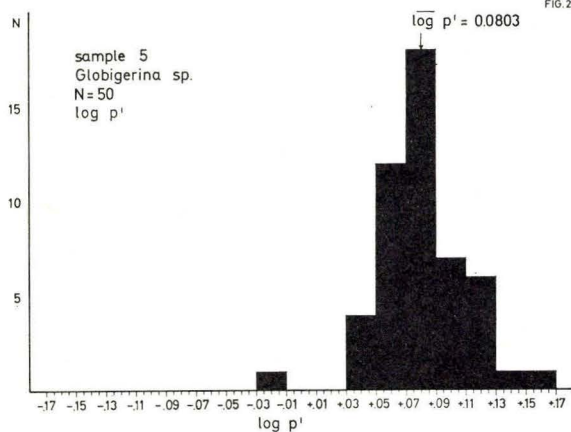
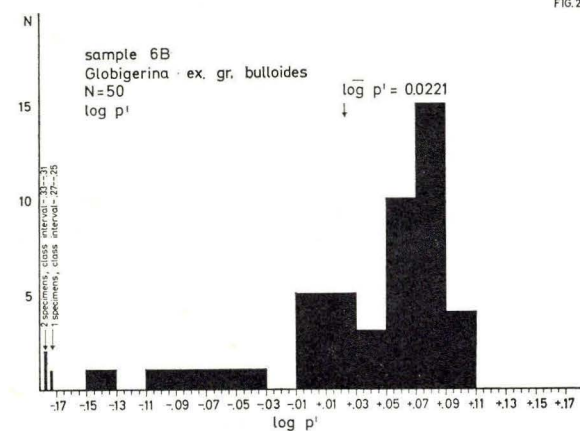
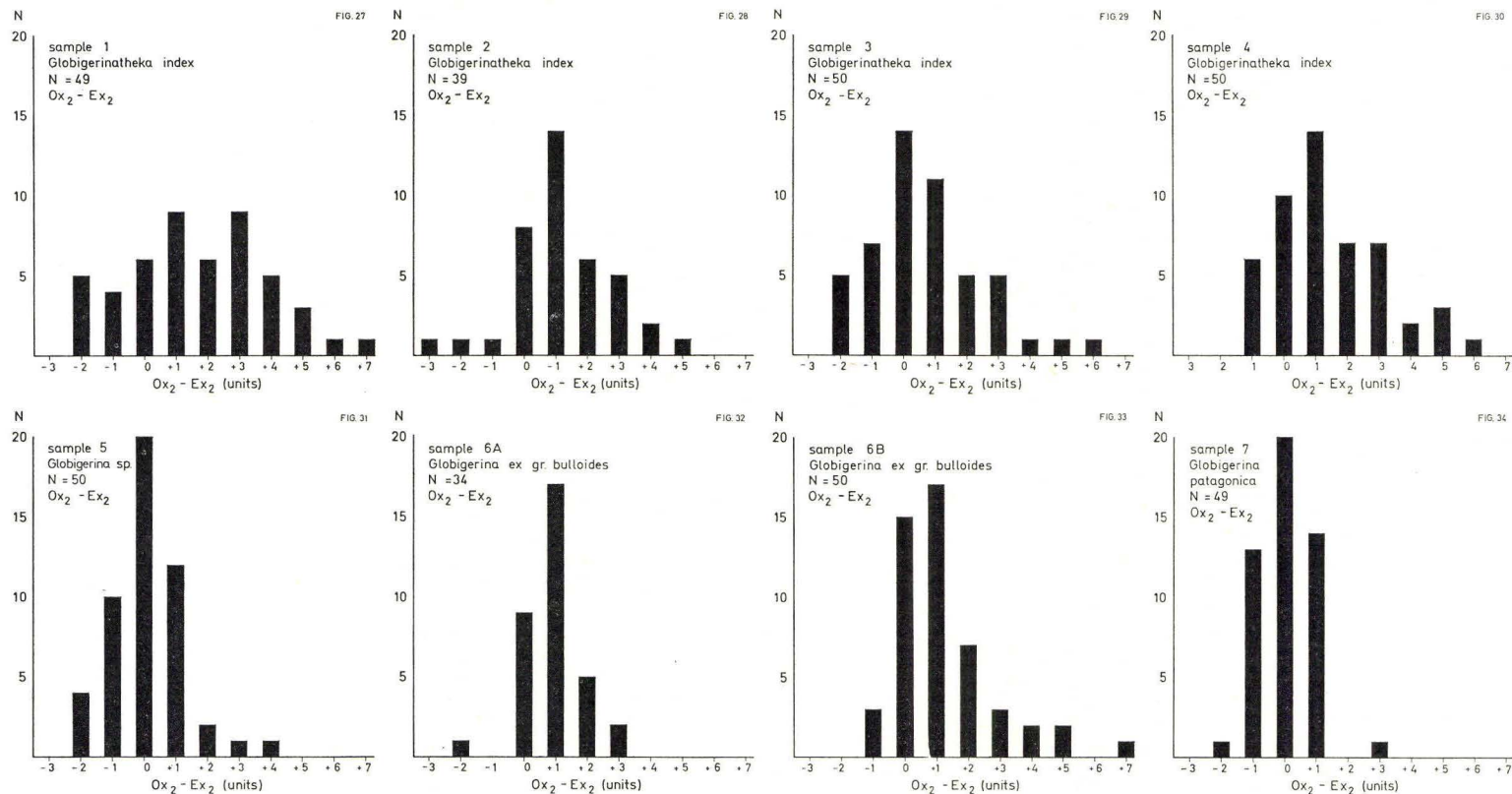


FIG. 25





Figs. 27–34. The distribution of the difference between the observed (Ox_2) and the calculated (Ex_2) diameter of the penultimate chamber (see text p. 121 for explanation).

The 'normal' growth spiral

Quilty (1969) studied the length (L) and the breadth (B) of the 'normal' growth spiral in *Globigerapsis index* according to the statistical method outlined by Imbrie (1956). The growth lines for L and B were constructed and tested as 'reduced major axis', the suitability of which is under current discussion. Christensen (1973) for instance preferred another type of regression line, whereas Hayami & Matsukuma (1970) recommended the reduced major axis as "more reasonable and advantageous in biometrical studies than the conventional regression analysis".

In the present context the same statistical procedure as applied by Quilty (1969) has been followed. However, Quilty defined L as the maximum distance from the distal extremity of the ultimate chamber in the normal growth spiral to the distal extremities of the antepenultimate and penultimate chambers in a line through the umbilicus, and B as the maximum diameter at right angles to L. It will be noted that the present definitions (see p. 120) have been slightly modified from the definitions used by Quilty.

The statistics given in table 2 stand for:

N	number of individuals in the sample	
OR _L	observed range of L	
OR _B	observed range of B	
\bar{L}	mean value of L	$\frac{\Sigma (L)}{N}$
\bar{B}	mean value of B	$\frac{\Sigma (B)}{N}$
S _L	standard deviation of L	$\sqrt{\frac{\Sigma (L - \bar{L})^2}{N - 1}}$
S _B	standard deviation of B	$\sqrt{\frac{\Sigma (B - \bar{B})^2}{N - 1}}$
a	growth ratio	$\frac{S_L}{S_B}$
b	initial growth index	$\bar{L} - \bar{B}a$
r	coefficient of correlation	$\frac{\Sigma (B - \bar{B})(L - \bar{L})}{\sqrt{\Sigma (B - \bar{B})^2 \Sigma (L - \bar{L})^2}}$
σ_a	standard error of a	$a \sqrt{\frac{1 - r^2}{N}}$

E	equation of growth line	$L = aB + b$
S_d	coefficient of absolute dispersion around reduced major axis	$\frac{2}{\sqrt{2(1-r)(S_B^2 + S_L^2)}}$
D_d	coefficient of relative dispersion around reduced major axis	$\frac{100 S_d}{\sqrt{B^2 + L^2}}$

The growth lines (figs. 35–43) are tested with respect to the slopes and the positions. The slope tests are based on the formula

$$z_1 = \frac{[a_1 - a_2]}{\sqrt{\sigma_{a_1}^2 + \sigma_{a_2}^2}}$$

and the results are given in table 3. The position tests are based on the formula

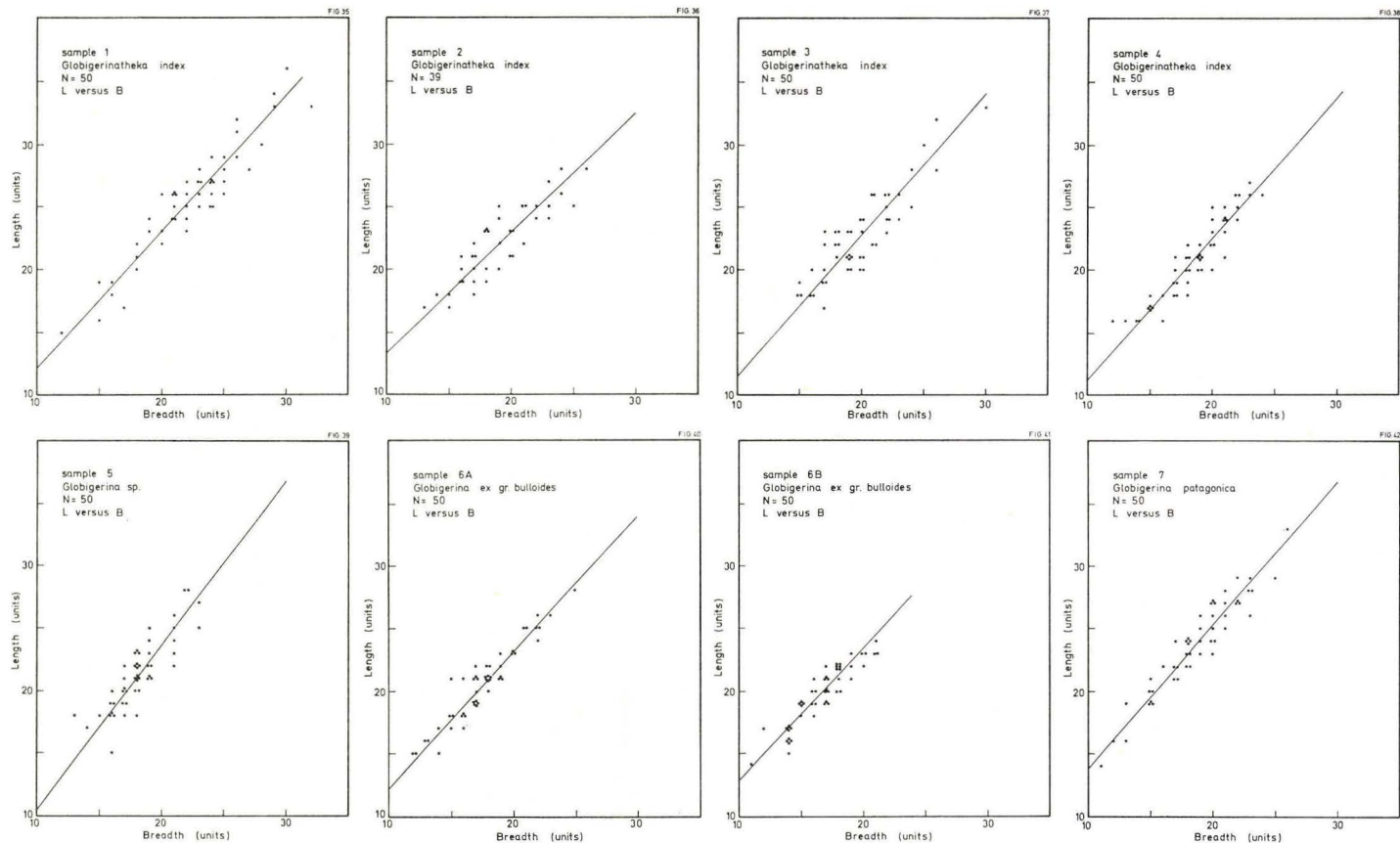
$$z_2 = \frac{B(a_1 - a_2) + (b_1 - b_2)}{\sigma_{a_1}^2 (B - \bar{B}_1)^2 + \sigma_{a_2}^2 (B - \bar{B}_2)^2}$$

and – calculating with such values of B that the vertical distance between the two growth lines concerned is at a maximum inside the observed range – the results are given in table 4.

In table 3 and 4 the values greater than 1.96 indicate that the observed differences in the slope and/or the position of two growth lines are significant, i.e. the probability that the difference arose purely by chance is less

Table 2.

sample statistics	1	2	3	4	5	6A	6B	7
N	50	39	50	50	50	50	50	50
OR_L	15–36u	17–28u	17–33u	16–27u	15–28u	15–28u	14–24u	14–33u
OR_B	12–32u	13–26u	15–30u	12–24u	13–23u	12–25u	11–21u	11–26u
\bar{L}	25.5u	22.1u	22.7u	20.9u	21.3u	20.6u	19.8u	23.8u
\bar{B}	22.3u	19.1u	19.9u	18.5u	18.2u	17.7u	16.6u	18.7u
S_L	4.5u	3.0u	3.5u	3.2u	2.8u	3.0u	2.4u	3.8u
S_B	4.1u	3.1u	3.1u	2.8u	2.1u	2.8u	2.3u	3.3u
a	1.096	0.951	1.123	1.123	1.313	1.083	1.056	1.150
b	+1.1u	+3.9u	+0.4u	+0.1u	–2.6u	+1.4u	+2.3u	+2.3u
r	0.940	0.882	0.890	0.932	0.846	0.944	0.914	0.948
σ_a	0.053	0.072	0.064	0.057	0.099	0.051	0.061	0.052
E	L=1.096B+1.1 L=0.951B+3.9 L=1.123B+0.4 L=1.123B+0.1 L=1.313B–2.6 L=1.083B+1.4 L=1.056B+2.3 L=1.150B+2.3							
S_d	2.096	2.105	2.203	1.565	1.955	1.961	1.383	1.615
D_d	6.186	7.208	7.297	5.607	6.979	7.221	5.352	5.335



Figs. 35-42. Scattergrams and growth lines of length (L) versus breadth (B) of the 'normal' growth spiral.

Table 3.

Values of z_1 from significance tests on the slopes of the growth lines.

sample	1	2	3	4	5	6A	6B	7
1	-	1.62	0.32	0.34	1.93	0.17	0.50	0.72
2	1.62	-	1.79	1.87	<u>2.96</u>	1.49	1.11	<u>2.24</u>
3	0.32	1.79	-	0.00	1.61	0.49	0.76	0.33
4	0.34	1.87	0.00	-	1.66	0.52	0.80	0.35
5	1.93	<u>2.96</u>	1.61	1.66	-	<u>2.07</u>	<u>2.21</u>	1.46
6A	0.18	1.49	0.49	0.52	<u>2.07</u>	-	0.34	0.92
6B	0.50	1.11	0.76	0.80	<u>2.21</u>	0.39	-	1.17
7	0.72	<u>2.24</u>	0.33	0.35	1.46	0.92	1.17	-

than 5 %. If the z values are less than 1.96, the probability that the observed difference arose by chance is greater than 5 %.

The results of the significance tests are visualized in fig. 44. There are only a few cases in which the slopes display a significant difference, for instance when sample 5 is compared with samples 6A and 6B. The ratio L:B decreases during growth in all the samples, but it is likely that this ratio decreases more slowly in *Globigerina* sp. than in *Globigerina* ex gr. *bulloides*, because the line of sample 5 is significantly steeper than the lines of sample 6A and 6B. On the other hand, the difference between sample 5 and 7 is non-significant with respect to the slope.

If the initial growth index and the position of the lines are different there will be a difference in the rate of the decrease in the L:B ratio, although the

Table 4.

Values of z_2 from significance tests on the positions of the growth lines.

sample	1	2	3	4	5	6A	6B	7
1	-	1.73	0.51	1.02	<u>2.22</u>	0.70	1.10	<u>3.40</u>
2	1.73	-	1.63	<u>2.75</u>	<u>3.17</u>	1.56	1.49	<u>5.72</u>
3	0.51	1.63	-	0.33	<u>2.02</u>	0.89	1.75	<u>3.10</u>
4	1.02	<u>2.75</u>	0.33	-	<u>2.84</u>	1.74	<u>2.67</u>	<u>5.08</u>
5	<u>2.22</u>	<u>3.17</u>	<u>2.02</u>	<u>2.84</u>	-	<u>2.27</u>	<u>2.75</u>	<u>3.80</u>
6A	0.70	1.56	0.89	1.74	<u>2.27</u>	-	1.25	<u>4.65</u>
6B	1.10	1.49	1.75	<u>2.67</u>	<u>2.75</u>	1.25	-	<u>3.55</u>
7	<u>3.40</u>	<u>5.72</u>	<u>3.10</u>	<u>5.08</u>	<u>3.80</u>	<u>4.65</u>	<u>3.55</u>	-

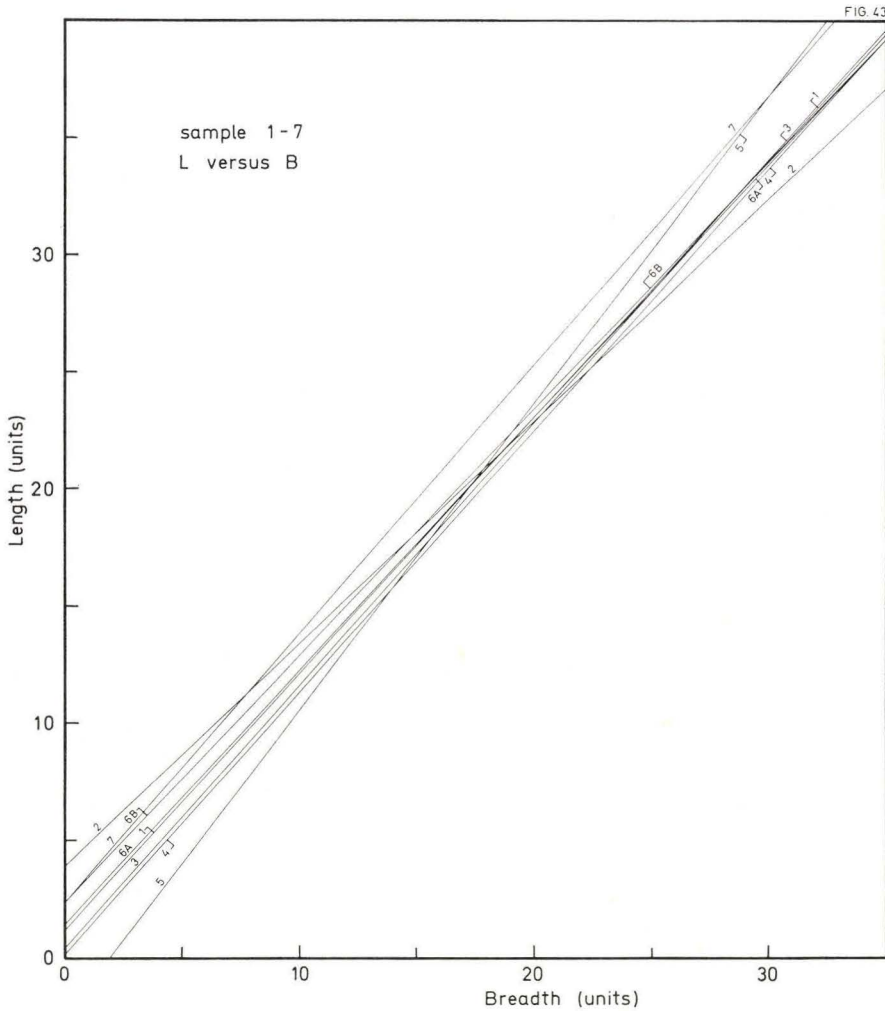


Fig. 43. The growth lines of L versus B in the samples 1-7.

observed difference in the slope is non-significant. By the z_2 -test it is found that the position of the line of sample 5 differs significantly from the line of sample 7. The line of sample 5 is situated below the line of sample 7, and it is likely that the L:B ratio decreases more rapidly with growth in *Globigerina* sp. than in *Globigerina patagonica*.

The analysis of L versus B supports the discrimination of *Globigerina* sp. and *G. patagonica* from each other and from *G. ex gr. bulloides* and *Globigerinatheka index*. These latter two units, represented by samples 6A-B and samples 1-4 respectively, are easily discriminated on the basis of

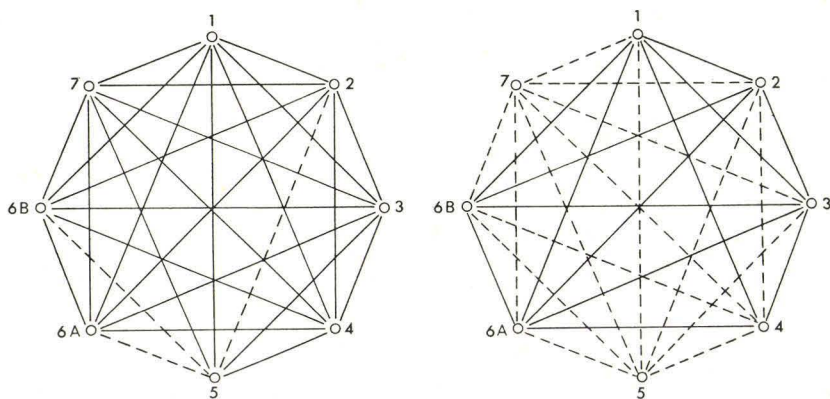


Fig. 44. Comparison of L versus B growth lines of the samples 1-7 with respect to the slopes of the lines (left) and the positions of the lines (right). A full line between two samples indicates values of z_1 and z_2 (see text p. 130) less than 1.96 (non-significant difference), whereas a dashed line indicates z_1 and z_2 values greater than 1.96 (significant difference).

other characters such as the height of the spire, the shape of the chambers, and the structure of the wall, but their growth lines for L versus B are very much alike according to the significance tests. However, sample 2 behaves otherwise than sample 1, 3, and 4 compared with samples 5 and 7 in the slope test, and sample 2 also displays a significant difference from sample 4 with respect to the position of the growth line. The meaning of this heterogeneity within the material referred to *Globigerinatheka index* is unknown.

Acknowledgements. The scanning electron micrographs plate 3, figs. 1-3, 7-8, plate 4, figs. 1, 4, 6-7, and plate 5, figs. 1, 3-9, were taken by Mrs. A. Nørgaard Jensen and Mr. J. Fuglsang at the Institute of Historical Geology and Paleontology, University of Copenhagen. The remaining part of the scanning work was done at the Geological Survey. Photographic development and printing was carried out by Mr. O. Neergaard Rasmussen and Mrs. I. Christiansen, whereas Mrs. H. Christensen and Miss K. Andersen (text-fig. 2) have done the drafting work. The English manuscript was linguistically corrected by Mr. C. M. Robson.

Dansk sammendrag

Indledning

I visse afsnit af Danmarks Eocæn optræder rige planktoniske foraminiferfaunaer (Berggren, 1961, 1969; Dinesen, 1972). Da de planktoniske foraminiferer udviser en betydelig fænotypisk variation, må biometriske metoder søges inddraget til hjælp for artsafgrænsningen. Når de statistiske »samples« udvælges som en præcis defineret »eksperi:

mentel klasse« (jvf. Scott 1966, 1967, 1970; Lindenberg 1969), opstår risiko for at det undersøgte materiale er »skævt«, enten ved kun at rumme en del af variationsformerne, eller ved at repræsentere bestemte variationsformer tilhørende forskellige arter. I det foreliggende arbejde er det statistiske materiale udvalgt fra formodede Mendel'ske populationer, selvom denne fremgangsmåde er klart subjektiv.

De statistiske prøvers oprindelse

Sample 1 (50 eksemplarer, i en del af undersøgelsen dog kun 49 eksemplarer), 2 (39 eks.), 3 (50 eks.) og 4 (50 eks.) repræsenterer materiale, der henføres til *Globigerina-theka index*, og som stammer henholdsvis fra en daglokalitet syd for Søvind og fra borerer ved Rodtenseje nær Odder, ved Viborg og ved Hesselho vest for Grindsted. Sample 5 (50 eks.) med *Globigerina sp.* er fra en daglokalitet vest for Søvind, medens 6A (50 eks., delvis 34 eks.) og 6B (50 eks.) – begge med *Globigerina ex gr. bulloides* – stammer fra en og samme prøve fra et dybere niveau på lokaliteten syd for Søvind. Sample 7 (50 eks., delvis kun 49 eks.) indeholder *Globigerina patagonica* og er fra en daglokalitet ved Ulstrup på Røsnæs.

Bjergartsprøverne svarende til sample 1 – 6B repræsenterer Søvind mergel og prøven svarende til sample 7 repræsenterer Røsnæs ler. Lokaliteternes beliggenhed fremgår af kortet, fig. 1.

Palæontologiske notater

Globigerinatheka index (Finlay) – tavle 3, figs. 1–8; tavle 4, figs. 1–7. Som påpeget af Quilty (1969) og Bolli (1972) foreligger forskellige vækststadier, der også kan skelnes i det danske materiale. I overensstemmelse med Proto Decima & Bolli (1970) betragtes *Globigeropsis* Bolli, Loeblich & Tappan 1957 som »junior synonym« for *Globigerinatheka* Brönnimann 1952. Der synes ikke at være grundlag for at udskille *G. tropicalis* Blow & Banner som en særlig art.

Globigerina sp. – tavle 5, figs. 1–3. Bolli har haft eksemplarer af denne art til undersøgelse og har peget på lighedspunkter med *Globigerina praebulloides* og *G. ouachitaensis ouachitaensis*, men efter min opfattelse har den foreliggende art en vægstruktur, som er forskellig fra de to nævnte arter. Det er derfor foretrukket foreløbig at lade nomenklatur-spørgsmålet stå åbent.

Globigerina ex gr. bulloides – tavle 6, figs. 1–5; tavle 7, figs. 1–5. Det har ikke været muligt at angive et opdelingsgrundlag for materialet, som er henført til denne gruppe. Der er en betydelig variation med hensyn til vægstruktur, men variationen gør sig i nogen grad gældende også inden for et og samme individ.

Globigerina patagonica Todd & Kniker – tavle 5, figs. 4–9. Der henvises til indgående behandlinger af denne art hos Berggren (1960) og hos Berggren & Kurtén (1961), hvor arten henførtes til *G. yeguaensis* Weinzerl & Applin. Berggren (1969) har imidlertid senere ændret artsbetegnelsen.

Biometri

Den individualiserede vækst, som ofte mødes hos planktoniske slægter som *Globigerina* og *Globigerinatheka*, nødvendiggør anvendelsen af biometriske metoder, men samtidig

kompliceres anvendelsen af sådanne metoder netop på grund af vækstformen. I løbet af væksten finder ændringer sted, dels i kamrenes tilvækstrate, dels i et nyt kammers placering i forhold til den ældre del af skallen. Disse ændringer medfører, at karakteristikker, der kan fremskaffes ved en simplere måleprocedure, kun giver tilnærmede udtryk for vækstformen. Desuden er det vanskeligt at fastlægge en akse eller et plan i det enkelte individ, som kan danne et ensartet orienteringsgrundlag for målingerne.

I det foreliggende arbejde er hovedvægten lagt på målinger af skallens længde og bredde, men da skallerne repræsenterer vidt forskellige vækststadier, er det klart at målingerne kun har begrænset værdi som udtryk for vækstformen. I mange eksemplarer falder det afsluttende kammer tydeligt uden for den »normale« vækstspiral. Sådanne »reducerede« kamre er ladet ude af betragtning, og længde og bredde er målt på den »normale« vækstspiral, hvorved sammenlignelighedsgraden forbedres. Da det afsluttende kammer varierer stærkt med hensyn til størrelse og placering i forhold til den ældre del af skallen, vil det i mange tilfælde dog stadig bero på et skøn, om dette kammer regnes med til den »normale« vækstspiral eller ej.

Der er i undersøgelsen benyttet karakteristikker som vist på fig. 2a–h. Det afsluttende kammer og dets relation til den ældre del af skallen er søgt belyst ved forskellige metoder. Figs. 3–10 viser kammerets absolutte størrelsesvariation, idet dimensionerne er målt i to stillinger. Forholdet $y_1 : y_2 : y_3 : y_4$ vil normalt være ret højt i eksemplarer, hvor det afsluttende kammer er af reduceret størrelse. Den relative størrelsesvariation fremgår af figs. 11–18.

Det afsluttende kamms variation kommer indirekte til udtryk på figs. 19–34, hvor log p' angiver et størrelsesforhold mellem kamrene, idet $p' = \sqrt{\frac{y_3}{x_3}}$ (og således er

modificeret fra p -værdien anvendt af Scott (1966) og Lindenberg (1969)), og hvor $O_{x_2} - E_{x_2}$ viser forskellen mellem den målte diameter på det næstsidste kammer og den ved hjælp af p' beregnede diameter for det samme kammer ($E_{x_2} = p' \cdot x_3$). Afbildningerne viser tydeligt, at det afsluttende kammer som oftest er et led i den »normale« vækstspiral hos *Globigerina* sp. (sample 5) og *Globigerina patagonica* (sample 7). Derimod er *Globigerinatheka index* (sample 1, 2, 3 og 4) og *Globigerina* ex gr. *bulloides* (sample 6A og 6B) præget af uregelmæssighed i slutstadiet.

Med forbillende i et arbejde af Quilty (1969), som igen er baseret på den af Imbrie (1956) opstillede statistiske metodik, er »vækstlinierne« (reduced major axis) for længde (L) versus bredde (B) optegnet og sammenlignet indbyrdes (se tabellerne 2–4 samt figs. 35–44). Det fremgår af tabel 3–4 og fig. 44, at vækstlinierne hos *Globigerina* sp. (sample 5) og *G. patagonica* (sample 7) er signifikant ($p = 0.05$) forskellige indbyrdes og fra de øvrige vækstlinier. *Globigerina* ex gr. *bulloides* (samples 6A og 6B) og *Globigerinatheka index* (sample 1, 2, 3 og 4), som let kan skelnes fra hinanden på basis af andre karakterer, synes derimod ikke at være signifikant forskellige med hensyn til længde versus bredde.

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9. *Ellen Louise Mertz*: Odense og omegns jordbundsforhold. En ingeniør-geologisk beskrivelse. (By-geologi nr. 6). 1974. 37 p.

Plates

- Figs. 1–2. *Granosaccus* cf. *sulcatus* Maedler 1964 1975–FB–01
Dansk Nordsø A–2 borehole, 11,090'–11,100'.
S1 321 PM: 42.0–100.4.
- Fig. 3. *Granosaccus* cf. *sulcatus* Maedler 1964 1975–FB–02
Dansk Nordsø A–2 borehole, 11,090'–11,100'.
S1 321 PM: 50.8–104.9.
- Fig. 4. *Granosaccus* cf. *sulcatus* Maedler 1964 1975–FB–03
Dansk Nordsø A–2 borehole, 11,090'–11,100'.
S1 321 PM: 47.6–97.5.

The plate shows examples of the variation of ornamentation within specimens identified as *G.* cf. *sulcatus*. Magnification $\times 1000$.

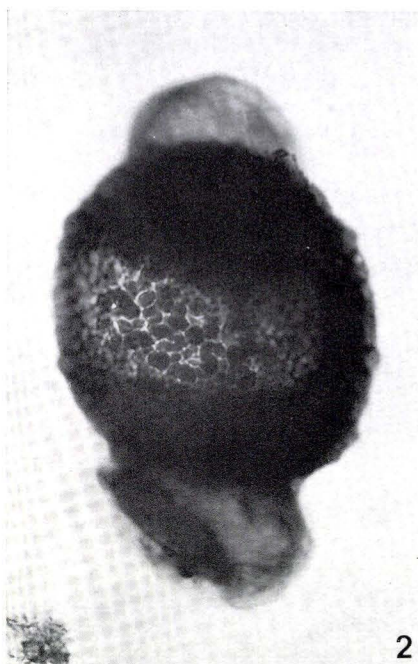
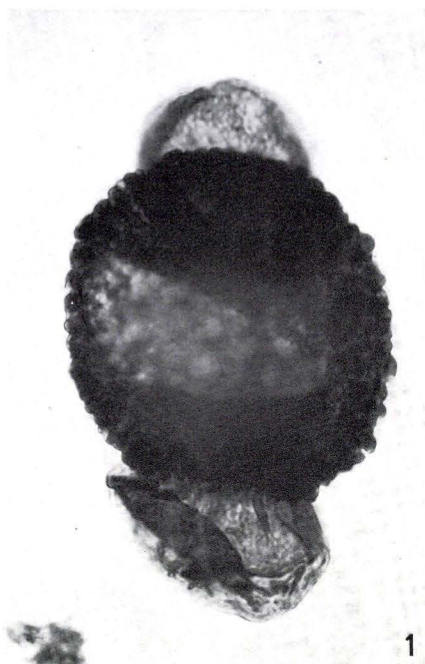
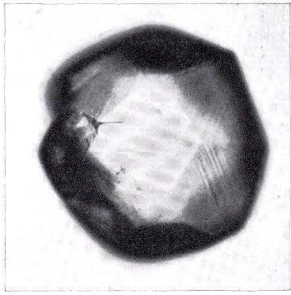


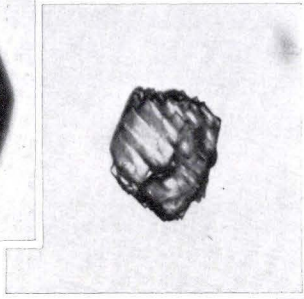
Plate 2

Microphotographs of heavy-minerals. Mounting medium: Clearax (R.I. = 1.666).

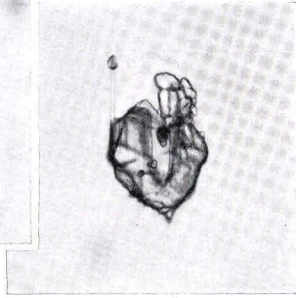
- A. Idiomorphic garnet. Sample no. 2. Skagen.
- B. Heavily corroded titanite. Original outline obliterated. Sample no. 4. Frederikshavn.
- C. Corroded epidote. Where protected by inclusions long spines of epidote have survived the diagenetic dissolution. Sample no. 3. Frederikshavn.
- D–E. Corroded epidote. As C. Sample no. 4. Frederikshavn.
- F–G. Fresh titanite. Sample no. 9. Tønder.
- H. Idiomorphic biotite. Sample no. 9. Tønder.



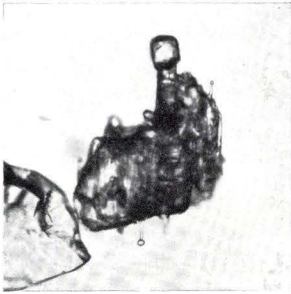
A



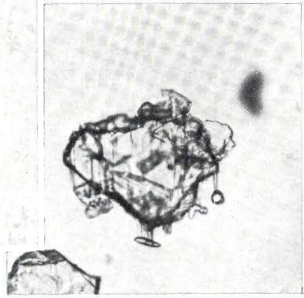
B



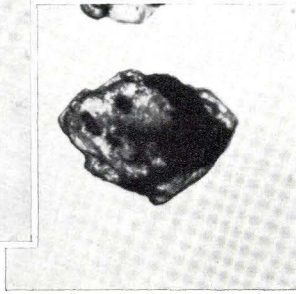
C



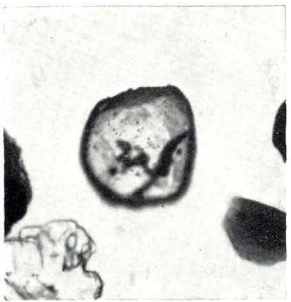
D



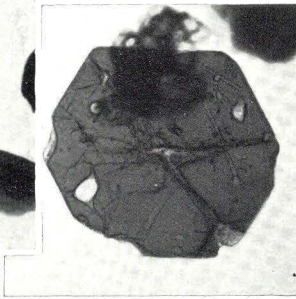
E



F



G



H

100 μ m

- Figs. 1–8. *Globigerinatheka index* (Finlay) p. 108
Søvind Marl. Outcrop about 0.3 km southwest of the church of Søvind.
All specimens derived from the same rock sample as the statistical
sample 1.
× 100

Fig. 1: Ventral view of morphotype C, with moderately developed calcite crust. AD–I–17.

Fig. 2: Ventral view of morphotype C, with calcite crust lacking in the upper part of the ultimate chamber. AD–I–4.

Fig. 3: Peripheral view of morphotype C, with strongly developed calcite crust. AD–I–16.

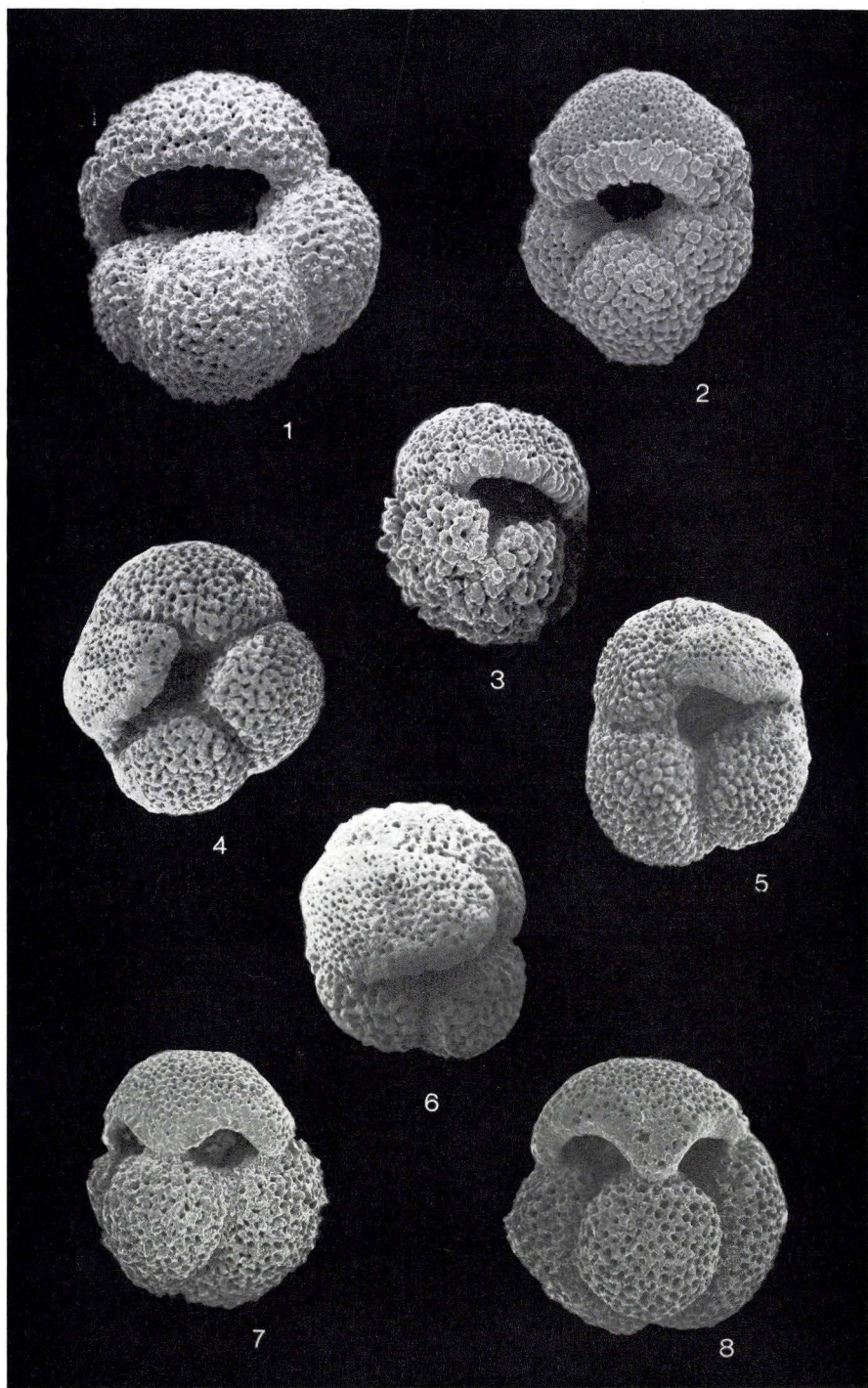
Fig. 4: Ventral view of morphotype D. AD–XXXV–8.

Fig. 5: Ventral view of morphotype D. AD–XXXV–5.

Fig. 6: Ventral view of morphotype D. AD–XXXV–2.

Fig. 7: Morphotype F, with slightly 'reduced' ultimate chamber. AD–I–13.

Fig. 8: Morphotype F, with slightly 'reduced' ultimate chamber and undeveloped (or dissolved ?) calcite crust. AD–I–5.



Figs. 1–5. *Globigerinatheka index* (Finlay) p. 108
Søvind Marl. Outcrop about 0.3 km southwest of the church of Søvind.
All specimens derived from the same rock sample as the statistical
sample 1.
× 100

Fig. 1: Morphotype E, with moderately developed calcite crust and
‘incised’ sutures. AD–I–19.

Fig. 2: Morphotype F, with strongly ‘reduced’ ultimate chamber. AD–
XXXV–10.

Fig. 3: Morphotype F, with strongly ‘reduced’ ultimate chamber and well-
developed calcite crust. AD–XXXV–9.

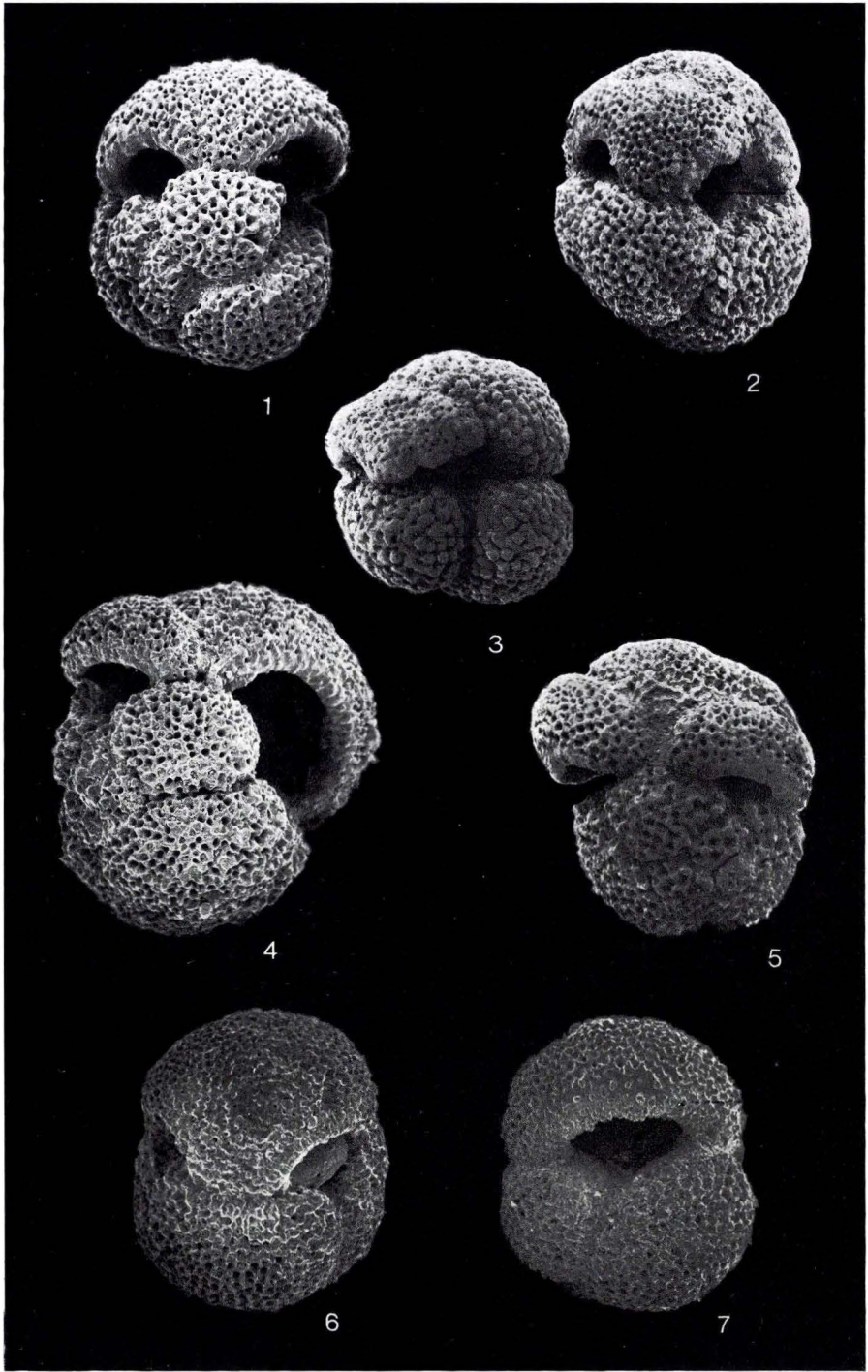
Fig. 4: Morphotype G, with a single ‘reduced’ (or ‘bulla-like’) chamber
added. AD–I–6

Fig. 5: Morphotype G, with ‘reduced’ (‘bulla-like’) chambers added to
both of the two apertures. AD–XXXV–4.

Figs. 6–7. *Globigerinatheka index* (Finlay) p. 108
Oamaru Diatomite. Jackson’s Paddock, Oamaru, New Zealand. Horni-
brook sample S 136/887.
× 100

Fig. 6: Specimen similar to morphotype E, with undeveloped (or dissolved
?) calcite crust (and with foreign material filling one of the apertures).
AD–II–10.

Fig. 7: Ventral view of specimen similar to morphotype A, with undevel-
oped calcite crust. AD–II–11.



Figs. 1–3. *Globigerina* sp. p. 114
Søvind Marl. Outcrop at Toftum, about 1.5 km westnorthwest of the
church of Søvind. Specimens derived from the same sample as the
statistical sample 5.
× 100

Fig. 1: Ventral view. AD–VII–2.

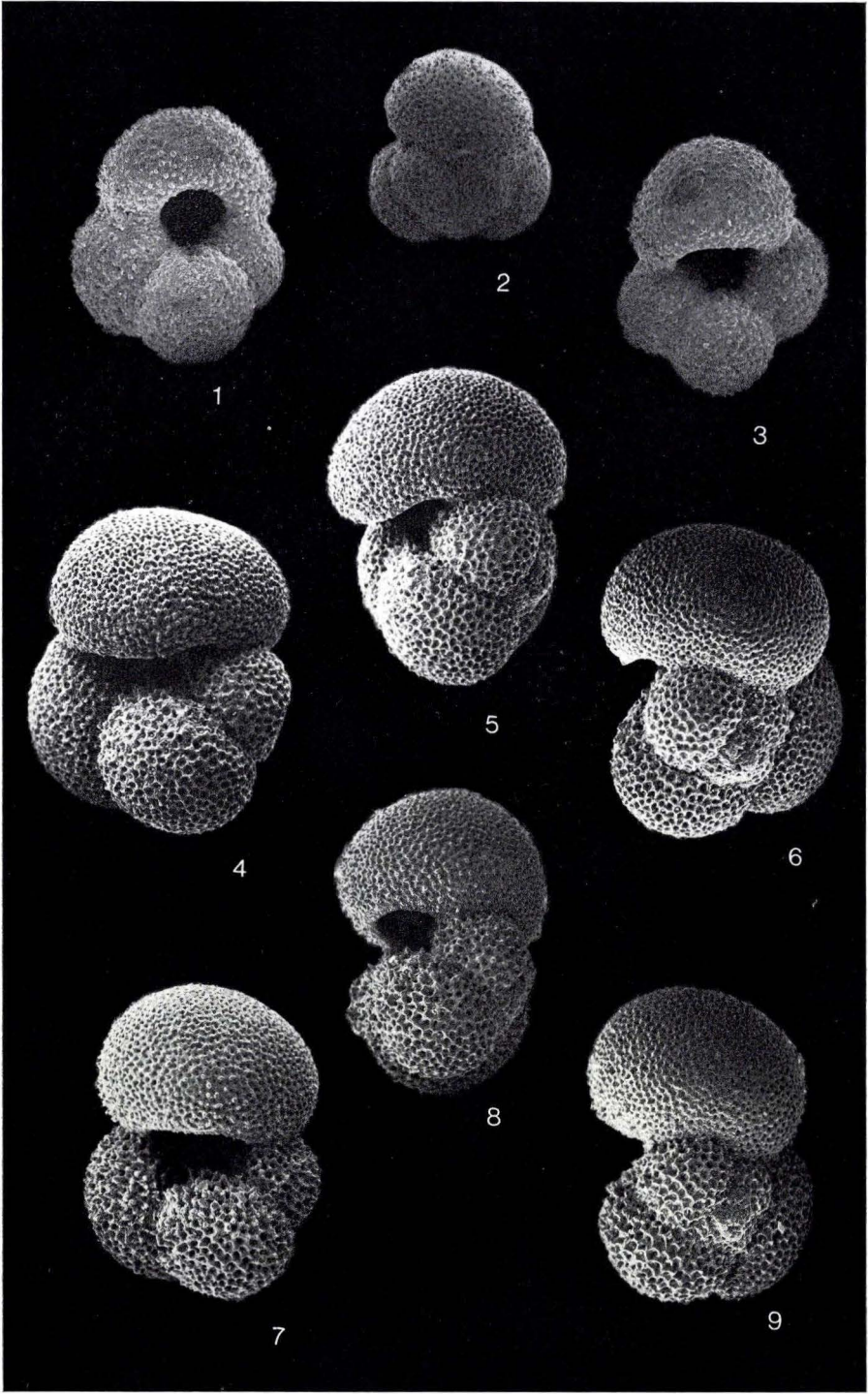
Fig. 2: Dorsal view of another specimen. AD–XXXIII–21.

Fig. 3: Ventral view of a third specimen. AD–VII–1.

Figs. 4–9. *Globigerina patagonica* Todd & Kniker p. 116
Røsnæs Clay. Outcrop about 0.8 km westsouthwest of the church of
Ulstrup. Specimens derived from the same rock ample as the statistical
sample 7.
× 100

Figs. 4–6: Ventral, peripheral and (periphero-) dorsal views of a single
specimen. AD–XIII–3.

Figs. 7–9: Ventral, peripheral and (periphero-) dorsal views of another
specimen. AD–XIII–5.



- Figs. 1–5. *Globigerina* ex gr. *bulloides* d'Orbigny p. 115
 Søvind Marl. Outcrop about 0.3 km southwest of the church of Søvind.
 All specimens derived from the same rock sample as the statistical
 samples 6A and 6B
 × 150

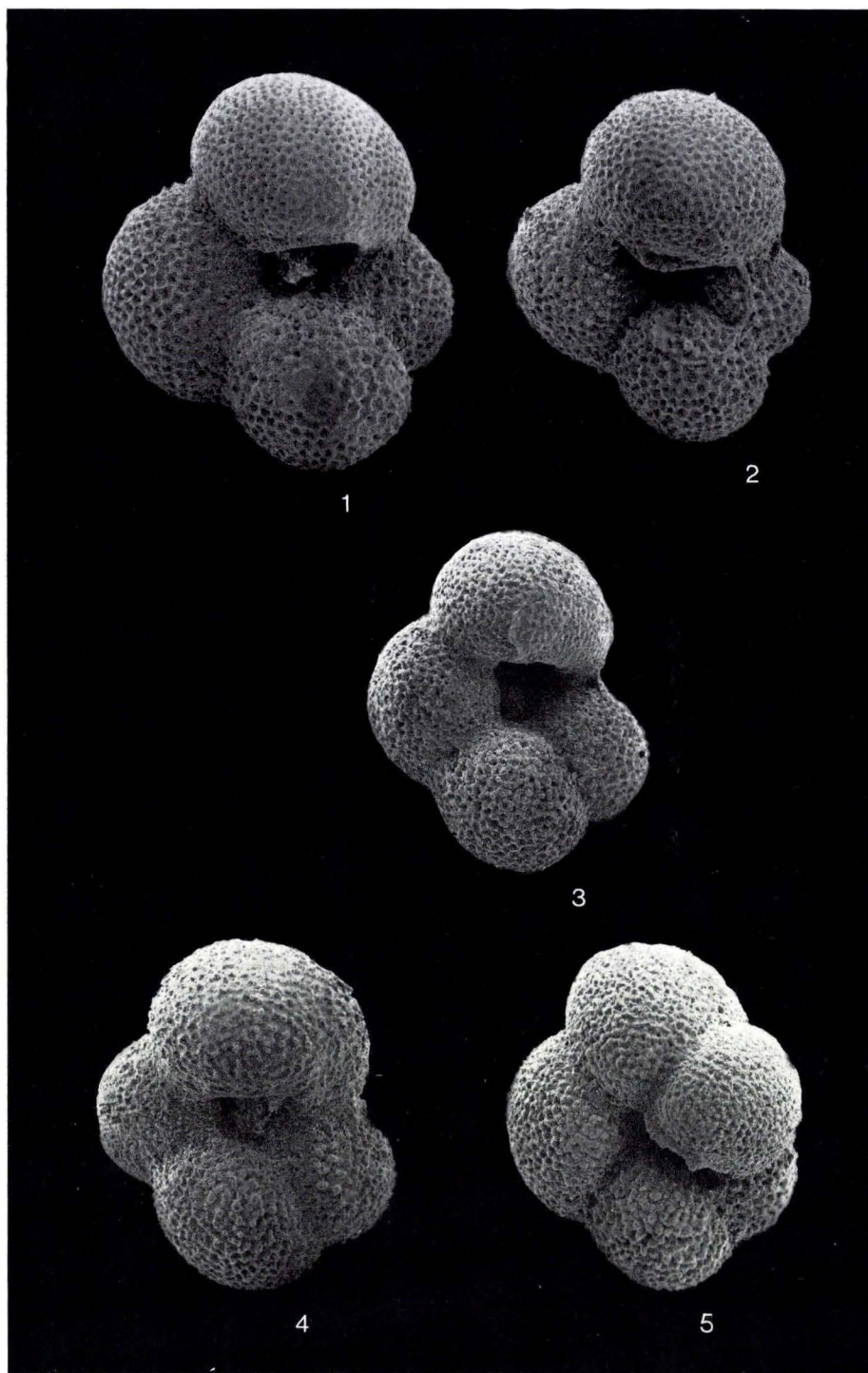
Fig. 1: Ventral view of a specimen with slightly 'reduced' ultimate chamber, rim-bordered aperture, and inter-pore ridges. (Features in common with *G. praebulloides leroyi* Blow & Banner, and with *G. officinalis* Subbotina). AD-XXXIV-5.

Fig. 2: Ventral view of a specimen with slightly 'reduced' penultimate chamber, remnants of a strongly 'reduced' ('bulla-like') ultimate chamber, and with lip-bordered aperture. AD-XXXIV-3.

Fig. 3: Ventral view of a specimen with slightly reduced ultimate (possibly penultimate) chamber, widely open umbilicus, and wall surface partly covered by a calcite crust. (Some of the features in common with *G. ouachitaensis* Howe & Wallace). AD-XXXIV-10.

Fig. 4: Ventral view of a specimen with 'normal' ultimate chamber, and with some variation in the character of the wall surface. AD-XXXIV-7.

Fig. 5: Ventral view of a specimen with strongly 'reduced' ultimate chamber, lip-bordered aperture, and wall surface covered by a calcite crust. AD-XXXIV-11.



- Figs. 1–5. *Globigerina* ex gr. *bulloides* d'Orbigny p. 115
Søvind Marl. Outcrop about 0.3 km southwest of the church of Søvind.
All specimens derived from the same rock sample as the statistic samples
6A and 6B.
× 150

Fig. 1: Ventral view of a specimen with 'normal' ultimate chamber, lip-bordered aperture, and interpore ridges. (Features in common with *Globigerina praebulloides leroyi* Blow & Banner). AD-XXXIV-2.

Fig. 2: Ventral view of a specimen with 'normal' penultimate chamber, remnants of strongly 'reduced' ('bulla-like') ultimate chamber, lip-bordered aperture, and inter-pore ridges. AD-XXXIV-1.

Fig. 3: Ventral view of a specimen with 'reduced' ultimate chamber, lip-bordered aperture, and wall surface partly covered by a calcite crust. AD-XXXIV-12.

Fig. 4: Ventral view of a specimen with 'normal' ultimate chamber, lip-bordered aperture, and with some variation in the character of the wall surface. AD-XXXIV-8.

Fig. 5: Ventral view of a specimen with strongly 'reduced' ultimate chamber, and wall surface covered by a calcite crust. AD-XXXIV-15.

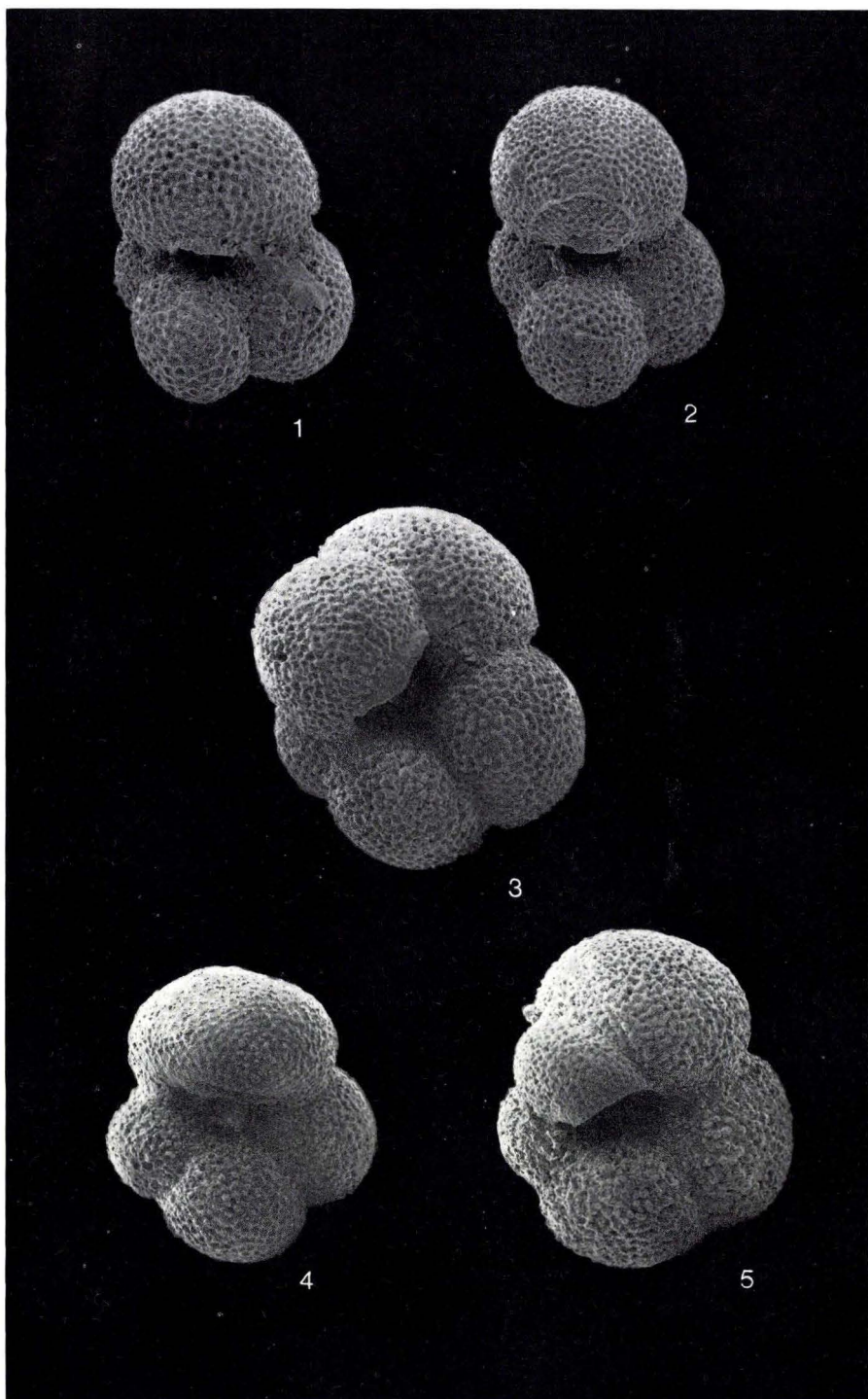


Plate 8

The north side of the section from 1971. The measurements given at the top of the section are calculated from the 1946 fix point. The height of the section is app. 1.25 m to the east and app. 1.75 m to the west. The vertical arrows point to the lower primary peat layer, while the marked peaty layer in the profile is the one that is expected mainly to consist of rebedded material. The locations of the analysed profiles are given on the section. Diagram 2 is composed of 2 profiles, the lower part from 20 m and the upper from 15 m. The horizontal arrow at 10 metres indicates the thin dark gyttja layer mentioned in the text. The profile in Plate 9 is for the main part from 33 m in this section.

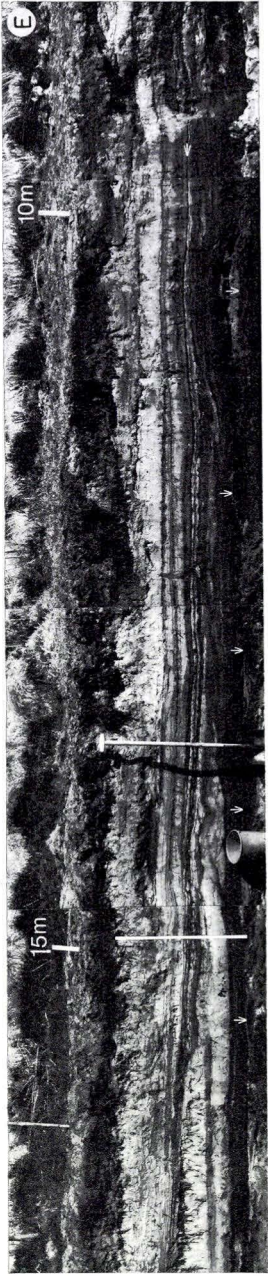
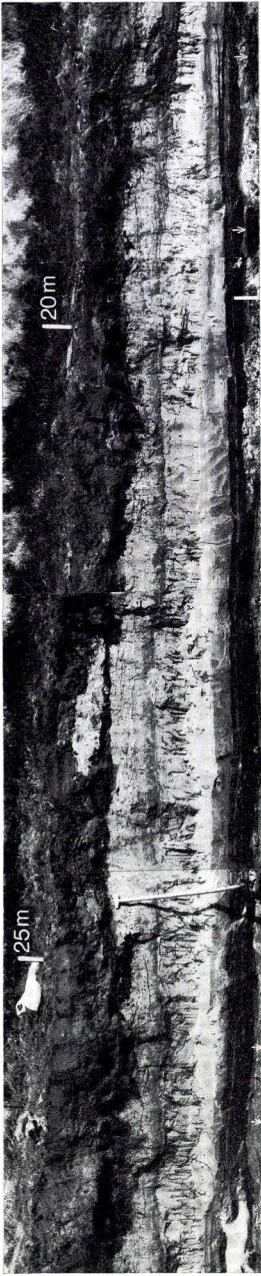


Plate 9

Butomus umbellatus pollen grain from Alleröd sand with drifted material (14 cm in diagram 2). $\times 1800$.

Sediment development given in a profile. The left profile is the oldest part from 20 m, taken below the section (Plate 8). This profile is the one used in diagram 2. The continuation in the two other profiles is from 33 m. The peat and gyttja layer from 30 to 53 cm was used in diagram 3. The organic bands from 86 to 90 cm and from 97 to 101 cm is thicker in diagram 2 (Fig. 4) and lies close together and close to the lower peat.

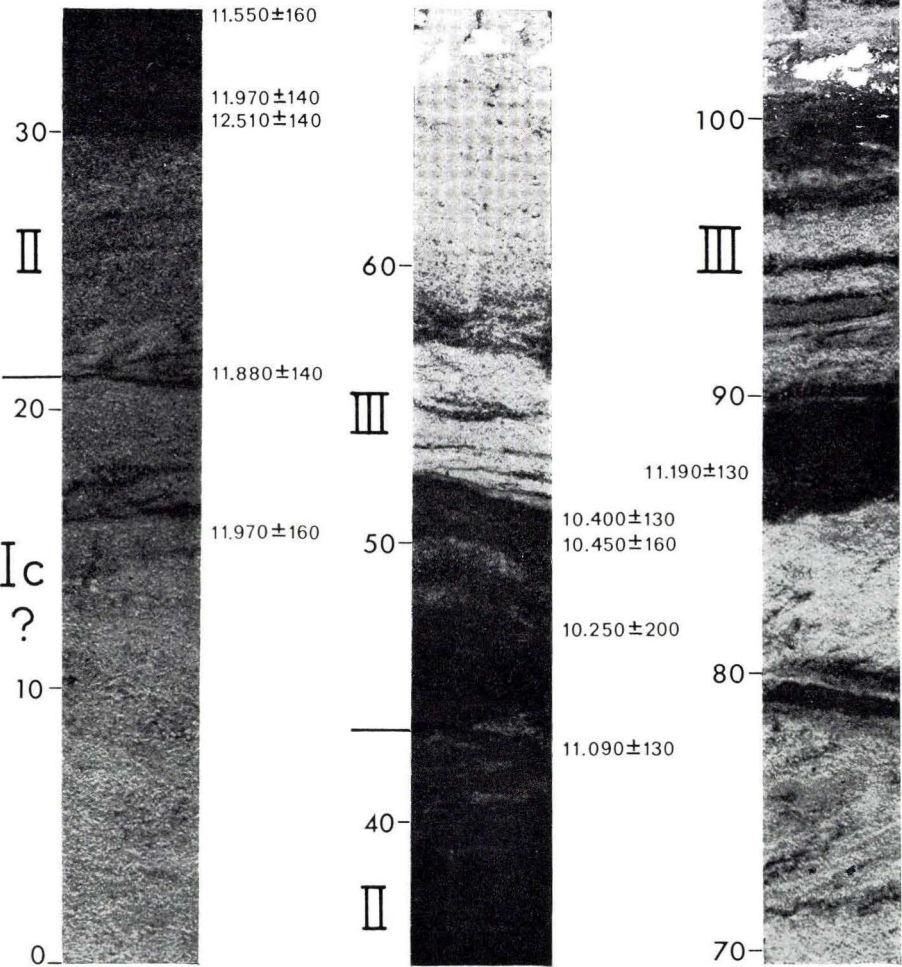
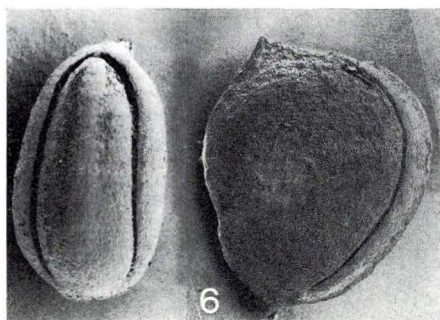
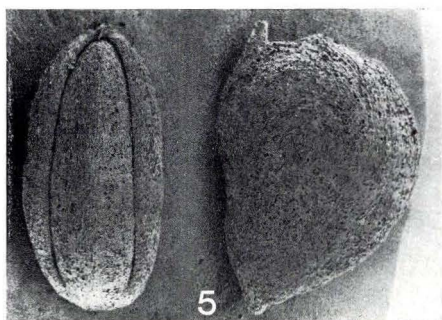
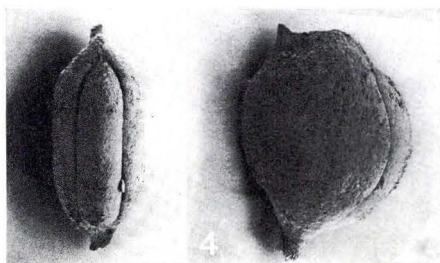
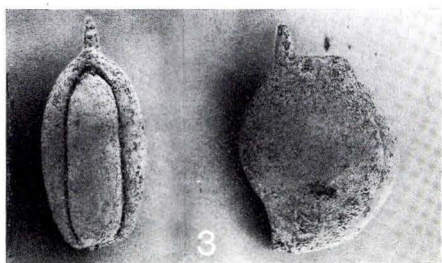
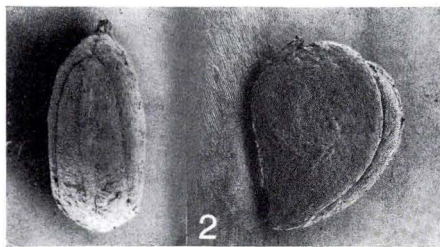
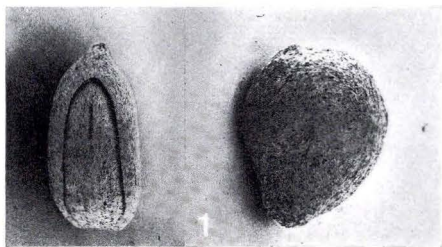


Plate 10

Scanning electron micrographs of modern, to the right, and fossil (Alleröd), to the left, *Potamogeton* fruitstones. Due to the size of the fruitstones, which is near the upper capacity limit for the microscope, the measurements on the side exposures are not fully correct. The ventral edge with the lid (to the right) is drawn out too much so that the fruitstones appear too broad. JEOL scanning microscope S 1. \times 24.

1. *Potamogeton filiiformis* Pers., fossil, diagram 2, 14 cm.
2. *Potamogeton filiiformis*, Pers., modern, Halleby å, Zealand, Denmark.
3. *Potamogeton alpinus* Balb., fossil, diagram 2, 12 cm.
4. *Potamogeton alpinus* Balb., modern, Bågö, Denmark.
5. *Potamogeton vaginatus* Turcz., fossil, diagram 2, 18 cm.
6. *Potamogeton vaginatus* Turcz., modern, Obbola, Västerbotten, Sweden.



HERNING

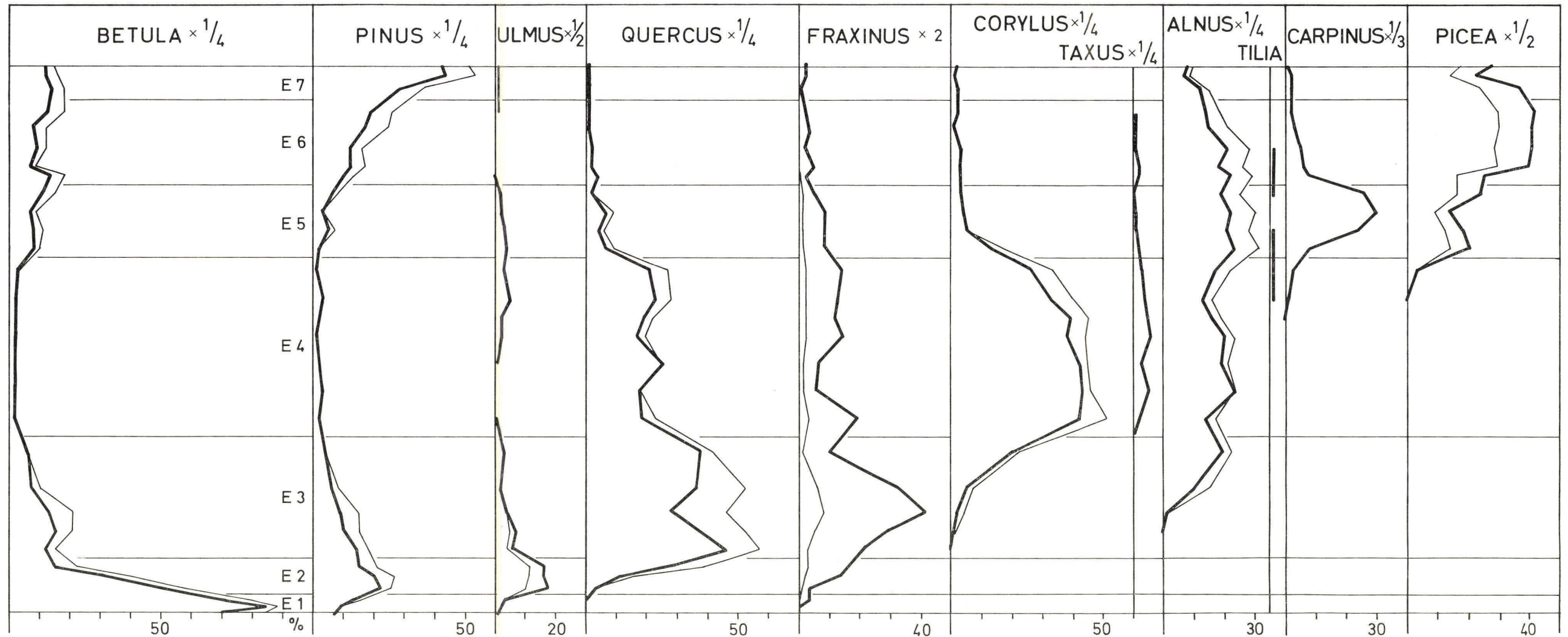


Plate 11.

Tree pollen diagram from the Eemian lake deposit at Herning. Thin line, tree pollen frequencies unchanged. Heavy line, tree pollen frequencies, corrected.

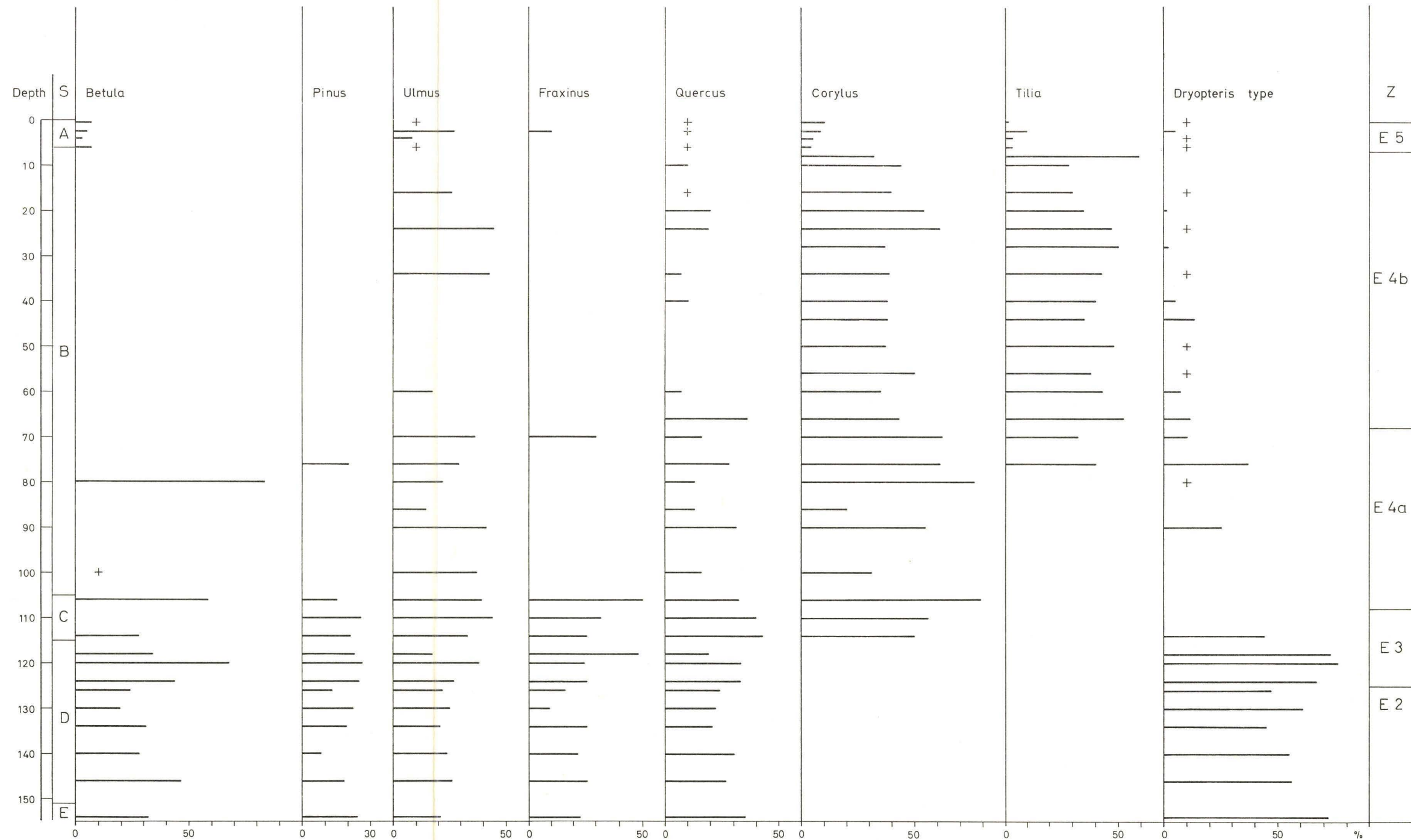


Plate 12.

Egersund. Frequencies of corroded grains. - A-E, lithologic units.

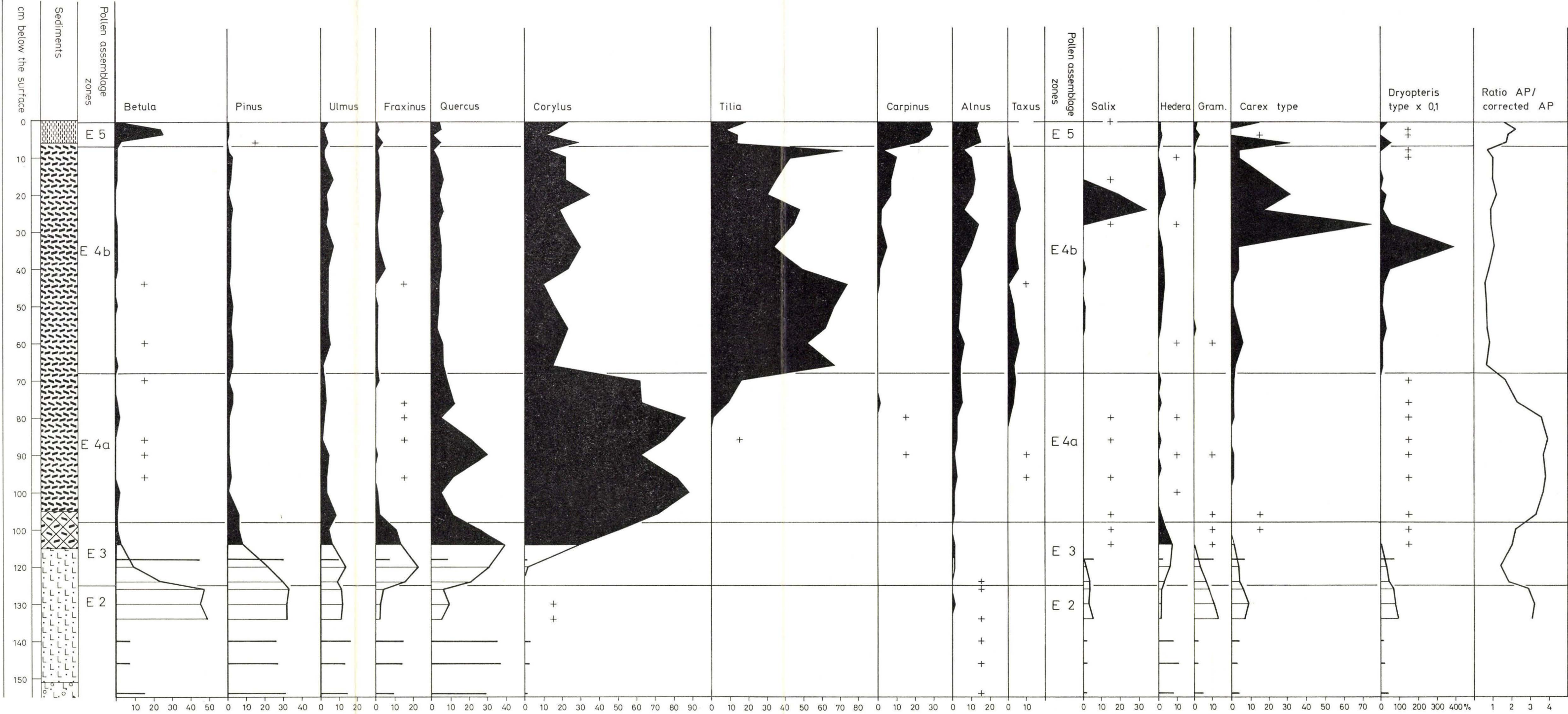


Plate 13.

Egersund. Pollen diagram based on the tree pollen total with tree pollen frequencies unchanged.

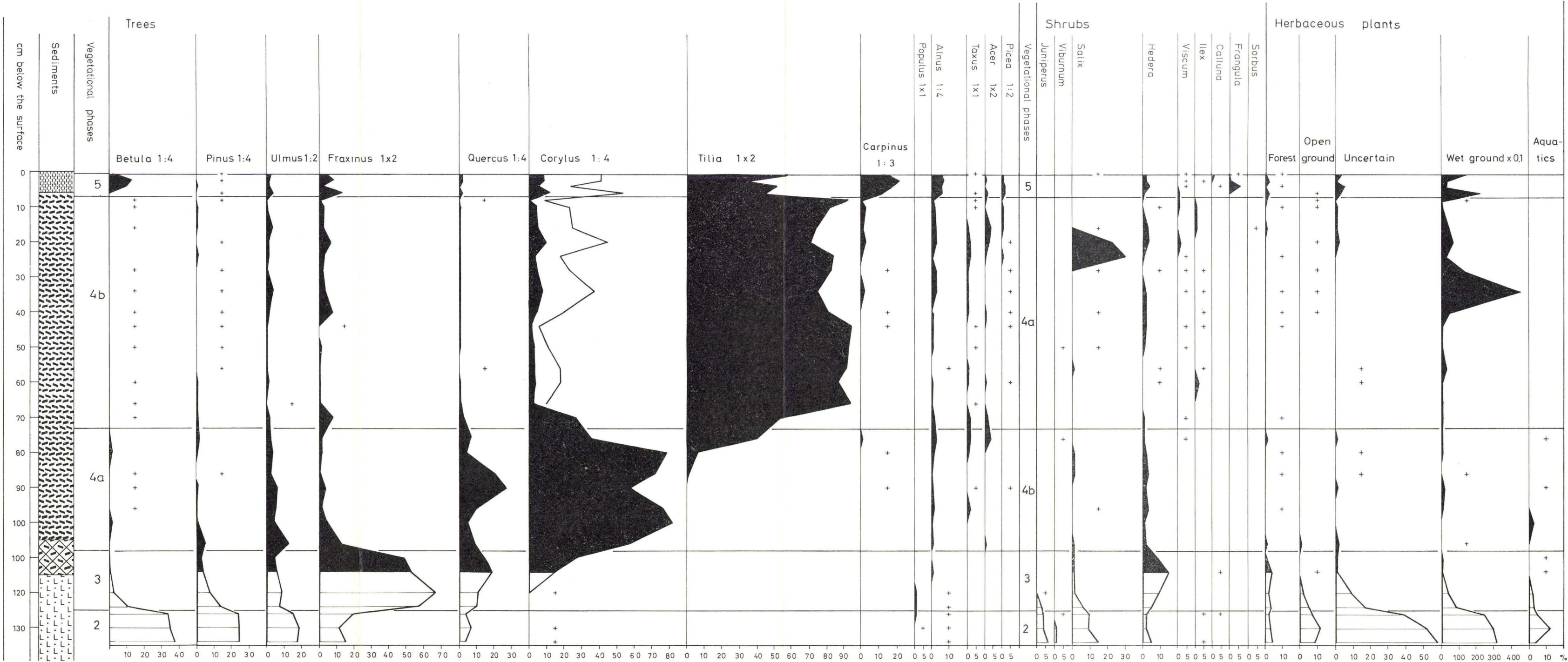


Plate 14.

Egersund. Pollen diagram based on the corrected tree pollen total with corrected tree pollen frequencies.

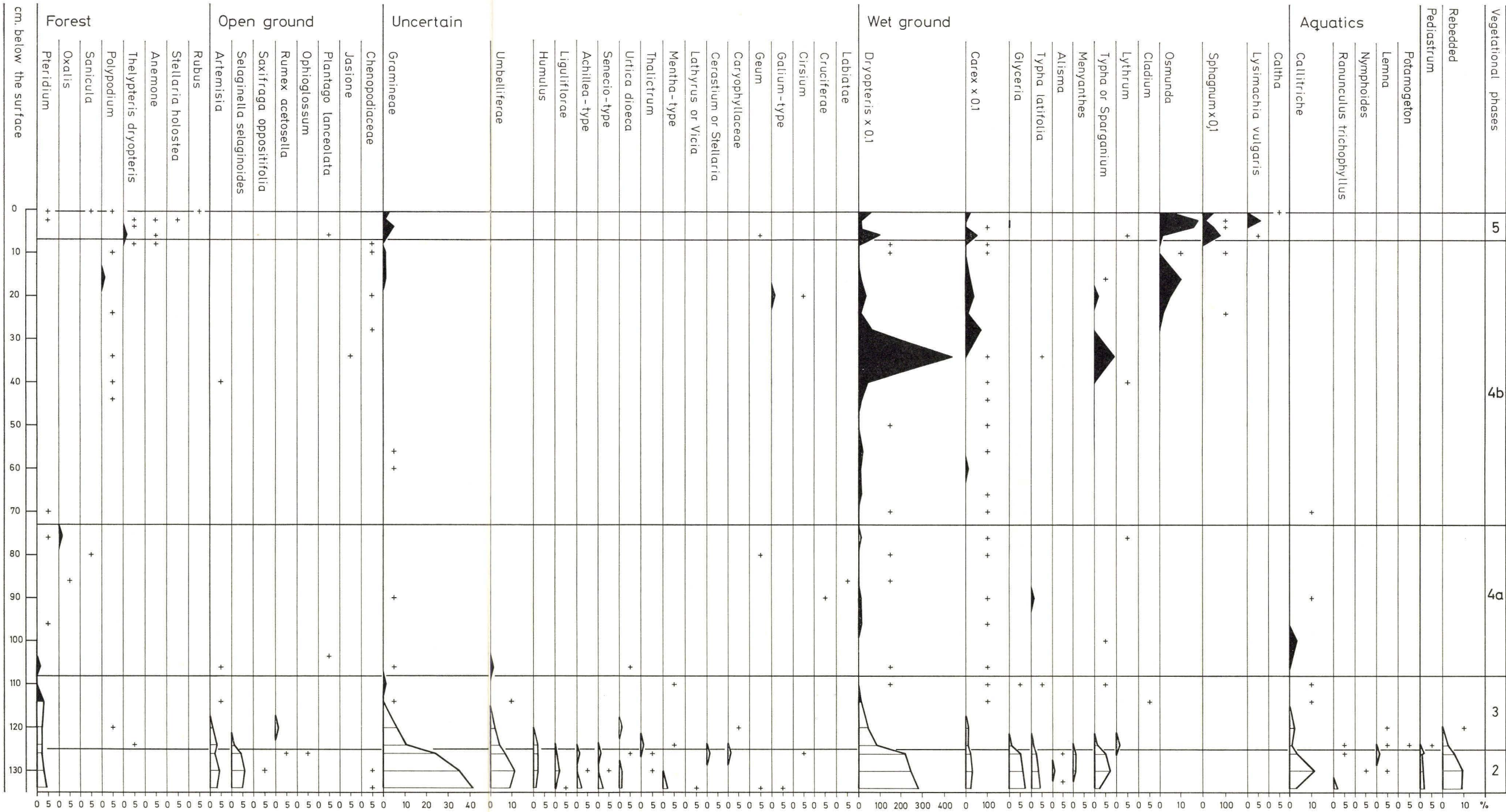


Plate 15.
Egernsund. Pollen diagram showing individual herbaceous plant frequencies based on the corrected tree pollen total.