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Contents

Indhold

On the environments and stratigraphy of the Late Tertiary of Rømø, SW Denmark

Finn Bertelsen and Finn Nyhuus Kristoffersen

Bertelsen, Finn and Kristoffersen, Finn Nyhuus: On the environments and stratigraphy of the Late Tertiary of Rømø, SW Denmark. *Danm. geol. Unders., Årbog 1973*, pp. 5–14, pl. 1. København, 3. oktober 1974.

A biostratigraphical analysis of Tertiary deposits from a borehole on Rømø is given, based on foraminifera and megaspores. The lowermost fossiliferous clay is of probable Upper Miocene/Lower Pliocene age, and the superjacent nonfossilifererous sands are supposed to be of Pliocene age.

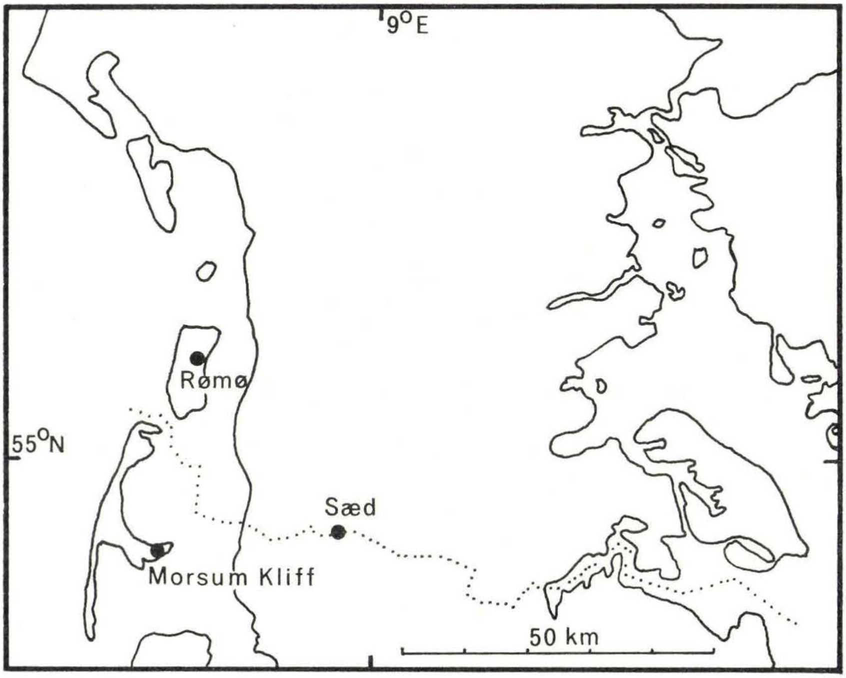
The borehole on the island of Rømø (text-fig. 1), of which the Tertiary fauna and flora are dealt with in the present paper, was drilled in the course of 1973 by the Geological Survey of Denmark. The purpose of the project was to investigate the Quaternary series, and thus the drilling was given up in a probably Tertiary micaceous clay, having reached a depth of 108 m below ground.

Samples of the clay proved to contain foraminifera and megaspores of Tertiary origin and were handed over to the authors for a stratigraphical analysis. This study was naturally extended to comprise an overlying sandy series, which from the lithological description was evaluated to be of Tertiary age.

The interpretation of the Quaternary deposits is excluded because it is planned as part of a future regional description. It is however desirable to illustrate the relationship between the Tertiary and Quaternary deposits and a shortened lithological description and evaluation made by Mr. Lars Clemmensen and Mr. John Frederiksen of the Department of Quaternary Geology is therefore given.

Materials and methods

The samples have been taken with a bailer and contamination in the form of caving has been eliminated by a continuous casing. In the upper sandy beds (51.5–93.3 m), the analysis is based on samples with intervals of



Text–fig. 1. Map of localities.

ca. 2.5 m. Of the lower clayey beds (93.3–108.0 m) all samples originally taken out (intervals of 0.5 m) are studied.

Before the sorting out of microfossils, the samples – 100–500 g in size – were washed on a 0.1 mm sieve, dried and gravity separated in bromoform/alcohol (spec. gr. 2.0).

To reduce the considerable amounts of mica the following technique of separation has proved to be very effective. The material is spread over a sheet of paper in great fans by tilting and slight trembling of the sheet. It is then possible to extract the microfossils from the mica, because the microfossils will dance away from the mica flakes, which more or less adhere to the paper.

Lithology

Lithological log of the Rømø borehole (D.G.U. File No. 148.33). Depths are in metres below ground (ca. +4 m).

0.0– 7.2 m. Sand, greyish, muddy, marine
7.2– 8.2 m. Clay, grey, marine

8.2–19.0 m.	Sand, greyish, muddy, marine
19.0–25.0 m.	Clay, marine and gyttja
25.0–31.5 m.	Sand, marine, clay and gyttja
31.5–34.0 m.	Sand, greyish, fine-grained, clayey and silty
34.0–45.0 m.	Sand, light grey with gravel and stones
45.0–46.0 m.	Sand, light grey, medium-grained
46.0–48.5 m.	Sand, light grey, with gravel and stones
48.5–49.5 m.	Gravel, light grey
49.5–51.5 m.	Sand, light grey with gravel and stones
51.5–54.0 m.	Sand, greenish grey, fine-grained, silty, micaceous
54.0–62.0 m.	Sand, greenish grey, fine-grained, micaceous
62.0–66.0 m.	Sand, greenish grey, fine-grained, silty, micaceous
66.0–93.3 m.	Sand, greenish grey, dark, fine-grained, micaceous
93.3–108.0 m.	Silt and clay, dark grey and blackish, rhythmically layered, rich in plant detritus.

Four distinct series are recognized. The previous knowledge of the regional geology permits the following evaluation of the stratigraphy and character of the sediments:

0.0– 34.0 m.	Quaternary, marine deposits
34.0– 51.5 m.	Quaternary, ? glaciofluvial deposits
51.5– 93.3 m.	Tertiary, marine deposits
93.3–108.0 m.	Tertiary, lagoonal, tidally influenced deposits

The megaspores

F. Bertelsen

Composition of the assemblage

The sandy beds 51.5–93.3 m are nonfossiliferous, whereas megaspores occur in almost all samples from the lower clayey deposits. Only the uppermost 1.7 m of the latter deposits contains no spores. The assemblage is mainly composed of species of the aquatic fern genera *Salvinia* and *Azolla,* whereas other sporetypes (e.g. Pl. 1, fig. 10) and also seeds are rare.

The state of preservation is poor and numerous fragments, especially of *Salvinia spp.* are encountered; thus it has been impossible to give the quantitative distribution of the species. However, the frequency of *Azolla* specimens, mainly *A. roemoeensis* Bertelsen n.sp. (see Bertelsen 1974), has however been calculated not to exceed 60 specimens per kg of sample by counting of the swimming apparatuses. It is also worth mentioning that no massulae (the microspore bodies) have been observed.

The uneven character of the material has not justified a general description of all specimens recovered, and the *Azolla* species have therefore been dealt with in a separate paper (Bertelsen 1974). A description of the recovered *Salvinia* species – well-known in the literature – is regarded to be less important, but for documentation scanning electron micrographs are given (Pl. 1, figs. 8, 9). The most common non-salviniaceous spore is also shown on Pl. 1, fig. 10.

Age of the assemblage

The following species are identified:

Salvinia cerebrata Nikitin ex Dorofeev 1955
Salvinia intermedia Nikitin ex Dorofeev 1955
Azolla tomentosa Nikitin ex Dorofeev 1955

Salvinia cerebrata (Pl. 1, fig. 8) has been recorded in Denmark from the Middle Miocene Fasterholt flora in central Jylland (E. M. Friis, personal communication). In Germany it is reported from the Upper Oligocene (rare) and the Lower Miocene (Kempf 1971). In the Siberian part of the Soviet Union the species is abundant in the Oligocene deposits (Dorofeev 1963), whereas in the European part it occurs less frequently in the Sarmatian and Meotian (Miocene and Pliocene) floras of the southern provinces (Dorofeev 1955, 1963).

Salvinia intermedia (Pl. 1, fig. 9) is according to Dorofeev (1963) in the SSSR mainly found in the Upper Miocene, but it is also recorded from a Pliocene flora at the river Don (Dorofeev 1957). From Poland there is a find in an Upper Miocene flora (Łańcucka-Środiniowa 1958), and in Germany a closely related species occurs in the Lower Miocene Rhenish lignites (Kempf 1971).

Azolla tomentosa (see Bertelsen 1974, Pl. 3, figs. 1–2) is characteristic in the Soviet Union in the Miocene deposits, but it is also known from the Oligocene (Dorofeev 1963). In Germany it occurs in the Lower Miocene Rhenish lignites (Kempf 1969).

The age of the previous records of the species indicates a probable Miocene age for the Rømø microflora. The records of the species are so scattered and sparse in the western part of Europe, however, that this indication must be very weak.

The foraminifera

F. Nyhuus Kristoffersen

Within the fossiliferous section foraminifera have been recorded only from the lowermost part (104.5–108.0 m), except for very few individuals found in the sample 103.0–103.5 m.

The foraminiferal fauna is extremely poor in species. The most important are shown on Pl. 1, figs. 1–7. Four species dominate the fauna. *Florilus boueanus* (d'Orbigny) and *Glandulina laevigata* (d'Orbigny) are the most frequent species, while *Valvulineria complanata* (d'Orbigny) and *Melonis affine* (Reuss) are less frequent. In addition to these forms the following rather scattered species are met with in the Rømø fauna:

Textularia gramen d'Orbigny
Textularia sagittula Defrance
Lagenids
Quinqueloculina sp.
Cibicides spp.
"Elphidium" sp.

All the species recovered are well-known from the Upper Miocene Gram Clay. The present fauna, however, does not in particular resemble any of the faunas found in the Gram Formation (Kristoffersen 1972). Only one form, *Textularia gramen,* seems distinctly to show the relationship to the Gram Clay. This form has, at least in Denmark, only been found in the Gram Clay.

Thus it seems evident that the present foraminifera are of Upper Miocene age. It is, however, very difficult to decide to which part of the Gram Formation the Rømø fauna should be referred. The absence of *Uvigerina pigmea* d'Orbigny is important because this form characterizes the main part of the Gram Formation. Thus only the uppermost part of the Gram Formation is characterized by the absence of *U. pigmea.* Faunas from this uppermost part of the Gram Formation have been described from the Sæd boring (Kristoffersen 1972) and from the Westerland boring on the island of Sylt (Boekschoten 1969). Three species, *Glandulina morsumensis* Voorthuysen, *Elphidium antoninum* (d'Orbigny) and *Globobulimina cf. auriculata* (Bailey) appear in these faunas, but none of them are found in the Rømø fauna. However, one of the Rømø species, *Glandulina laevigata,* seems in some respects to resemble *Glandulina morsumensis* Voorthuysen, which in the authors' opinion might prove to be an ecological variety of *G. laevigata.* Thus among the Rømø individuals a minor part show a number of basal spines (Pl. 1, fig. 3), which were found to be important features in distinct *G. morsumensis* recorded from the Sæd boring. None of the Rømø individuals, however, are as long as true *G. morsumensis,* but quite a number are longer than distinct *G. laevigata.*

It has not been possible to identify the species *"Elphidium" sp.* (Pl. 1, fig. 4a–b), of which only three badly preserved individuals have been recovered. *E. antoninum* (cf. above), which previously was the only known

Elphidid species within the uppermost Miocene of this area is clearly different from these specimens.

Although it seems obvious that the Rømø fauna is of Late Upper Miocene age, it is not evident that the embedding sediment is of the same age. A number of reasons at least give rise to the assumption that the fauna has been reworked.

To solve these problems it is necessary to discuss the genesis of the deposits by combining the available data given by the sediments and the fossils.

The environments of deposition

The fossiliferous beds (93.3–108.0 m)

The sediments of this interval consist of rhythmically layered silts and clays with a rather high content of mica and fine plant debris (loss of ignition ca. 10 %).

The embedded fossils are mainly megaspores of the freshwater ferns *Azolla* and *Salvinia,* which occur throughout the section, and foraminifera confined to the lowermost part.

The spores are fragmentary and not well-preserved, and it is believed that they have been transported to some distance from their place of origin. The massulae (microspore bodies) which are commonly found together with the megaspores in autochthonous and parautochthonous deposits are thus absent.

The foraminifera have probably been reworked. All individuals are badly preserved and with exception of the rather big and thickwalled *G. laevigata* most specimens have lost one or more chambers. Furthermore the number of specimens per 100 g sediment is extremely low compared with the number normally encountered in the Gram Formation. In the Rømø sediments less than 70 specimens per 100 g sediment were found, whereas in the Gram Formation the frequency commonly exceeds 5000 specimens per 100 g.

Small greyish green bodies – 'micro-ellipsoids' (Rasmussen 1966, p. 17) – which are extremely common in the Gram Clay, occur in the samples containing foraminifera. The wash residues of three samples with maximum content of foraminifera are almost exclusively made up of these bodies.

It is deduced that the deposition of the fossiliferous beds took place within a deltaic system in partly closed lagoonal or estuarine environments. The rhythmical bedding is regarded as being caused by tidal influences, which are apparently most distinctly marked in the lower part by the occurrence of foraminifera. The salinity never reached values which permitted the presence of living foraminifera, and freshwater conditions must have existed within the area of deposition. The sediments were mainly supplied by river waters and the plant material originated from sources within the delta.

The non-fossiliferous beds (51.5–93.3 m)

The arenaceous deposits of this interval proved to be barren and for purely lithological reasons (grain size distribution) they are classified as marine sands.

The age of the studied section

The foraminiferal fauna in the lower part of the fossiliferous beds has proved to be of Late Upper Miocene age, and also the megaspore flora points towards a Miocene age. It is however doubtful if the deposits are contemporaneous with the fauna because the foraminifera have apparently been re-worked and two of the megaspores at least are also reported from Pliocene floras.

The stratigraphical importance of the re-embedding of the fauna is difficult to estimate. If the foraminifera indicate minor short marine invasions it is reasonable to believe that the deposits are of upper Upper Miocene age. If, however, the fauna originates from erosion of exposed Gram Clay a younger age (Pliocene) of the beds is reliable.

In an attempt to solve these stratigraphical problems a comparison with supposedly corresponding deposits within the region was made.

In the Sæd boring (D.G.U. File No. 167.445) situated near the Danish-German border (text-fig. 1) lithologically comparable beds are described above proven Gram Clay (Rasmussen 1966, Kristoffersen 1972). The lowermost part of these beds (86.4–90.3 m) were regarded as non-fossiliferous, whereas the upper part (72.0–86.4 m) contained casts of gastropods (Rasmussen loc. cit., fig. 104).

Rasmussen compared the 'non-fossiliferous' beds of the Sæd boring with the marine 'Mica clay with beds of mica silt' overlying the 'Mica clay' in the Morsum Kliff at the island of Sylt. These beds are regarded as belonging to the 'Sylter Stufe'. The beds with casts of gastropods were compared by Rasmussen with 'Limonite Sandstone, marine' of the 'Morsumer Stufe' of Sylt.

Test samples of the 'non-fossiliferous' beds of the Sæd boring have, however, proven to contain microfossils comparable with those of the Rømø boring. The presence of *Azolla roemoeensis, Salvinia spp.* and a poor fauna with *Glandulina laevigata* and *G. morsumensis* was demonstrated.

Rømø	Sæd	Morsum Kliff	Probable age (after Gripp 1964)
Sands, micaceous, non-fossiliferous, marine (51.5)-93.3 m	Mica silt with concretions and siderit casts of gastropods, marine 72.0-86.4 m	Silts, white, marine Silt with limonite, marine Limonite sandstone, marine	Lower Pliocene
Silt and clay, micaceous, rhythmic layered, brackish- -limnic 93.3-(108.0) m	Mica clay with beds of silt, marine 'non-fossiliferous' 86.4-90.3 m		
	Gram Clay, slightly silty , marine 90.3-92.7 m	Mica clay, with beds of sand, marine	Upper Miocene
	Gram Clay, marine 92.7-(100.1) m		

Text–fig. 2. Comparison of the Rømø profile with Sæd and Morsum Kliff (partly after Rasmussen 1966).

Samples of the 'Mica clay with beds of mica silt' of the Morsum Kliff collected by one of the authors (F. N. Kristoffersen) have shown a foraminiferal fauna remarkably rich in the number of specimens. This fauna compares well with the fauna found immediately below the 'non-fossiliferous' beds of the Sæd boring. Deposits equivalent to the 'non-fossiliferous' beds of the Sæd boring and the corresponding beds in the Rømø boring are therefore probably absent at Morsum Kliff. The correlation proposed by Rasmussen of the 'non-fossiliferous' beds with the marine 'Mica clay with beds of mica silt' of Morsum Kliff may therefore be doubted.

The upper non-fossiliferous marine sands of the Rømø boring are supposed to be comparable with the cast-containing sequences in the Sæd profile and the probable corresponding 'Limonite Sandstone' of Morsum Kliff, and the results of the comparisons may therefore be expressed schematically as shown in text-fig. 2.

Finally, it may be concluded that the correlation of the Rømø sequence with the profiles from Sæd and Morsum Kliff has not clarified the chronostratigraphical problems concerning the reworked foraminifera. It has been shown that the fossiliferous deposits from Rømø should probably be placed stratigraphically between deposits, which in the Morsum Kliff profile have been referred to the late Upper Miocene ('Sylter Stufe') and the Lower

Pliocene ('Morsumer Stufe'). However, the chronostratigraphical age determinations of the Sylt deposits are regarded as uncertain and problematic by the present authors.

Dansk sammendrag

De nedre, tertiære lag i en boring på Rømø (D. G. U. Arkiv nr. 148.33) udført af Danmarks Geologiske Undersøgelse i løbet af 1973 er analyseret biostratigrafisk på grundlag af megasporer og foraminiferer.

Den tertiære lagserie omfatter to lithologisk velafgrænsede afsnit. Nederst (93,3–108,0 m) findes en fossilførende og fint lagdelt ler- og siltserie, rig på glimmer og fint fordelt plantemateriale, og øverst (51,9–93,3 m) en fossilfri og glimmerførende sandserie.

Den nedre serie indeholder megasporer af vandbregner (*Azolla, Salvinia*) og omlejrede foraminiferer af sen øvre miocæn alder. Det konkluderes, at denne serie er afsat i et afspærret, lagunalt eller æstuarint miljø. Den øvre fossilfri serie er på grundlag af lithologiske karakterer regnet for marin.

Sammenlignelige lagserier kan påvises i Sæd boringen ved den dansk-tyske grænse og til dels på Morsum Kliff, Sylt. Resultatet af disse sammenligninger er sammenfattet i tekstfig. 2.

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Late Tertiary *Azolla* species from Rømø, SW Denmark

Finn Bertelsen

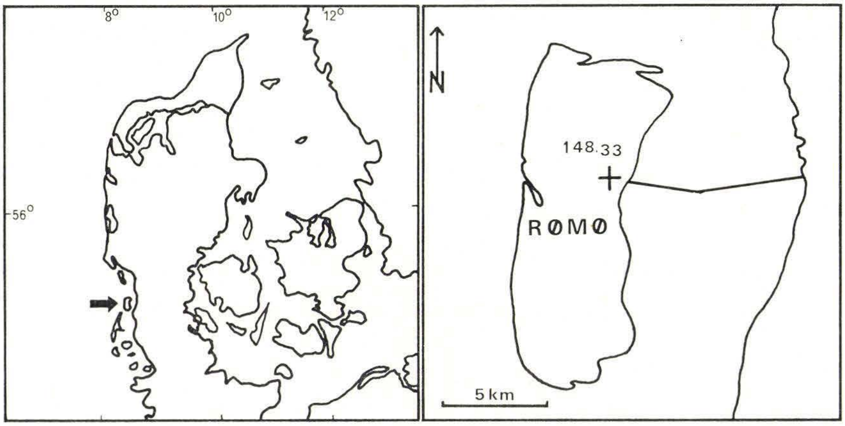
Bertelsen, Finn: Late Tertiary *Azolla* species from Rømø, SW Denmark. *Danm. geol. Unders., Årbog 1973*, pp. 15–25, pls. 2–3. København, 3. oktober 1974.

Megaspores of the genus *Azolla* (Salviniaceae) from probably Late Upper Miocene strata at Rømø, SW Denmark, have been studied by means of scanning electron microscopy. Four species are recognized: *Azolla roemoeensis* n. sp. a form with nine floats, *A. tomentosa* Nikitin ex Dorofeev, previously recorded from the Oligocene and the Miocene in Eurasia, and two species of uncertain affinity, which are described with open nomenclature. Closely related species seem to have the same type of perine structure. Future SEM analysis of the perine structure may lead to formation of new subgeneric groups within the 'sections'.

The study of the reproductive organs, megaspore apparatuses, and massulae of the fossil representatives of the aquatic fern genus *Azolla* Lam., ranging from Cretaceous to Recent, has developed steadily during the last decades. It has been proven that these fossils are important in biostratigraphy as well as palaeoecology.

The records of *Azolla* from western Europe outside Denmark are mainly confined to the interglacial Quaternary deposits (see Bertelsen 1973), whereas there are only a few finds from the Tertiary (Reid & Chandler 1926, Florschütz 1945, Łańcucka-Środoniowa 1958, Dijkstra 1961, Kempf 1969a). In Denmark both vegetative and reproductive *Azolla* remains have been recently recovered from the Middle Miocene Fasterholt flora (Koch *et al.* 1973, E. M. Friis pers. communication), but they have not yet been described. It has therefore seemed reasonable to report this new occurrence of *Azolla* from the Late Tertiary (?Upper Miocene) beds of a borehole (D.G..U File No. 148.33) on the island of Rømø, on the southwestern North Sea coast of Jylland (Text-fig. 1).

The numerous finds of the Soviet palaeobotanists, especially from the Middle and Late Tertiary deposits (see Dorofeev 1955–1968), stand in contrast to the limited number of West European records. Several species have been described and their importance for biostratigraphy has been substantiated.



Text-fig. 1. Situation of the Rømø borehole (D.G.U. File No. 148.33).

Although carefully selected, a number of these species are difficult to identify in foreign assemblages, however, because they are rather similar in general appearance. If, for instance, the state of preservation is poor, some of the commonly used criteria of identification, e.g. size differences, differences in general form and in form of the floats, are not reliable.

A good approach to the solution of the identification problems was therefore given in the paper of Kempf (1969a), in which ultra-thin sections of five Cenozoic *Azolla* species were studied by means of transmission electron microscopy (TEM). A fundamental similarity in the built-up of the sporoderm of the studied species was demonstrated, but characteristic differences in the outer zone of the perine, of which the sculpture of the megaspore body is formed, were also shown. These observations led Kempf to the opinion that the fine structure of the perine is useful for identification at the species level. The similarity in the structure of the perines of the recent *A. pinnata* R. Br. and the closely related *A. tegeliensis* Florschütz, shown in the paper of Kempf (1969b), has apparently not changed this theory (see also Kempf 1973).

The availability of the scanning electron microscope in recent years has led to new improvements in the study of *Azolla* (Bergad & Hall 1971, Hall & Bergad 1971, Bertelsen 1973). This instrument (SEM) generally permits a better interpretation of sculptural and structural details than the TEM, although the resolving power is smaller. The preparation of specimens is also much easier and less time-consuming; thus more specimens may be studied in a given period.

By the use of SEM in the present study another purpose additional to the purely descriptive one has therefore been pursued: to determine to what extent it is possible to use the structure of the perine, when studied in the SEM, in taxonomy.

Materials and methods

The specimens studied are derived from the lower, fossiliferous part of the Rømø borehole (95.0–108.0 m). They occur together with *Salvinia cerebrata* Nikitin ex Dorofeev, *S. intermedia* Nikitin ex Dorofeev, and a few other megaspores in concentrations not exceeding 60 specimens per 1000 g. The age of the assemblage, which is probably Late Upper Miocene, is discussed in Bertelsen & Kristoffersen (1974). In this article the lithology of the borehole (D.G.U. File No. 148.33) is given and the results of the biostratigraphical analyses are summarized.

For comparison, specimens of *Azolla cf. aspera* Dorofeev, *A. nana* Dorofeev and *A. tomentosa* Nikitin ex Dorofeev from the Neogene of Germany have also been studied. These specimens were kindly sent to the author by Dr. E. K. Kempf, Köln.

The preparation procedure has been identical with that described in Bertelsen (1973). To reduce the considerable amounts of mica in the samples before the sorting of fossils, the material is spread over a sheet of paper in great fans by tilting and slightly trembling the sheet. It is then possible to extract the microfossils from the mica, because the microfossils will dance away from the mica flakes, which more or less adhere to the paper.

The specimens are stored in the collections of the Geological Survey of Denmark.

Descriptions of species

The descriptive terms used below correspond with those summarized in Jain & Hall (1969). The definition of a glochidium is widened, as done earlier by the author (Bertelsen 1973), to comprise all sorts of appendages that can serve to anchor the massula to the megaspore apparatus. The layers of the megaspore wall are designated in accordance with Kempf (1969a).

The four species described are referred to the sections *(Eu)-Azolla,* megaspore apparatus with three floats and *Rhizosperma,* megaspore apparatus with nine floats.

Genus *Azolla* Lamarck 1783
Section *Azolla* Meyen 1836
Azolla tomentosa Nikitin ex Dorofeev 1955
Pl. 3, figs. 1–4.

For synonyms see Dorofeev 1963.

Material. 6 specimens of which 5 are rather well preserved, but slightly compressed. In addition, comparative material from the quarry 'Vereinigte Ville' near Köln, Germany (cf. Kempf 1969a) in the form of megaspore apparatuses with or without attached massulae.

Description of specimens. The megaspore apparatus has three floats. It has a semiglobular basal part (the megaspore), a distinct equatorial girdle and a rounded, broadly conical, apical part (the swimming apparatus), which give the megaspore apparatus a broad ovoid shape (Pl. 3, fig. 1). Polar axis 292–394 μm. Diameter of megaspore apparatus (eq. girdle) 254–318 μm (5 specimens).

The surface of the megaspore body (Pl. 3, fig. 2) is more or less densely covered with hairs (0.3–1 μm in diameter), which wind in and out from the cavities of the perine. A real sculpture is not formed on the rather uneven surface of the perine, but some specimens show a row of low protuberances along the edge of the incision zone below the equatorial girdle as in Pl. 3, fig. 3. The surface layer of the perine has a spongy, microreticulate structure in which the connection points are thickened to plate-like structures (Pl. 3, fig. 2). The unthickened elements are approximately 1–2 μm in diameter.

The equatorial girdle with a width of ca. $^1/_6$ length of polar axis is covered by a smooth to densely wrinkled skin from which single hairs originate. It is commonly hidden under hairy masses protruding along the edges of the three floats of the swimming apparatus.

The swimming apparatus consists of a central columella to which the three, discoidal, foamy floats are attached by means of hairs. The top of the swimming apparatus is hidden under a skin-like cap and the columella is therefore only visible on defective specimens.

Remarks. Specimens compare well with specimens from the Lower Miocene of Germany (Pl. 3, figs. 3–4). The German specimens have a slightly denser surface structure than the Danish specimens, but both types are characterized by the plate-like thickenings. The thin-section of Kempf (1969a, Pl. 12, fig. 4) made from material identical with the above, shows how this surface layer with columella-like structures (in pollen morphological meaning) is connected to the compact inner zone of the perine. It may also be added that the identification of the German material has been proven by Dr. P. I. Dorofeev (Kempf *loc. cit.*).

Previous records. In the Soviet Union the species is known from the Oligocene and the Miocene, but it seems to be characteristic for the Miocene (Dorofeev 1963). In Germany it occurs throughout the Lower Miocene main seam complex of the Rhenish lignite (Kempf pers. communication).

Section *Rhizosperma* Meyen 1836
Azolla roemoeensis n. sp.
Pl. 2, figs. 1–8.

Holotype. Pl. 2, figs. 3–4. SH–36–FB–4. Polar axis 496 μm.

Type locality. Rømø borehole (D.G.U. file No. 148.33), island of Rømø, SW Denmark.

Type stratum. 102.0–102.5 m below ground, Late Tertiary (?Late Upper Miocene).

Derivation of name. The species is named after the island of Rømø.

Diagnosis. Megaspore apparatus with broadly ellipsoid shape, without equatorial girdle. Polar axis 445–572 μm, diameter of megaspore body 292–368 μm. Ratio eq. diameter to length of polar axis 0.64. Diameter of the swimming apparatus approx. equal to the diameter of the megaspore body. Lower floats ovoid in outline. Ultrastructure of the perine surface spongy, granular. Sculpture of non-erected, more or less knotty and irregular bacula. Bacula commonly 10–15 μm long and 2–5 μm in diameter. Massulae not known.

Material. Ca. 140 specimens of which many are badly preserved from the interval 95.5–108.0 m. 25 specimens have been studied in the SEM.

Description of specimens. The megaspore apparatus has nine floats; the basal part is globular (the megaspore body) and the apical part is rounded and conical (the swimming apparatus). Uncompressed specimens (Pl. 2, fig. 1) are oval in outline (diameter of swimming apparatus equal to or slightly larger than diameter of megaspore body). Polar axis 445–572 μm, mean 519 μm, standard deviation 2.2 (24 measurements). Diameter of megaspore body 292–368 μm, mean 331 μm, standard deviation 1.4 (19 measurements). The ratio megaspore diameter to length of the polar axis 0.64.

The megaspore body is ornamented with evenly distributed non-erected bacula or rods which are easily seen in the light microscope (Pl. 2, figs. 2,4). The degree of ornamentation varies from specimen to specimen and may be partly lacking due to corrosion or natural reduction (Pl. 2, fig.

6). The length of bacula is ca. 5–20 μm, commonly ca. 10–15 μm and the diameter ca. 2–5 μm. Bacula are smooth or with minor knobs, narrowings, and incisions, commonly giving them an 'embryo-like' appearance.

The spore wall (Pl. 2, figs. 7–8) consists of two distinct layers, the exine and the perine (*sensu* Kempf 1969a). The inner layer, the exine, has a thickness of ca. 7–8 μm (1 measurement only) and it has a dense, spongy ultrastructure. The outer layer, the perine, is ca. 10–15 μm thick and is divisible into two zones (*iz* and *oz* of fig. 8). The inner zone, less than 5 μm thick, has an ultrastructure comparable with that of the exine and is rather massive. The outer zone, which includes the sculpture, is composed of a spongy, granular framework in which the single elements have a diameter of 0.5–2 μm. Greater, radiating cavities are found in the inner part of this zone.

The swimming apparatus consists of a central columella in the depressions of which the foamy floats (cf. Pl. 2, fig. 1) are attached in three groups by means of hairs. Each group consists of two lower, symmetrically arranged, eggshaped floats and one upper diamond-shaped float, which is normally partly hidden under a skin-like cap at the top of the swimming apparatus. Hairs protruding around each group of floats may spread fanwise over the upper part of the megaspore body. These hairs are 1–2 μm in diameter and form dense felty masses between the groups of floats.

Massulae have not been observed.

Comparison and discussion. Azolla roemoeensis is distinguished from the rather uniform and comparable group of nine-floated species, *A. aspera* Nikitin, *A. parapinnata* Dorofeev, *A. parvula* Dorofeev, *A. pseudopinnata* Nikitin, *A. sulaensis* Dorofeev and *A. ventricosa* Nikitin of the Middle and Late Tertiary of the Soviet Union by its characteristic rod-like skulpture (cp. Dorofeev 1959, 1962, 1963, 1968).

This type of sculpture is however found in the Early Pleistocene species *A. tegeliensis* Florschütz and in the two recent species *A. nilotica* DeCaisne and *A. pinnata* R. Br. (see Strasburger 1873, Florschütz 1938, Bertelsen 1973). It is readily separated from *A. nilotica* if the drawings of Strasburger (1873, pl. 7, figs. 108 a and b – also used by Florschütz 1938) are representative, because this species has smooth, pointed rods. The rather coarse rods of *A. pinnata,* which according to Florschütz *loc. cit.* are up to 36 μm long and 13 μm thick, differ by their size from those of *A. tegeliensis* and *A. roemoeensis,* in which they are ca. 10–15 μm. Generally the sculpture of *A. roemoeensis* seems to be coarser, more complex and not so erect as found in *A. tegeliensis,* but the two species overlap with regard to the ornament and there are no clear differences in the ultrastructure of the spore wall (cp. Kempf 1969b, Bertelsen 1973).

A. roemoeensis is ellipsoid, however, with an equatorial narrowing, whereas *A. tegeliensis* is elongated ovoid. Furthermore the lower floats of *A. roemoeensis* are eggshaped in outline, not angular as in the latter species.

Two specimens of *Azolla cf. aspera* from ? Upper Miocene/Pliocene of the Rhineland, Germany (see Kempf 1969a) have been studied for comparison. They have a perinal surface structure comparable with that of *A. roemoeensis,* but apparently differ from this in a sculpture of spread minor granules and a thinner sporoderm (cp. Kempf 1969a, Pl. 11, fig. 2).

Remarks. The above size range of *A. roemoeensis* is based on selected specimens from the total material, not from the type stratum alone and it is therefore not correctly representative, only guiding. It is believed that measurement of specimens from one large sample may lead to approximately the same results, since no sample has yielded solely well-preserved specimens, yet the samples are very uniform. The size of the species, under the above circumstances, is measured to be slightly smaller than that of *A. tegeliensis.*

Azolla sp. A
Pl. 3, figs. 5–6

Description. The megaspore apparatus has an unknown number of floats, and is ovoid in shape. The diameter of the megaspore body is 254 μm.

The megaspore body has an indistinct subverrucate sculpture. Each element is ca. 20 μm in diameter (Pl. 3, fig. 5). The structure of the surface of the perine is spongy microreticulate, and the diameter of the elements and the cavities is ca. 1 μm. There is no differentiation of the structure within the sculpture (Pl. 3, fig. 6).

An equatorial girdle is absent. Felty masses of hairs and a skinlike cap at the top of the compressed swimming apparatus obscure the floats.

The spore wall is ca. 8 μm thick measured in a basal fracture seen on Pl. 3, fig. 5. It is composed of a 3 μm thick inner layer (the exine) with a dense, spongy structure and a 5 μm thick outer layer (the perine). The perine consists of an inner zone ca. 2 μm thick with a structure almost similar to that of the exine, and an outer zone ca. 3 μm thick with a structure as seen on the surface, but with larger cavities towards the inner zone.

Discussion and comparison. This species most probably belongs to the nine-floated group *Rhizosperma,* because it has no equatorial girdle, which is present in all known three-floated species, whereas it is only rarely described from one nine-floated species, *A. nikitinii* Dorofeev. It has not been possible to refer the species examined here to any species with nine floats.

Azolla sp. B
Pl. 3, figs. 7–8

Description. Two megaspore apparatuses, both strongly compressed, were recovered. Their outline is oval and the dimensions 381 × 292 μm and 496 × 343 μm.

Both specimens are densely covered with hairs, but on the one figured these hairs are partly eroded away. This specimen has a basal sculpture of 10–20 μm wide, irregular, and evenly distributed knobs. Each knob has a dense surface with protruding minor rods and hairs ca. 1 μm in diameter (Pl. 3, fig. 8). The surface of the perine between the knobs is spongy, microgranulate. The diameter of the elements and the cavities is ca. 0.5–1 μm.

The basal part of the other specimen is covered with dense 'spaghetti-like' hairmasses, which hide any sculpture and structure.

The hairy masses of the figured specimen originate mainly from the lower edges of the swimming apparatus, but they are fastened to the surface of the megaspore body by being tangled with hairs originating in the knobs. Most hairs are ca. 1 μm in diameter and circular in cross-section, others are tape-like and up to 3 μm wide.

The swimming apparatus is without equatorial girdle and probably with nine floats.

Discussion and comparison. No comparable *Azolla* species have been described from Tertiary or Quaternary strata. The combination of hairs and sculpture shows some resemblance to the system seen in *A. filiculoides* in which the hairs are stretched as a network over the tops of the sculpture (cp. Bertelsen 1973).

Conclusions

The purpose of the investigation has been to give a description of a new record of Tertiary *Azolla* spores and by means of SEM studies to try to find new criteria of species identification.

Through the study of the megaspore wall in *Azolla roemoeensis* and *Azolla sp. A* the conclusions of Kempf (1969a and b) regarding the fundamental construction of the sporoderm have been confirmed. Both species have a sporoderm dividable into an inner exine and an outer perine (*sensu* Kempf 1969a). The exine has a dense structure of low porosity, which is also found in the inner zone of the perine. The outer zone of the perine has a coarser and more open structure compared with the exine.

Each of the four species have also proven to have a characteristic sculpture and structure of the perine, which immediately seems to confirm the hypothesis of Kempf (1969a, 1973), that each species is characterized by its own perine structure. However, by comparison of *Azolla roemoeensis* with the morphologically closely related species, *A. tegeliensis* and *A. pinnata,* it seems that these species have almost identical perine structures. The observed differences are at least of the same range as seen within *A. roemoeensis,* and may be due to natural variations of no taxonomic importance. The observations can therefore not substantiate the above hypothesis, which was originally based on observations of only six species, of which at least four were not closely related (Kempf 1969a, b).

In support of the idea that related morphospecies seem to have similar perine structures, the author has had the opportunity to compare SEM micrographs of *Azolla nana* Dorofeev from the Miocene of Germany with micrographs of *A. nikitinii* Dorofeev from the Miocene of Jylland (at the locality Fasterholt). Both species seem to have the same dense surface structure and it is only possible to distinguish *A. nikitinii* from *A. nana* by the presence of an equatorial girdle in the former.

Future investigations of the structure of the perine of other *Azolla* species by means of electron microscopy may therefore lead to the formation of new subgeneric groups inferior in rank to the 'section'. The separation of the known species into such groups may perhaps help to clarify the evolutionary history of the genus *Azolla.*

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Dansk sammendrag

Fire arter megasporer af vandbregneslægten *Azolla* fra de ungtertiære lag i en boring på Rømø (tekst-fig. 1) er undersøgt ved hjælp af scanning elektron mikroskopi. Hyppigt forekommende er *Azolla roemoeensis* n. sp., der har stor lighed med *Azolla tegeliensis* Florschütz fra det ældste pleistocæn (Tegelen interglacial) og *Azolla pinnata* R. Br. (recent). Af de øvrige tre former, der alle er sjældne, er *Azolla tomentosa* Nikitin ex Dorofeev tidligere kendt fra eurasiske oligocæne og miocæne aflejringer, medens de to øvrige arter må beskrives med åben nomenklatur.

Detailstudier af sporevæggen har ikke ført til opdagelsen af nye mulige identifikationskriterier på artsniveau. Former med stor morfologisk, ydre lighed, synes at besidde noget nær identiske sporevægsstrukturer. En tidligere af Kempf (1969a) fremsat hypotese, i hvilken der formodes at strukturen af sporevæggens yderste lag, perinen, er artsspecifik, må derfor betvivles. Fremtidige undersøgelser af andre *Azolla*-arter vil derfor antageligt føre til skabelsen af nye subgeneriske enheder baseret på vægstrukturer, og herigennem vil det måske være muligt at bidrage til klarlæggelsen af slægtens evolutionære historie.

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Stratigraphy of Quaternary deposits in the Skærumhede II boring: lithology, molluscs and foraminifera

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The new Skærumhede II boring penetrated the upper glaciofluvial deposits and the upper part of the marine Skærumhede series. On the basis of the results of sedimentological and lithological investigations such as grain counting and determination of ignition residue and of grain size, it has been possible to subdivide the sequence into several sediment zones. The coarser material in part of the fine-grained marine sediment has presumably been conveyed by drift ice.

Studies of the molluscs in the boring show a development from a boreal *Turritella communis* community on a muddy bottom to a cold fauna with *Portlandia arctica* in an environment with drop till. This cold zone is divided into assemblage-zones characterized by, from below, *Turritella erosa, Balanus crenatus* and *Macoma calcarea.* The difference between the boreo-lusitanian community in the boring and the typical Eem community is regarded as difference in facies and not in time.

The marine sequence of the boring has been divided into nine assemblage-zones on the basis of ecologically conditioned changes in the foraminifera faunas. The lower two zones indicate boreo-lusitanian to boreal conditions and are probably referable to the Eemian Interglacial. The upper seven zones contain arctic faunas, some of which possess variable boreal elements. This is regarded as indication of three interstadials before the main Weichselian glaciation.

The locality of Skærumhede, about 10 km west of Frederikshavn in Vendsyssel, is indicated on the sketch-map, fig. 1. In 1905 a boring was carried out at Skærumhede by the Geological Survey of Denmark (D.G.U. file No. 10.4), and the deposits were described by Jessen *et al.* (1910). A simplified diagram of the deposits is given in fig. 2. The ground level at the bore site was 24.2 m above M.S.L. In the boring a 200 m thick sequence of Quaternary deposits was found resting upon chalk. The Quaternary se-

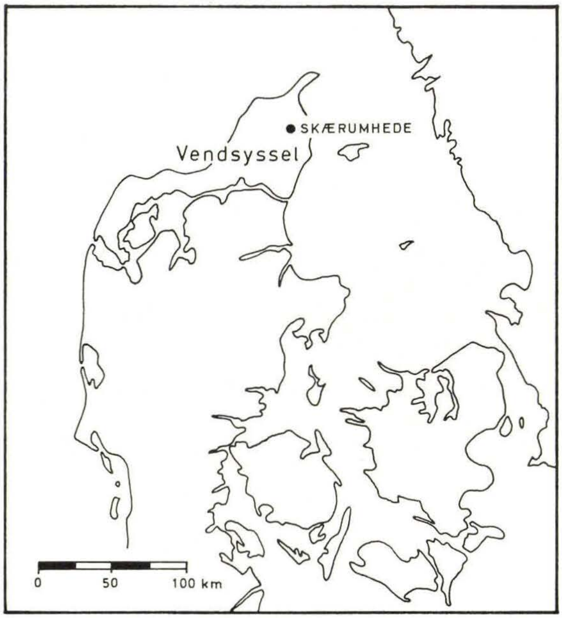

Fig. 1. Location of Skærumhede in Vendsyssel, Denmark

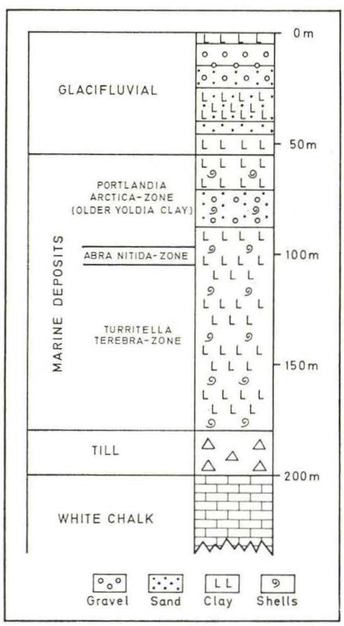

Fig. 2. Deposits in the Skærumhede boring of 1905. After S. T. Andersen 1967.

quence consisted of a 123 m thick marine series, resting on 20 m of till and glaciofluvial deposits, and followed by c. 57 m of glaciofluvial sediments in the upper part of the boring.

On the basis of the mollusc content, the marine sequence in the Skærumhede I boring was divided into three zones (Jessen *et al.* 1910). The zones were not separated by sharp boundaries, but formed a continuous series from temperate to arctic deposits. The *Turritella terebra* Zone, the lowermost of the marine zones, was c. 74 m thick, and consisted of soft clay with a rich boreal mollusc fauna. It was succeeded by the *Abra nitida* Zone, which was c. 8 m thick, and consisted of soft dark clay with a boreo-arctic mollusc fauna. The uppermost zone, the *Portlandia arctica* Zone, was c. 41 m thick, and it was described as a marine clay with arctic molluscs, mixed with sand and gravel layers containing shell fragments of boreal molluscs. Jessen *et al.* (1910) correlated the Older *Yoldia* Clay in Vendsyssel with the *Portlandia arctica* Zone of the Skærumhede series.

The stratigraphical position of the marine series in the Skærumhede I boring has been much discussed. In the description of the boring, Nordmann *in* Jessen *et al.* (1910) placed the *Portlandia arctica* Zone at the beginning of the Weichselian in direct continuation of the other two marine zones, which he suggested to belong to the last interglacial (Eemian). The Skærumhede series was later placed in the Eemian by A. Jessen (1918 and 1936), K. Jessen and Milthers (1928), Ødum (1933) and Hansen (1965). Other authors proposed that the Skærumhede series might be an interstadial deposit from the Weichselian (Wennberg 1949, Rasmussen 1966, S. A. Andersen 1966, Hillefors 1969, Mörner 1969). S.T. Andersen (1967) suggested that the *Turritella terebra* Zone probably belonged to an interglacial, whereas the two upper zones might represent deposits from the following glacial stage. Halichi (1951), Cepek (1967) and Woldstedt (1969) suggested that the Skærumhede series was of Holsteinian age.

On the basis of examinations on a collection of foraminifera from the Skærumhede I boring (left by the late Dr. A. Nørvang), Feyling-Hanssen *et al.* (1971) found that the foraminifera in the two lower zones, the *Turritella terebra* Zone and the *Abra nitida* Zone reflected interglacial conditions, and might belong to the Eemian, whereas the *Portlandia arctica* Zone was suggested to be of Weichselian age (fig. 8).

In 1971–72 the Geological Survey of Denmark carried out a new boring (D.G.U. file No. 10.392) at Skærumhede only a few metres from the bore site of the Skærumhede I boring at 24.6 m above M.S.L. The purpose of this boring was to make more detailed investigations of the sediments and the faunal succession and thus attempt to get a better basis for considering the paleoecology and age of the Skærumhede sequence.

The lithology of samples from the Skærumhede II boring is described by Henner Bahnson. Kaj Strand Petersen described the macrofauna, and the foraminifera content is described by Peter B. Konradi and Karen Luise Knudsen.

In spring 1974 the Geological Survey of Denmark carried out an additional boring (Skærumhede III, D.G.U. file No. 6,369) on the plateau just above the ravine, where the two earlier borings were situated, to complete the profile of the deposits at the locality. The Skærumhede III boring was situated at 42.7 m above M.S.L. and reached 8.7 m above M.S.L. It penetrated the following strata, from above: 6.0 m of sandy and clayey till, 20 m of silt with subordinate layers of clay and fine sand, 5.5 m of poorly sorted sand with fragments of molluscs and 2.5 m of medium sand. The 5.5 m of poorly sorted sand can probably be correlated with the sequence of medium and coarse sand with clay from 6.0 to 13.5 m below surface in the Skærumhede II boring.

Lithology of the Skærumhede II boring

Henner Bahnson

Description and analyses

The Skærumhede II boring was carried out with an "Ideal 105" drilling device (Celler Maschinenfabrik). The sampling was made by means of a "sand pump" on a wire with a maximal length of about 120 metres. 241 samples were taken in the present boring, each representing half a metre of the profile. This drilling method causes a stirring of the samples, but owing to the great diameter (12″–8″) most of the samples contain undisturbed lumps, showing the original sediment structures. It is mainly material from these lumps that has been treated in the analyses.

The lithological sample description is shown in a simplified version on the left in fig. 3. Most of the sediments in the boring are fine-grained and comparatively well sorted, with the exception of three stony horizons at 6.0–15.0, 72.5–86.5 and 94.5–104.0 m.b.s. (metres below the surface). Two or more types of sediment are found in all samples from these intervals. Each interval seems to consist of alternating layers of homogeneous clay, laminated clay and silt, boulder-clay, and possibly unsorted sand and gravel. However, the drilling method may have mixed these layers to a greater or lesser extent. The mixture often resembles boulder-clay. Between the two deepest stony horizons from 86.5 to 94.5 m.b.s., a homogeneous clay with numerous sliding surfaces is found.

In connection with the sample description it is worth mentioning that shells of marine molluscs and other well preserved fossils are frequently found from about 50 m.b.s. to the bottom of the boring, with the exception

Table 1: Grain-counting table.

Metres below the surface	Chert	Limestone, Cretaceous	Limestone, Palaeozoic	Ign. & Metamorph. rocks	Sandstone & Quartzite	Shale	Various	Total
6.0 – 6.5	18	2	0	38	7	4	0	69
7.0 – 7.5	229	45	13	620	24	7	0	938
9.0 – 9.5	206	34	7	702	25	10	0	984
10.0 – 10.5	18	0	0	37	5	1	0	61
13.0 – 13.5	57	14	1	337	8	2	0	419
70.0 – 70.5	37	2	14	176	33	10	0	272
70.5 – 71.0	108	7	17	296	31	6	0	465
71.0 – 71.5	28	1	0	132	7	6	0	174
72.0 – 72.5	34	1	8	493	37	11	0	584
73.0 – 73.5	48	2	7	883	49	15	0	1004
74.0 – 74.5	315	55	7	547	15	3	0	942
75.0 – 75.5	339	84	5	259	49	3	0	739
77.0 – 77.5	439	82	5	257	66	5	0	854
79.0 – 79.5	462	228	3	190	33	5	0	921
81.0 – 81.5	362	198	9	187	35	4	0	795
83.0 – 83.5	235	94	8	178	16	4	0	535
85.0 – 85.5	188	43	4	86	11	2	0	334
86.0 – 86.5	332	55	3	252	32	5	0	679
88.0 – 88.5	281	30	4	161	10	5	0	491
89.0 – 89.5	119	6	2	74	10	3	0	214
90.0 – 90.5	44	5	2	93	8	6	0	158
92.0 – 92.5	34	6	1	108	7	1	0	157
94.0 – 94.5	29	14	1	144	9	1	0	198
96.0 – 96.5	69	1	7	534	35	16	0	662
98.0 – 98.5	39	3	4	497	47	16	0	606
100.0 – 100.5	44	3	0	287	33	22	0	389
102.0 – 102.5	36	6	6	420	34	27	0	524
103.5 – 104.0	121	0	4	313	28	26	0	492

of the homogeneous clay horizon from 86.5 to 94.5 m.b.s. Shell fragments are also found in the upper part of the boring, but here they are usually in a worn and rolled condition.

Plant remains, especially leaves of mosses, occur in most samples, but they are not treated in the present investigation.

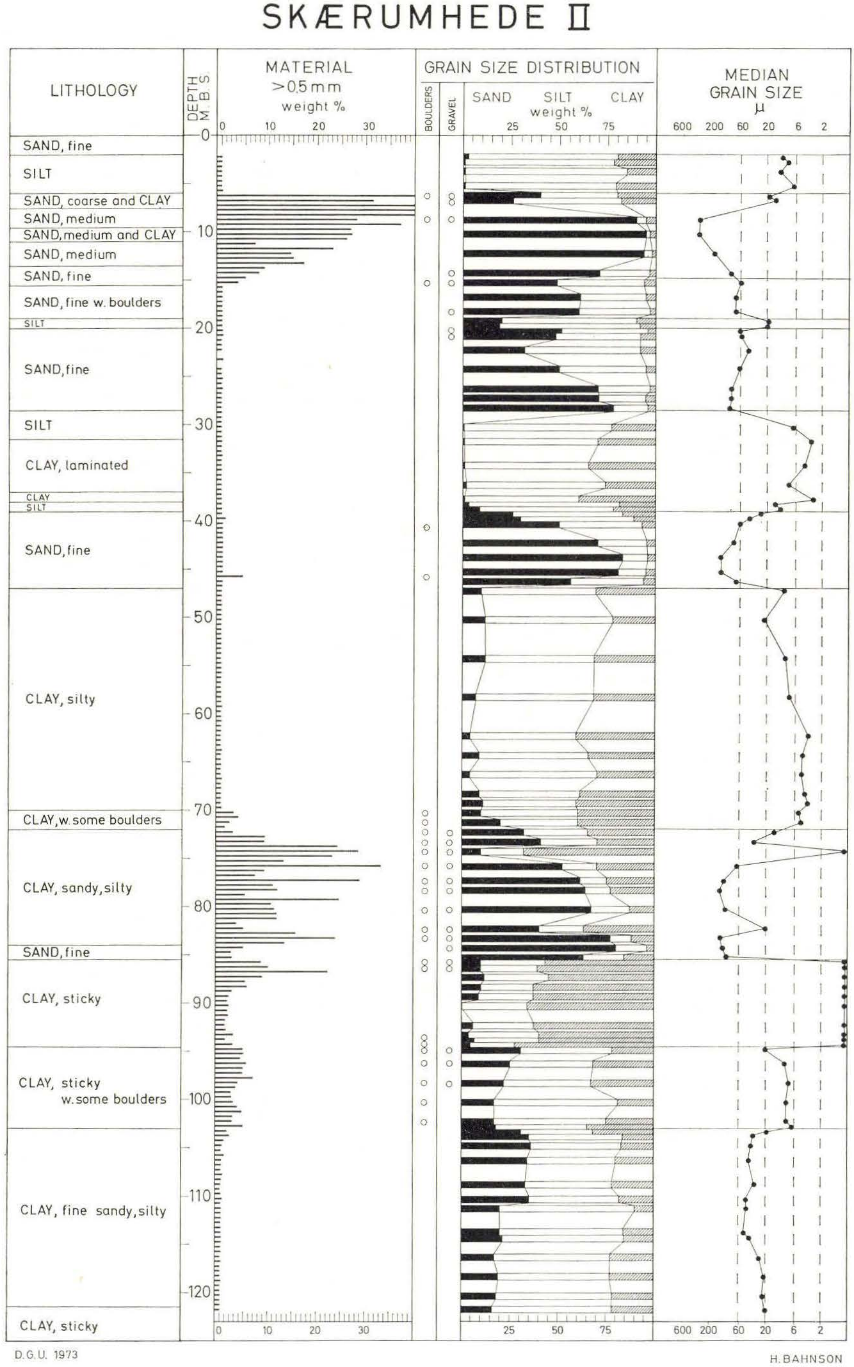

Fig. 3. Granulometric parameters of Skærumhede II.

Fig. 4. Zonation and lithological parameters of Skærumhede II.

The column diagram to the right of the lithological description in fig. 3 shows the amounts of material sifted out on a 0.5 mm sieve by wet sifting of about 3 kg of the dried samples. The results are given as weight-percentages. The three stony horizons, 6.0–15.0, 72.5–86.5 and 94.5–104.0 m.b.s., contain relatively more coarse material ($>$ 0.5 mm) than the rest of the boring, where only little material, occasionally only a few grammes, was left on the sieve.

In fig. 3 the grain size distribution, determined by hydrometer and dry sifting analyses, is also illustrated by a column diagram, but only for selected samples. In the diagram only the fine-earth fractions (material with grain diameters smaller than 2 mm) are used, as the amounts of stone and gravel will not be representative. The presence of these coarse fractions is indicated by small circles to the left of the diagram.

These diagrams show that the deposits of the boring can be divided into different sediment zones with clearly-defined boundaries. The high content of silt in most of the fine-grained zones is remarkable. The zone from 86.5 to 94.5 m.b.s. is characterized by an exceptionally high homogeneous clay content. In the overlying boulder-clay-like zone there is a low silt content, less than in "normal" Danish boulder-clay. This may have been caused by the above-mentioned mixing together of different layers in this zone.

The sediment zones also appear in the curve for the median grain size on the right in fig. 3, and again the boundaries between the zones are distinct. The curve is particularly divergent in the horizon with homogeneous clay, mentioned above.

To the left in fig. 4, curves for total and for reduced loss on ignition and for the content of $CaCO_3$ are shown. All of these parameters seem to be closely connected with the grain size. The $CaCO_3$-content is often high in a silt-rich sediment, as seen in three horizons: 19.0–20.0, 28.5–38.0 and 47.0–69.0 m.b.s. The reduced loss on ignition (the total loss – 0.44 $\times$ the $CaCO_3$-content) is less than five percent for most of the analysis. Therefore the loss on ignition caused by plant-remains can only be very small.

At no level is the amount of plant-remains or shell material great enough for a C^{14}-dating.

Petrographic grain countings (Table 1) have been carried out in samples where this was possible. The method used has been published by the present author (Bahnson 1973). It is based on the experience that in units of boulder-clay the ratios between different rock groups are practically constant in the fine gravel and coarse sand fractions (about 6.0–1.14 mm). Owing to this the countings can be carried out even on small amounts of material.

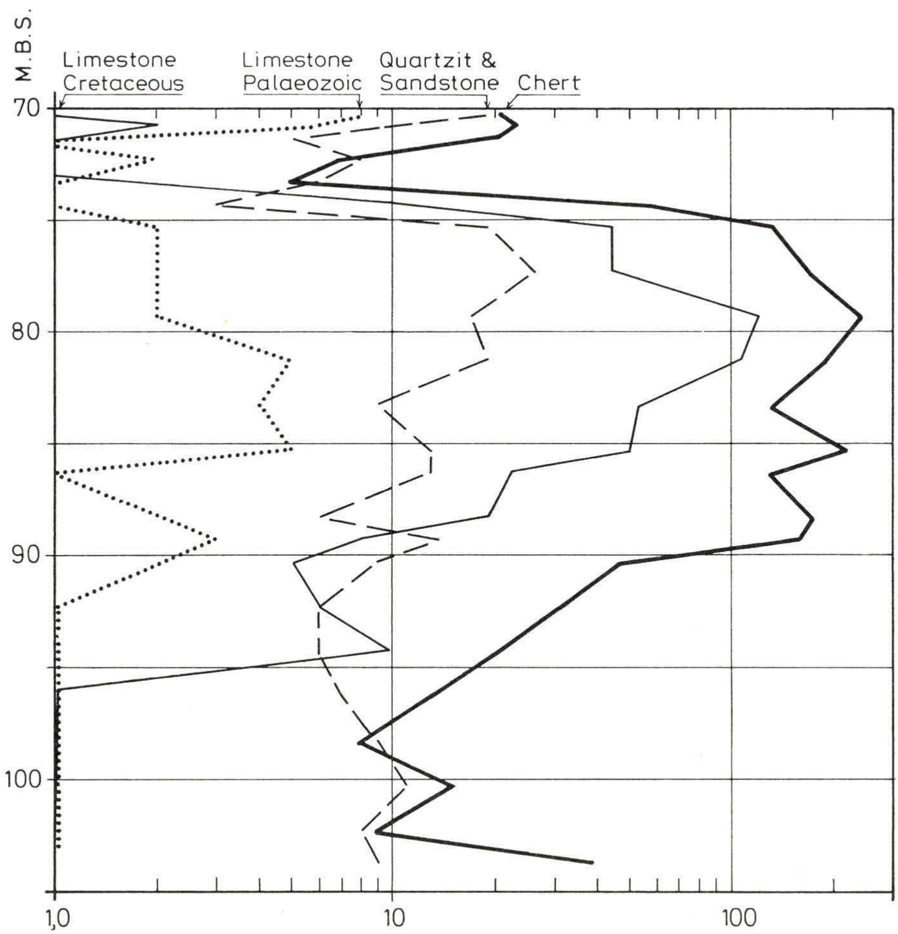

Fig. 5. Distribution of rock groups in stony interval of Skærumhede II. Igneous and metamorphic rocks equal to 100.

The countings show that there is a pronounced difference between the stone assemblages in the different zones. A sudden increase in the content of chert at 90 m.b.s. and a similar sudden decrease at 74 m.b.s. are shown both in fig. 4 and fig. 5. In fig. 5 these variations are seen to be accompanied by corresponding variations in the content of Cretaceous Limestone and, to a smaller degree, in the content of Quartzite and Sandstone.

The content of chert is shown in fig. 4 in relation to the total amount of chert plus igneous and metamorphic rocks.

In fig. 5 the number of grains in the group of igneous and metamorphic rocks is made equal to 100. The number of grains in the other rock groups is converted proportionally to that.

Above the stony sequence, fine grained sediments with a high silt content and almost without variation in the grain size distribution are found from 72.5 to about 47.0 m.b.s. A distinct stratification is seen in most of this zone, and clear indications such as burrows and mollusc shells show that the sediment has a marine origin.

In the Skærumhede I boring the uppermost fifty-five metres were described as meltwater deposits. The lithological investigations in the Skærumhede II boring do not seem to justify a change of this interpretation for the uppermost forty-seven metres. A great part of the fine grained samples from this interval shows a laminated structure with small foldings and faultings in it (pl. 7, fig. 2), as found in normal ice lake deposits. The shell fragments seen mainly in the uppermost layers are, as mentioned, in a worn and rolled condition, indicating a transport.

At the bottom of this interval a large boulder had to be blown up before the drilling could go on.

Six metres below the surface some lumps of boulder-clay occur in a mixed-up sample, but it is impossible to decide whether the lumps originate from a real boulder-clay unit or whether they have been transported to this place in a frozen state as boulders in a meltwater stream.

Conclusions

As mentioned above it is possible to divide the Skærumhede II boring in several well defined sediment zones solely on the basis of the lithological investigations. The zones from the top of the boring to about 47 metres below the surface seem to consist of glaciofluvial sediments, whereas the rest of the boring has a marine origin.

The differences between the various types of sediment in the zones indicate discontinuous sedimentation. The very abrupt sediment changes in some horizons (for instance at 103, 94.5, 86.5, 47 and 28.5 m.b.s.) must be the result of suddenly changed sedimentation conditions, eventually in connection with erosion of passage beds.

The lowermost twenty metres consist of fine sandy, silty clay and correspond to the *Turritella terebra* Zone and the *Abra nitida* Zone of the Skærumhede I boring.

The rest of the marine sequence, the *Portlandia arctica* Zone in Skærumhede I, includes several different sediment units. As mentioned, one of these units consists of homogeneous clay with only few particles of sand and gravel in it. This unit must have been sedimented under extremely quiet conditions.

Above and below the clay zone are found stony sediments with apparently poor sorting. This could to some extent have been caused by a mixing of different sediment-units by the drilling method. On the other hand, this can not explain the remarkable change in the stone assemblage that occurs at the top of the clay zone.

In the sediment zone above the clay zone the occurrence of lumps of real boulder-clay and of remnants of boulder-clay in cavities in the stones seems to reject the obvious possibility that the chert-rich materials originate from beach ridges (Søndergaard 1959). This is also in agreement with the fact that the stones and the particles of gravel size in these layers have sharp edges and irregular forms.

Nevertheless, well preserved mollusc shells occur in the sediment zones above and below the homogeneous clay and indicate marine environments in these zones. The coarse material might therefore have been transported to this place by icebergs or icefloes.

The almost simultaneous rising of the chert and limestone content in relation to the content of igneous and metamorphic rocks (fig. 5) at 90 m.b.s. seem to indicate that the increased supply of coarse material from 86.5 m.b.s., in all probability, must be contemporary with a change in the place of origin of the coarse material. On the other hand, the conspicuous similarity between the stone assemblages above 74 m.b.s. and below 90 m.b.s. seems to suggest a joint place of origin for these sediments. The grains have sharp edges in these zones, too, and a little stone with several glacial striae on it was found at 101 m.b.s. (pl. 6, fig. 2).

The stony intervals are overlain by a zone about 25 metres thick (47.0–72.5 m.b.s.), consisting of fine grained marine sediments.

The macrofauna, particularly the molluscs, in the Skærumhede II boring

Kaj Strand Petersen

The zonation of the marine sequence in the first Skærumhede boring from 1905 was based mainly on the content of molluscs and their affinities to temperature. The upper boundary of the marine deposits was defined by the uppermost occurrence of non-transported shell material. However, shell fragments of molluscs found in the overlying meltwater deposits as well as in the glacial deposits below the marine sequence were also examined.

Detailed descriptions of the molluscs from the Skærumhede I boring were given by V. Nordmann in Jessen *et al.* (1910).

The present discussion and correlation of the Skærumhede II boring with the older boring must be based on the molluscs. However, in combination with the examination of foraminifera faunas (Konradi and Knudsen, present paper) a more detailed zonation of the marine sequence can be made.

In the Skærumhede II boring 241 samples were taken down to a depth of 122 m.b.s. (below surface). The shells have been studied in situ in the samples before sieving the material. They are usually fractured in the sediment (pl. 4, fig. 9), and are partly broken down by the washing. Samples of approximately 3 kg dry weight were washed through sieves with mesh diametres of 0.5 mm, and the fractions larger than 0.5 mm were studied for the content of macrofossils.

The occurrences of the more characteristic molluscs in the Skærumhede II boring are shown in fig. 7. The species are arranged in the same way as presented by Nordmann (*in* Jessen *et al.* 1910, fig. 8) for the old boring. However, for the present boring the occurrence of transported molluscs in the non-marine strata is also illustrated, to show the connections with the marine sequence.

To obtain a better understanding of the changing bottom communities, the representation of Cirripedia, Echinoidea and Ophiuroidea are also shown in the diagram.

The weight percentages of the size fractions larger than 0.5 mm (shells inclusive) are calculated and illustrated.

The lowermost part of the Skærumhede II boring is referred to the *Turritella communis* Zone. There is a very high representation of *Ophiura* and *Echinocardium* (pl. 6, fig. 1). Otoliths and fish vertebrae are also found. The material is not sufficient for quantitative analysis, so the different zones must be regarded as tentative. Some of the molluscs characterizing the lower zone are shown in plates 4 and 5: *Corbula gibba* (pl. 4, figs. 10 and 11), *Mangelia brachystoma* (pl. 5, fig. 2) and *Turritella communis* (pl. 5, fig. 3). The assemblage shows full marine conditions, and there are no indications of influence from littoral environments.

Above the *Turritella communis* Zone a transitional bed is found and the designation *Abra nitida* is maintained for this zone. The substrate can be characterized as muddy bottom. All the species in this zone also occur either in a higher or a lower level in the marine sequence. However, the Echinoidea and other characterizing elements mentioned from the underlying zone are not present in the *Abra nitida* Zone. The only molluscs occurring both in the present zone and in the layers above and below are *Nucula tenuis* and *Macoma calcarea* (fig. 6).

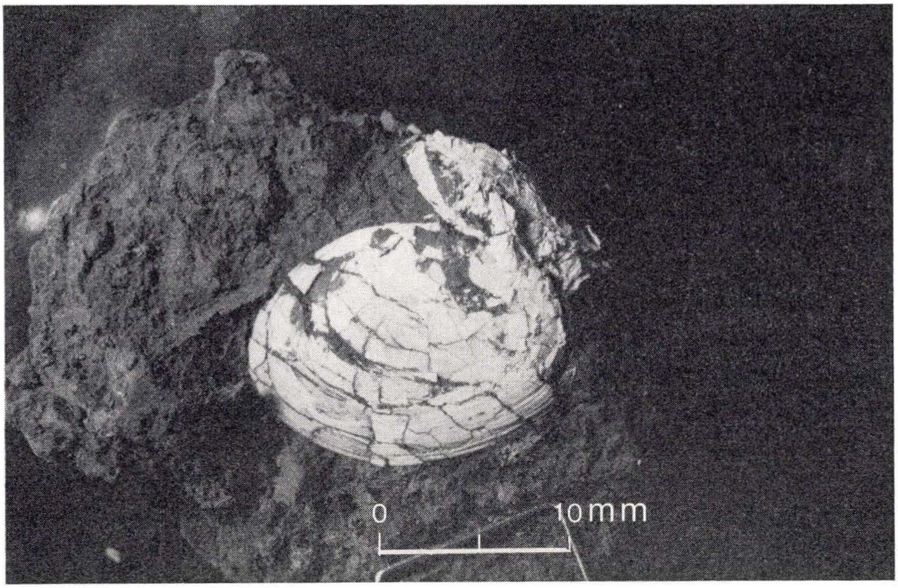

Fig. 6. *Macoma calcarea* in position in the clay, with both valves, but both fractured. Sample No. 113. Gives a residue when sieved, as seen on pl. 7, fig. 1.

A number of species were rather common in the deeper layers of the Skærumhede I boring, but are rare or even absent in the *T. communis* Zone of the new boring. These are *Cardium ciliatum* (pl. 4, fig. 7), *Leda pernula, Nucula tenuis, Hiatella arctica, Macoma calcarea* and *Bela incisula* (pl. 5, figs. 4 and 5) of the species in fig. 7. The sporadic occurrence of these species in the present material may be due either to the smaller samples analysed here, or to the fact that the Skærumhede II boring only includes the uppermost part of the zone with boreo-lusitanian faunas.

Concerning the upper boundary of the *Abra nitida* Zone, the macrofossils give rather good indications. The boundary may be defined by the uppermost occurrence of *Cardium fasciatum* and *Abra nitida* (pl. 4, fig. 9) and by the sudden abundance of arctic forms introduced in the faunas above. A few transported skeletal elements of Cirripedia as well as fragments of mytilids and *Arctica islandica?* are found in the *Abra nitida* Zone. In the upper part of the zone there is an increase of particles $>$ 0.5 mm.

The *Turritella erosa* Zone (pl. 5, fig. 1) contains the following molluscs besides the gastropod giving name to the zone: *Alvania cruenta* Odhner 1915 (pl. 5, fig. 8) [*Rissoa scrobiculata* Møller according to Nordmann (Jessen *et al.* 1910 pl. 6, fig.10)], *Yoldia hyperborea* and *Portlandia arctica* (pl. 4, fig. 1). These species indicate arctic conditions, and occur through the upper part of the marine sequence, the *Portlandia arctica* Zone of the first Skærumhede boring. However, there is a change in assemblages through this upper part of the sequence, which on this basis has thus been divided in zones. The occurrence of the characteristic species in the zones will now be discussed.

There is a sudden change from boreal to arctic conditions, and shell material from Cirrepedia, Echinoidea and Ophiuroidea as well as *Dreissena polymorpha* (pl. 4, fig. 5) occurs as transported fragments in the arctic deposits in the *Turritella erosa* Zone. The high content of material coarser than 0.5 mm may be due to a supply of ice-rafted material during the arctic conditions. Some of the stones even show glacial stria (pl. 6, fig. 2); so it might be called drop till.

The *Turritella erosa* Zone is rich in species. *Portlandia lenticula* (pl. 4, fig. 4) is found in situ in the clay, and a specimen of *Portlandia* sp. juv. (pl. 4, fig. 3) shows a borehole from a predatory gastropod. In addition, fragments of the following genera are found: *Chlamys, Mytilus, Arctica, Astarte, Rissoa, Natica, Buccinum* and *Utriculus,* and some otoliths also occur.

Above the *Turritella erosa* Zone there is a layer of about 3.5 m thickness without macrofossils. Only very small fragments of transported shells are found in the clayey sediment. This phenomenon may be explained by the observations of Gunnar Thorson (1933, p. 65) from the Franz Joseph Fjord, quot: "... anyone who has experienced the breaking up of the large rivers in East Greenland, is aware that it takes place while the unbroken fjord ice still covers the fjords. The large amounts of fresh water which are emptied into the fjords at an enormous pressure, are thus forced in below the ice, and under such conditions it is highly probable that the fresh water is pressed towards the bottom and there forms a fresh water current. If such a fresh water layer is present at the bottom for period of only about 3–4 days annually it will be able to kill all animal life."

In the investigated area all invertebrates in the bottom communities were killed down to a depth of 40 m. In this connection it must be mentioned that samples from the present layers in the Skærumhede II boring contain rather rich high-arctic foraminifera faunas (Konradi and Knudsen, present paper).

The following zone, including the foraminifera zone IV, is called the *Balanus crenatus* Zone. It is characterized by a low species diversity, and no fragments of Echinoidea and Ophiuroidea are found. The content of sediment particles > 0.5 mm amounts to maximaly 30 ‰, but varies considerably within the samples. As shown by Bahnson (present paper) the lithological composition is clearly different from that in the *Turritella erosa*

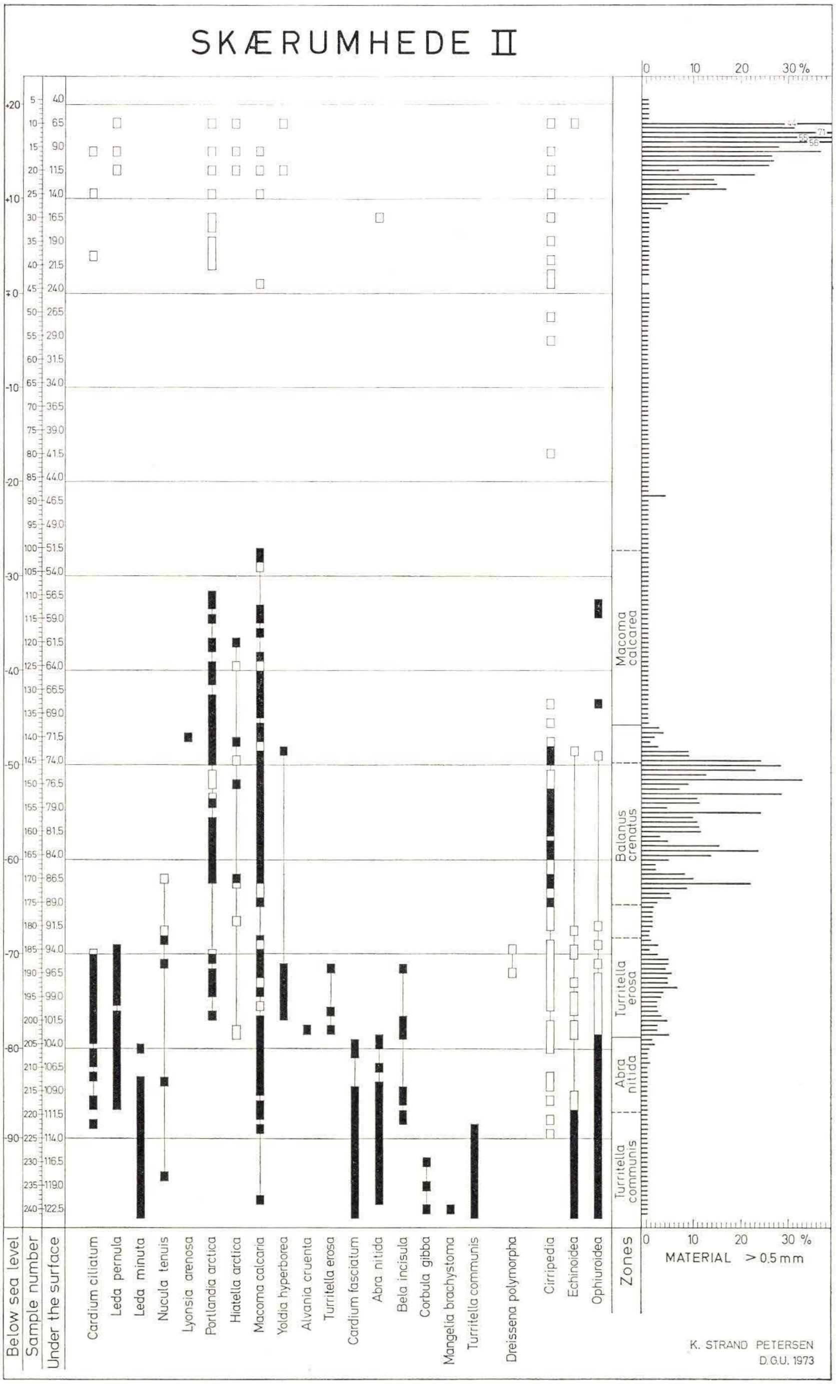

Fig. 7. Occurrence of characteristic molluscs in Skærumhede II. The representation of Cirripedia, Echinoidea and Ophiuroidea is also shown. Signatures in blank indicate transported state. Depth in meter.

Zone. The coarser sediments with a content of larger stones are supposed to be the substratum of the *Balanus crenatus* epifauna. *Portlandia arctica* occurs in most of the samples within the *Balanus crenatus* Zone (see fig. 7).

The boreal shallow water species *Zirphaea crispata* is found as a single fragment in sample No. 149. This species is not typical of environments with a supply of ice-rafted material.

Concludingly can be said that judging from the macrofossil content no important rise in temperature can be suggested. This is opposed to the conclusion arrived at by Knudsen (present paper) on the basis of the microfossil content which is said to show a rather strong influence of boreal elements in this zone.

Above the *Balanus crenatus* Zone there is a layer of about 4.0 m thickness where some fragments of Echinoidea and Ophiuroidea are found, with *Lyonsia arenosa* in one sample (pl. 4, fig.2). The lithological composition corresponds to that in the *Turritella erosa* Zone (see fig. 4).

An arctic muddy bottom community of exclusively *Portlandia arctia* and *Macoma calcarea* (fig. 6 and pl. 7,fig. 1) occurs in the uppermost part of the marine series. The boundary of the non-marine deposits is here defined by the uppermost occurrence of molluscs in situ. However, as seen in the deposits between the zones of *Turritella erosa* and *Balanus crenatus,* the lack of macrofossils might be caused by other circumstances than a supra-aquatic position. In the arctic today, *Portlandia arctica* and *Macoma calcarea* can also be found in shallow water deposits (Thorsen 1934), so the molluscs give no faunistic indications of the water depth in the present deposits.

In the lower part of the non-marine deposits only few redeposited shells are found. Ten metres below the surface the meltwater deposits are coarser, and rebedded shells are found in abundance. The identified species represent mostly cold water forms.

Conclusion

The present study confirms V. Nordmann's observation of faunas changing from boreo–lusitanian to arctic in the Skærumhede I boring. The assemblages of the *Portlandia arctica* Zone of V. Nordmann indicate changing environments, which permits a subdivision additionally confirmed by the microfossils (Knudsen, present paper).

The transition to this cold fauna is traced at a deeper level in Skærumhede II (5 m) than was the case in the old boring. With regard to the microfossils the sudden advent of cold water forms is found at similar levels, this level corresponding to the level of cold water molluscs in Skærumhede II.

It must be stressed that the problem of whether the occurrence of boreal species within the *Balanus crenatus* Zone – part of which is correlated with the Brørup Interstadial on the basis of microfossils (zone IV) – may be regarded as indicating a rise in temperature, remains unsolved: *Portlandia arctica* occurs through the sequence, and a coarser sediment without traces of a littoral fauna is prevalent.

The transition to non-marine deposits, as judged from the mollusc content, is found where the last in situ mollusc occurs. But since transported shell material does occur at a higher level without any change in sediment-composition, this transition may have occurred at a higher level, as is suggested on the basis of microfossils (Knudsen, present paper). An argument against this is that, owing to a lowering of sea-level as a consequence of a new climatic deterioration, the Weichselian Glacial, a redeposition of former sea deposits could have occurred.

Concerning the correlation between faunas from the Skærumhede deposit and Eem deposits on the basis of macrofossils it should be noticed that the Skærumhede fauna does not include any littoral, non-transported elements whereas the Eem fauna (Nordmann 1928), represented in the southern part of Denmark, is a shallow water fauna. It is the writer's view that the two faunas (the Skærumhede boreo–lusitanian and the Eemian) might represent different facies of one sea.

Foraminifera in the Skærumhede II boring

Peter B. Konradi and Karen Luise Knudsen

Introduction and methods

In the marine sequence of the present boring the foraminifera faunas from samples at intervals of about 0.5 m or 1.0 m were analysed (cf. Bahnson, present paper, p. 30).

In the laboratory, samples were treated largely as described by Wick (1947), Bartenstein (1954) and Feyling-Hanssen (1958). Samples of 200 g dry weight were disintegrated by soaking in warm water with a few drops of synthetic detergent for about one day. Where insufficient, the treatment was repeated or the samples were soaked for about 15 minutes in a 2–5% solution of hydrogen peroxide (H_2O_2). The samples were washed through sieves with mesh diametres of 1.0, 0.1 and 0.063 mm, and the residues were dried and weighed. Foraminifera in the size fraction 0.1–1.0

mm were concentrated by means of a heavy liquid made of ethylene bromide mixed with absolute alcohol to a specific gravity of 1.8 g/ccm.

In poor samples the entire Quaternary foraminifera content was identified and counted; in rich samples at least 500 specimens were counted, and the total number per 100 g sediment estimated by extrapolation (Phleger 1960).

A rough outline of the lithology in the marine sequence is indicated on the left in the diagram, fig. 10 (legend fig. 9). The grain size distribution curves are based on weight percentages of the size fractions in the treated samples. More detailed sediment analyses are described by Bahnson in the present paper.

The statistical record of 17 selected foraminifera taxa is plotted in the range chart (fig. 10), where the symbols indicate percentage frequencies of each taxon (legend fig. 9). In a few very poor samples with less than 100 specimens present, the number of specimens is entered directly on the chart.

The percentages of boreal specimens in the faunas, including lusitanian specimens, are diagrammatically illustrated. The following species are considered boreal or lusitanian: *Bulimina marginata* d'Orbigny, *Virgulina fusiformis* (Williamson), *Uvigerina peregrina* Cushman, *Bolivina* cf. *robusta* Brady, *Hyalinea baltica* (Schroeter), *Nonion barleeanum* (Williamson), *N. depressula* (Walker and Jacob), *Elphidium albiumbilicatum* (Weiss), *E. articulatum* (d'Orbigny), *E. gerthi* van Voorthuysen, *E. macellum granulosum* (Sidebottom), *E. magellanicum* Heron-Allen and Earland, *E. margaritaceum* Cushman, *Protelphidium anglicum* Murray and *Ammonia batavus* (Hofker). The occurrences of *Elphidium excavatum* (Terquem) as the boreal *forma selseyensis* (Heron-Allen and Earland) (cf. Feyling-Hanssen 1972) are not given in the present countings, and this form is therefore not included in the boreal elements.

The faunal diversity, defined as the number of ranked species whose cumulative percentage accounts for 95 % of the total fauna (Walton 1964), is indicated for each of the samples. This measure is used in the interpretation of palaeoenvironments of the deposits. A high diversity usually indicates favourable marine conditions, whereas low diversity may be the faunal response to severe conditions.

The number of Quaternary foraminifera per 100 g sediment is shown for each of the counted assemblages, and in a column to the right of this diagram the number of derived Pre-Quaternary specimens per 100 g sediment is given.

On the basis of the changing composition of foraminifera faunas through the boring the marine sequence is subdivided into 9 assemblage-zones, called zones I to IX. Zone I is the uppermost and assumed to be the youngest, whereas zone IX is the lowermost and assumed to be the oldest. This zonation is a stratigraphical interpretation of faunal assemblages which are ecologically conditioned, and it has therefore only a limited regional applicability.

Systematic remarks

Concerning classification of the foraminifera, taxonomic remarks, and photographs of the species, the reader is referred to the systematic part in Feyling-Hanssen *et al.* (1971). However there are a few deviations and three species which are not treated in that paper:

Nonion depressula (Walker and Jacob)

1798 *Nautilus depressulus* Walker and Jacob. *In:* Adams, G.: *Essays on the Microscope*. F. Kanmacher. Ed. 2, London, p. 641, fig. 33.
1965 *Nonion depressulus* (Walker and Jacob) emend. diagn. – Murray, p. 148, pl. 25, figs. 6, 7; pl. 26, figs. 7, 8.
1971 *Nonion umbilicatulum* (Walker and Jacob) – Feyling-Hanssen *et al.*, p. 263, pl. 10, figs. 3, 4; pl. 19, figs. 2, 3.

Elphidium articulatum (d'Orbigny)

1839 *Polystomella articulata* d'Obigny: *Voyage dans l'Amerique Méridionale – Foraminifere*. 5 (5). Atlas 9, (1847). Paris, p. 30, pl. 3, figs. 9, 10.
1968 *Cribrononion articulatum* (d'Orbigny) – Lutze, p. 27, pl. 1, figs. 1, 2.
1971 *Elphidium umbilicatulum* (Williamson) – Feyling-Hanssen *et al.*, p. 281, pl. 13, figs. 8–11; pl. 23, figs. 1–4.

Elphidium cuvillieri Lévy

1957 *Elphidium sp. A* van Voorthuysen, p. 31, pl. 23, figs. 10 a, 10 b.
1966 *Elphidium cuvillieri* Lévy: Vie et Milieu, 17, 1–A, p. 5, pl. 1, figs. 6 a, 6 b, 6 c.

Elphidium excavatum (Terquem)

1875 *Polystomella excavata* Terquem: *Essai sur le Classement des Animaux qui vivent sur la Plage et dans les environs de Dunkerque*. Paris, p. 25, pl. 2, fig. 2.
1965 *Cribrononion excavatum* (Terquem) – Lutze, p. 96, pl. 15, figs. 39–41.
1971 *Elphidium clavatum* Cushman – Feyling-Hanssen *et al.*, p. 273, pl. 11, figs. 10–13; pl. 20, figs. 5–8.

Elphidium macellum granulosum (Sidebottom)

1909 *Polystomella macella* (Fichtel and Moll) var. *granulosa* Sidebottom: Manchester Lit.Philos.Soc.Mem. and Proc., 53 (21), p. 16, pl. 5, fig. 5.
1939 *Elphidium macellum* (Fichtel and Moll) var. *granulosum* (Sidebottom) – Cushman, p. 52, pl. 14, fig. 4.

Protelphidium dittmeri (Lafrenz)

1963 *Elphidium dittmeri* Lafrenz: Meyniana, 13, p. 33, pl. 4, figs. 15–19.
1972 *Protelphidium dittmeri* (Lafrenz) – Wiegank, p. 46, pl. 6, figs. 8, 9.

Foraminifera in the lower part of the marine sequence

Peter B. Konradi

Fauna and environment

The lower part of the Skærumhede II boring, from 94.5 to 122.0 m.b.s. (metres below surface) is divided into four assemblage-zones, called zone VI to IX (fig. 10). The zones will be described from below.

In the lowermost zone, *zone IX* from 122.0 to 112.0 m.b.s., the sediment consists mainly of silt with some clay and some sand. The foraminifera fauna in the zone is dominated by several species. The most frequent is *Elphidium excavatum* (Terquem) which occurs partly as *forma selseyensis* (Heron-Allen and Earland) and partly as *forma clavata* Cushman (Feyling-Hanssen 1972), and with frequencies of 16–41 ‰. The second in number is *Elphidium gerthi* van Voorthuysen with about 15–20 ‰ of the fauna. Other frequent species are *Nonion depressula* (Walker and Jacob), *Elphidium macellum granulosum* (Sidebottom), *E. magellanicum* Heron-Allen and Earland and *E. margaritaceum* Cushman, which each constitute about 5–12 ‰ of the fauna. Less frequent are *Buccella frigida* (Cushman) and *Elphidium albiumbilicatum* (Weiss) with frequencies of 2–4 ‰. Other accessory species occurring with 1 or 2 ‰ are *Cassidulina crassa* d'Orbigny and *Buliminella elegantissima* (d'Orbigny), found in most samples, and *Quinqueloculina seminulum* (Linné), *Virgulina fusiformis* (Williamson), *Cassidulina laevigata* d'Orbigny, *Elphidium macellum* (Fichtel and Moll) and *Ammonia batavus* (Hofker), found in several samples.

The frequency of boreal and lusitanian foraminifera in zone IX exceeds 50 ‰ in almost all samples and reaches a maximum of 65 ‰ in sample No. 225. The faunal diversity is mostly between 14 and 20, and the number of specimens in 100 g sediment is about 2–3000.

The assemblage in the present zone resembles recent faunas found in the Channel at depths of less than about 20 m (Dupeuble *et al.* 1971). *Elphidium excavatum* in the present forms is found mainly at shallow depths in the North Sea today (van Voorthuysen 1960, Jarke 1961, Haake 1962, Lutze 1965, Lévy *et al.* 1969, Feyling-Hanssen 1972), but here *Elphidium macellum granulosum* is not found. This species is recorded from the Mediterranean (Cushman 1939, Daniels 1970), and it is regarded as lusitanian.

In the middle part of zone IX there is a rise in faunal diversity and in the content of Miliolidea. This interval is also characterized by occurrence of the two species *Virgulina fusiformis* and *Cassidulina laevigata,* which are found at depths of more than 10–20 m (Höglund 1947, Risdal 1964). This is followed by a decrease in the number of *Elphidium excavatum,* and is taken as indication of increased water depth in this part of the zone.

The foraminifera assemblage in zone IX indicates southern-boreal to lusitanian environments, a water depth of less than about 20 m and shallower water in the lower and upper part of the zone than in the middle part of it.

In *zone VIII,* from 112.0 to 103.0 m.b.s., the sediment is again dominated by silt, but the content of sand in most of the zone is now about 35 %, mainly fine sand. The foraminifera fauna of this zone is a continuation of the fauna from zone IX, but it now includes a prominent cold element, as the cold species *Cassidulina crassa* accounts for about 10–20 % of the fauna and even reaches 27 % in sample No. 211. *Elphidium excavatum* is still the most frequent with 24–45 %. Quite frequent are *Nonion depressula, Elphidium gerthi, E. macellum granulosum, E. magellanicum* and *E. margaritaceum* with frequencies from 2 to 10 %. Less frequent are *Buccella frigida* and *Elphidium albiumbilicatum* with about 2–5 %. Accessory species occurring with 1 or 2 % are *Buliminella elegantissima* and the cold *Protelphidium orbiculare* (Brady), which are found in most samples. *Ammonia batavus* is found in several samples in the lower part, whereas the cold species *Islandiella islandica* (Nørvang) and *I. teretis* (Tappan) occur in the upper part of the zone.

The transition from zone IX to zone VIII is gradual and probably represents a continuous sedimentation. The boundary between the zones is fixed at the point where the percentage of boreal specimens decreases to the level of zone VIII, which is around 40–30. The faunal diversity in this zone is from 11 to 17, and the number of foraminifera in 100 g sediment is about 3–5000.

The species *Cassidulina crassa* is today found in the northern part of the North Sea (Jarke 1961) and in arctic regions (Nørvang 1945). It is abundant in normal marine areas at water depths of more than 15–20 m (Buzas 1965, Nagy 1965). The occurrence of this species in zone VIII therefore indicates colder conditions and greater water depth than in zone IX, but probably not much more, as the warm species still constitute a higher percentage of the fauna. The zone presumably represents an area where cold and warm faunas meet and mingle, i.e. the boreal area.

The foraminifera assemblage in zone VIII therefore indicates normal marine boreal environments with water depth exceeding 20 m, but probably not much more.

A characteristic feature of zone VIII and IX is a content of charred plant remains and of Pre-Quaternary foraminifera. The number of the latter is normally equal to 15–25 % of the Quaternary specimens, but may be as high as 31 %. This reworked material presumably originates from the erosion of a coast, from where it has been transported by a coastal current. This interpretation is in agreement with the sediment, which consists mainly of relatively well-sorted silt and fine sand.

In *zone VII,* from 103.0 to 98.0 m.b.s., the sediment has changed. It is more clayey and the fine sand has disappeared, but scattered stones and gravel-size particles occur. The content of plant remains has almost disappeared and the Pre-Quaternary foraminifera amount to only a few percent. The foraminifera fauna has also changed markedly, and it is now dominated by the two species *Elphidium excavatum,* appearing as *forma clavata,* and *Cassidulina crassa,* which together account for about 70 % of the fauna. Important are also the cold species *Islandiella norcrossi* with 6–9 % and *Islandiella teretis* with 3–4 %. Less frequent are *Virgulina loeblichi* Feyling-Hanssen and *Islandiella islandica,* which are found in most samples at a few percent. *Buccella frigida* is found mainly in the lower part of the zone, whereas *Nonion labradoricum* (Dawson) occurs in the upper part. Other accessory species with scattered occurrences are *Bulimina marginata* d'Orbigny, *Trifarina fluens* (Todd), *Astrononion gallowayi* Loeblich and Tappan, *Elphidium groenlandicum* Cushman and *Protelphidium orbiculare.*

The boreal and lusitanian species have almost disappeared, and this is reflected in the frequency of boreal foraminifera, which is now only a few percent. The faunal diversity increases slightly from 10 to 16 upwards through the zone, and the number of specimens in 100 g sediment is around 4–6000.

The species *Islandiella norcrossi, I. teretis* and *Nonion labradoricum* belong to moderately deep arctic waters (Feyling-Hanssen 1971). The decrease of *Elphidium excavatum* (from 54 to 33 %) and of the shallow water species *Buccella frigida* upwards in the zone and the simultaneous increase of *Cassidulina crassa* (from 20 to 33 %) and of *Nonion labradoricum* are taken as indications of increasing water depth.

The foraminifera fauna in zone VII therefore indicates normal marine arctic conditions and water depths of more than 20 m, probably increasing upwards through the zone. The change in fauna from zone VIII to zone VII is so abrupt that the existence of a hiatus at the boundary between the two zones can not be excluded. Because of the arctic conditions, the

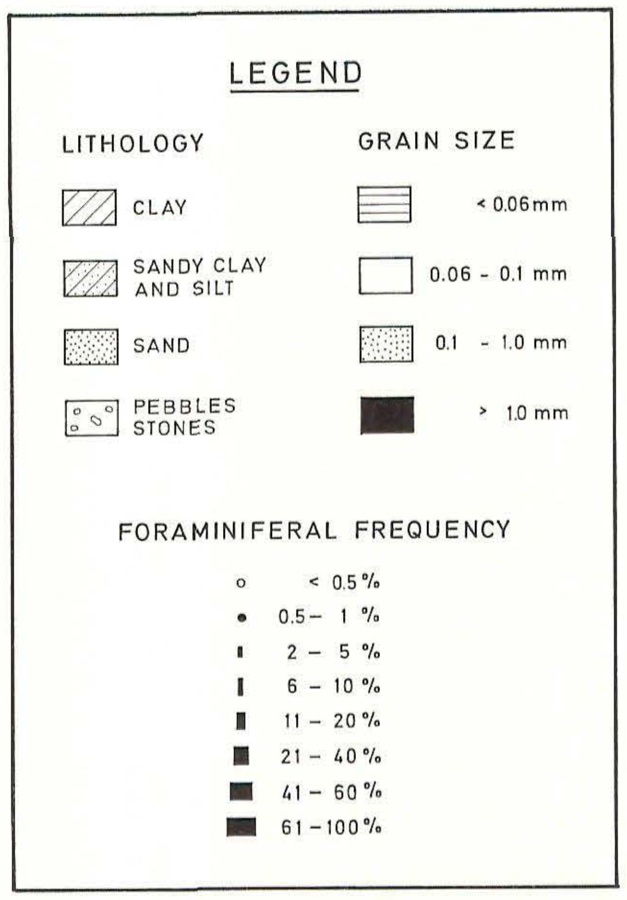

Fig. 9. Legend to the range chart fig. 10.

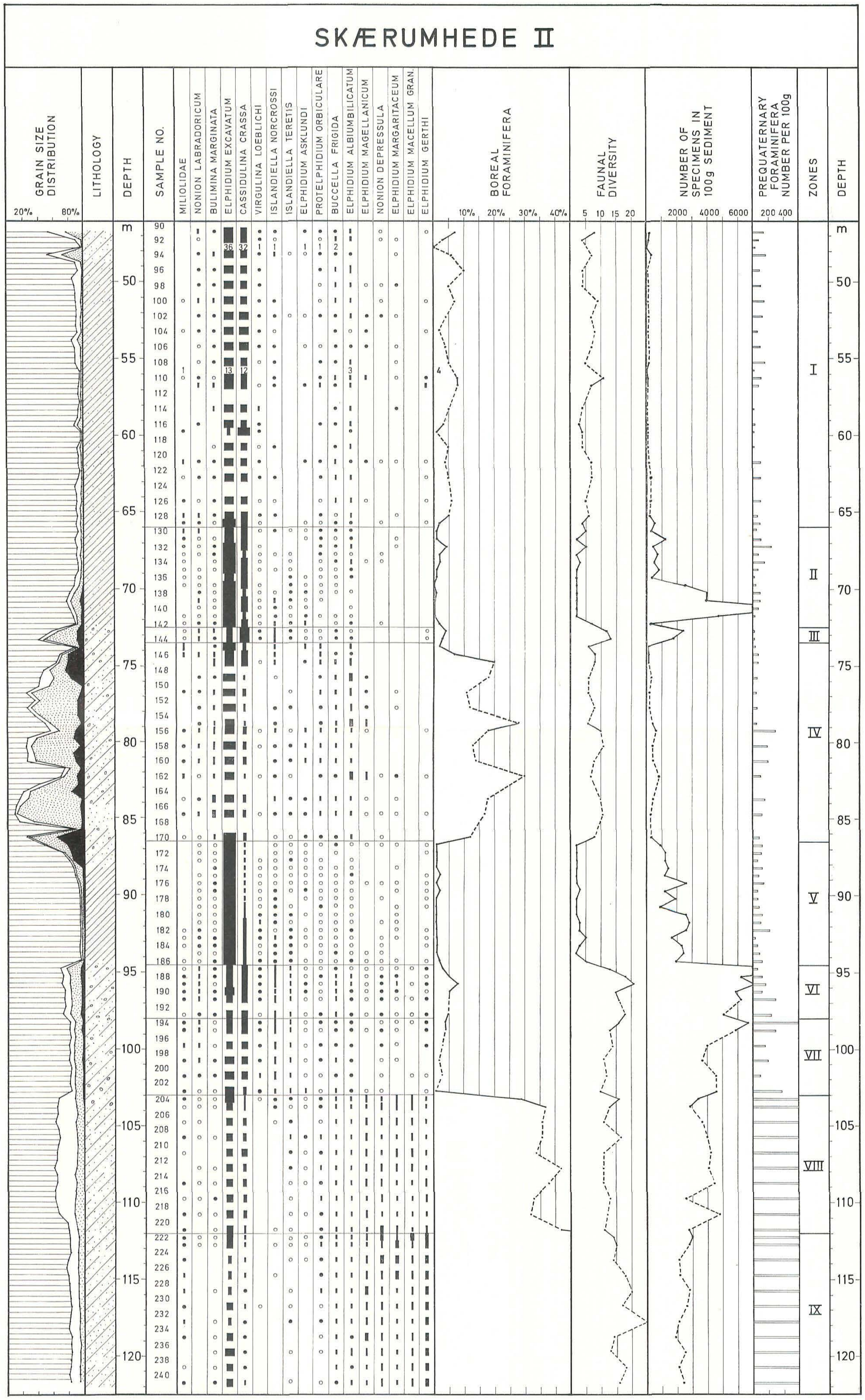

Fig. 10. Range chart for the Skærumhede II boring. Legend fig. 9.

presence of coarse particles in the clayey sediment may be explained as ice-rafted material dropped from floating icebergs.

The uppermost zone in the present sequence, *zone VI* from 98.0 to 94.5 m.b.s., is a continuation of zone VII. The clayey sediment has a slightly increased content of coarse particles, and the foraminifera fauna is mainly the same arctic assemblage as in the upper part of zone VII. In addition, *Buccella frigida* occurs in most samples with a few percent, and the boreal species *Bulimina marginata* accounts for 1 ⁰/₀. Further accessory species are *Cibicides lobatulus* (Walker and Jacob), *Buccella tenerrima* (Bandy) and the boreal *Uvigerina peregrina* Cushman and *Nonion depressula*.

The transition from zone VII to zone VI is gradual, and the boundary is fixed at the point where the slight increase in the boreal foraminifera brings their frequency to 5 ⁰/₀. In zone VI the boreal element is still increasing and reaches 8 ⁰/₀. This rise coincides with a rise in the faunal diversity, which is now from 15 to 21. The number of foraminifera in 100 g sediment has increased to 5–7000. The uppermost sample from zone VI shows a decrease in the percentage of boreal specimens to 3 and in the faunal diversity to 13, whereas the number of foraminifera increases to more than 10 000 in 100 g sediment.

The increase in the number of boreal specimens and in faunal diversity in the present zone support one another in the indication of a slight amelioration in the environment. The increase of the boreal element is caused both by a greater number of shallow water species e.g. *Nonion depressula,* and of species preferring deeper waters as *Bulimina marginata* and *Uvigerina peregrina* (Nørvang 1945, Höglund 1947, Risdal 1964). The amelioration is therefore believed to have been caused by a slight rise in temperature. This could also have caused a retreat of the glaciers and thus an increase in the number of floating icebergs, which may explain the slight increase in the amount of probably ice-rafted material, seen in the coarse fraction. The decrease in the graphs for the uppermost sample could indicate a fall in temperature.

The foraminifera fauna in zone VI therefore indicates normal marine conditions and water depths of more than 20 m. There is a gradual transition from the arctic zone VII to the low arctic zone VI. At the top of zone VI there seem to be indications of a new decline in temperature.

Correlations

The foraminifera faunas in assemblage-zones VIII and IX contain foraminifera which are found today in boreal and southern-boreal to lusitanian areas.

The foraminifera in zone IX indicate temperatures higher than in the North Sea area today, and clearly belong to an interglacial. A comparison with investigations of interglacial foraminifera faunas in the North Sea area (van Voorthuysen 1950 a, 1950 b, 1957, 1958, Buch 1955, Woszidlo 1962, Lafrenz 1963, Brodniewicz 1969, Fisher *et al.* 1969, Mangerud 1970, Wiegank 1972, Konradi in press) leads to the conclusion that the interval deeper than 103.0 m b.s. of the Skærumhede II boring most probably belongs to the Eemian Interglacial (fig. 8). Its foraminifera fauna indicates a temperature as known from Eemian deposits (van Voorthuysen 1957, Lafrenz 1963, Wiegank 1972, Konradi in press). The following species, found in the Skærumhede II boring: *Nonion depressula, Elphidium bartletti* Cushman, *E. cuvillieri* Lévy, *E. gerthi, E. macellum, E. magellanicum, E. margaritaceum, Protelphidium dittmeri* (Lafrenz), and the combination of these are characteristic of the Eemian faunas. The lusitanian element in Eemian marine fossils is also known from mollusc faunas (Madsen *et al.* 1908, Nordmann 1928).

The foraminifera assemblages in zones VI and VII indicate arctic environments, and the zones therefore belong to a glacial. This is also indicated by the occurrence of scattered, probably ice-rafted, coarse particles in the clayey sediment. The interval above 103.0 m.b.s. of the Skærumhede II boring is therefore considered to belong to the Weichselian Glacial (fig. 8). The foraminifera fauna in zone VI seems to indicate a slight amelioration of the environment compared with the fauna in zone VII. Zone VI may therefore perhaps be correlatable with an interstadial in the Weichselian.

It should be mentioned that the interglacial sequence of the boring Skærumhede II represents the end of an interglacial, whereas it has been compared to deposits which belong to the beginning or the optimum of an interglacial. Therefore the present correlation might be revised by additional investigations either of deposits representing the end of well-known interglacials, or of a new boring also penetrating the deeper parts of the marine sequence at Skærumhede.

A comparison with the old boring at Skærumhede (Jessen *et al.* 1910) leads to the conclusion that the boundary between the boreal assemblage-zone VIII and the arctic assemblage-zone VII corresponds to the boundary between the boreo-arctic *Abra nitida* Zone and the arctic *Portlandia arctica* Zone (fig. 8). This is in agreement with investigations of the molluscs in the Skærumhede II boring (Strand Petersen, present paper). It also agrees with the change in the sediment, which in fact was the original basis for the fixation of the boundary between the *Abra nitida* and the *Portlandia arctica* Zones. This boundary was situated at 97.9 m.b.s., whereas in the Skærumhede II boring the corresponding boundary is at approximately 103.0 m.b.s.

Even though the two borings are placed close to one another, there is a difference of around 5 m in the position of the boundary between the boreal and the arctic zone in the two borings.

The assemblage-zone VIII has a thickness of 9 m and is a transitional zone between boreo-lusitanian and arctic environments. In this way it corresponds to the transitional *Abra nitida* Zone, which has a thickness of 8.5 m. The assemblage-zone IX thus corresponds to the upper part of the *Turritella terebra* Zone, and the arctic assemblage-zones VII and VI correspond to the lower part of the arctic *Portlandia arctica* Zone (fig. 8).

Foraminifera in the upper part of the marine sequence

Karen Luise Knudsen

Samples from the upper part of the Skærumhede II boring contain foraminifera faunas from the deepest sample at 94.5 m.b.s. (metres below surface) up to about 45 m.b.s. The upper boundary of the marine deposits is not clearly defined.

Fauna and environment

The foraminifera faunas from the upper part of the marine sequence are usually dominated by the two species *Elphidium excavatum* (Terquem) as the arctic *forma clavata* Cushman (Feyling-Hanssen 1972) and *Cassidulina crassa* d'Orbigny. This indicates a rather cold climate during the sedimentation. However, the faunal composition changes through the sequence, and it has been possible to separate five characteristic foraminiferal assemblages (zones I to V, fig. 10).

Zone V (94.5–86.5 m.b.s.) is about 8 m thick and consists mainly of clay with a few scattered gravel-size particles. The clay becomes more sandy in the upper part of the zone. There is a very high dominance of *Elphidium excavatum forma clavata* in the fauna of zone V; this form accounts for 78–85 % of the fauna in the lower part and 89–93 % in the upper part. *Cassidulina crassa* is next in abundance with a percentage of 10–13 in the lower part decreasing to 4–5 % in the upper part of zone V. The most common accessory species are *Bulimina marginata* d'Orbigny, *Virgulina leoblichi* Feyling-Hanssen, *Islandiella norcrossi* (Cushman), *I. teretis* (Tappan) and *Nonion labradoricum* (Dawson). Each of these species usually accounts for up to 1 % of the total fauna. In most of the samples occur in addition single specimens of Polymorphinidae, *Trifarina fluens* (Todd), *Bolivina pseudoplicata* Heron-Allen and Earland, *Buccella frigida* (Cushman), *Hyalinea baltica* (Schroeter), *Cibicides lobatulus* (Walker and Jacob), *Astrononion gallowayi* Loeblich and Tappan, *Elphidium albiumbilicatum* (Weiss), *E. asklundi* Brotzen, *E. bartletti* Cushman, *E. groenlandicum* Cushman and *Protelphidium orbiculare* (Brady).

The number of specimens is about 1000 to 2000 per 100 g sediment, but the faunal diversity is very low in the assemblages from zone V; in the lower part of the zone it varies from 2 to 5, decreasing to only 2 in the upper part. The percentages of boreal specimens are very low (1–2 %), and the climate thus seems to have been high-arctic. The fauna indicates extreme environments; the temperature was lower and the water shallower than in zone VI (Konradi, present paper). The high dominance of *Elphidium excavatum* and the decreasing percentages of *Cassidulina crassa* in the upper part of zone V, together with the gradually coarser sediment, may indicate decreasing water depth upward in this zone. It may also indicate a lowered salinity, for instance caused by the increased influence of meltwater. The depth tolerance of *Cassidulina crassa* is not known exactly, but it seems not to be frequent in shallow water (Buzas 1965, Nagy 1965). The water depth in zone V was probably about 10–20 m; it must at any rate have been shallower than in the underlying zone VI.

Zone IV (86.5–73.5 m.b.s.) is about 13 m thick, and consists of a very mixed sediment series with alternating layers of clay, sandy clay and sand, and with a high content of stones. The content of Quaternary foraminifera in zone IV varies from about 100 to 700 specimens per 100 g sediment. *Elphidium excavatum* is the dominant species with a percentage of 43–73 % of the total fauna, whereas *Cassidulina crassa* usually amounts to 5–25 %. The most important of the accessory species are *Elphidium albiumbilicatum* (usually 3–15 %), *Bulimina marginata* (usually 4–10 %), *Buccella frigida* and *Protelphidium orbiculare*, each with a percentage of up to 5 %. *Islandiella norcrossi* and *Nonion labradoricum* each normally account for up to 2 % of the fauna.

The present assemblage is characterized by the rather marked influence of boreal foraminifera, normally about 10–20 % of the fauna. The faunal diversity is also higher (6–11) than in zone V. This indicates a less extreme marine environment and a milder climate than in the other arctic zones of the Skærumhede II boring.

Elphidium albiumbilicatum was originally described from the interglacial Gardiners Clay of Long Island, New York (Weiss 1954), and is frequent also in Recent boreal shallow water environments at depths of less than 20 m (Lutze 1965, Risdal 1964, Knudsen 1971). *E. albiumbilicatum* tolerates very low salinity. *Bulimina marginata* also prefers temperate water (Nørvang 1945), and is most frequent at water depths of more than 15–20 m, where it usually dominates the fauna (Höglund 1947, Risdal 1964). *B. marginata* does not seem to tolerate low salinities (Lutze 1965).

It is difficult to give exact conclusions about the ecological conditions during the deposition of zone IV. The water was probably no shallower than in zone V, i.e. about 10–20 m, and the salinity may have been somewhat lowered, perhaps owing to a greater supply of fresh water during the milder conditions. The rather low number of specimens per 100 g sediment presumably results from a higher rate of sedimentation in zone IV.

Zone III (73.5–72.5 m.b.s.) is only about 1 m thick and the sediment is clay and sandy clay with stones. The samples contain rich foraminifera faunas both with respect to number of species and number of specimens. *Cassidulina crassa* is the dominant species with percentages of 41 and 49 %, whereas *Elphidium excavatum* is second most abundant with 28 and 32 %. The most frequent accessory species are *Islandiella norcrossi* (7 and 9 %) and *Nonion labradoricum* (2 %). The species *Bulimina marginata, Virgulina loeblichi, Trifarina fluens, Islandiella teretis, Buccella frigida, Cibicides lobatulus, Astrononion gallowayi* and *Elphidium groenlandicum* each occur with frequencies of about 1 % of the total fauna. The faunal diversity is high, 12 and 13, but the boreal element is only 3 and 4 %, which is less than in the preceding zone. Among the boreal species are *Bulimina marginata, Uvigerina peregrina* Cushman, *Hyalinea baltica, Nonion barleeanum,* and *Elphidium albiumbilicatum.*

The present faunas are similar to those of zone VI. They indicate favourable marine conditions with water depths of more than 20 m and a decreasing temperature.

Zone II (72.5–66.5 m.b.s.) is about 6 m thick, and consists mainly of clay and silt with a few scattered gravel-size particles. The content of foraminifera is high, 4000–10,000 per 100 g sediment in the lower part of this zone, decreasing to 500–2000 in the upper part. *Elphidium excavatum* (53–78 %) and *Cassidulina crassa* (18–43 %) are the dominant species. The most common accessory foraminifera are *Islandiella norcrossi, Nonion labradoricum* and *Elphidium asklundi* in the lower part of the zone, whereas *Elphidium albiumbilicatum* is more common in the upper part. Single specimens of *Bulimina marginata, Virgulina loeblichi, Trifarina fluens, Islandiella teretis, Buccella frigida, Cibicides lobatulus* and *Protelphidium orbiculare* occur in most of the samples.

The faunal diversity is very low in zone II, usually only 2–3, and the influence of boreal foraminifera is negligible, mostly 0–2 % of the total fauna. The present faunas indicate high-arctic conditions. The water was probably not quite as deep as in zone III, but still no shallower than about 20 m.

Zone I is more than 20 m thick, with the lower boundary at about 66.5 m.b.s. The sediments are mostly clay and silt with scattered gravel-size particles, but in the upper part the deposits are more sandy. The number of foraminifera is rather low in this zone, usually between 100 and 300 specimens per 100 g sediment. *Elphidium excavatum* and *Cassidulina crassa* are dominant with percentages of 44–59 and 32–46 respectively. The most common accessory species are *Bulimina marginata, Buccella frigida, Nonion labradoricum* and *Elphidium albiumbilicatum*. The faunal diversity is higher than in zone II, usually between 4 and 8. A higher content of boreal specimens in the faunas, mostly 3–8 %, is also characteristic. The commonest of the boreal species are *Bulimina marginata* and *Elphidium albiumbilicatum*.

The assemblages of zone I indicate milder conditions than in zone II, but the climate was colder than during deposition of zone IV. The water depth was probably not very much different from that in zone II, i.e. about 20 m, and there is no faunal indication of decreasing water depth in the upper part of the zone. The low number of specimens in samples from zone I is probably due to a rich supply of sediment to the area during the milder conditions, and the presence of *Elphidium albiumbilicatum* in the faunas may also indicate lowered salinity.

As mentioned above, the upper boundary of the marine sequence is not well-defined. Samples have been analysed for their content of foraminifera up to 35 m.b.s. Samples up to about 45 m.b.s. contain foraminifera faunas. From 45 m to 40 m there are only very few badly preserved, probably redeposited specimens, and above 40 m there are no foraminifera. The faunal composition does not change in the upper part of zone I, but the sediment becomes coarser. The supply of sediment to the sea was probably greater, with no change in the marine conditions for the foraminifera fauna. From a depth of about 45 m the influence of fresh sediment-loaded melt-water was probably so great that the deposits may be considered glacifluvial and non-marine.

Correlations

On the basis of the different foraminifera assemblages in the upper part of the marine sequence in Skærumhede it has been possible to make a subdivision into five assemblage-zones as described above. The ecological succession through the upper four of these zones corresponds closely to the succession in the Older *Yoldia* Clay of Hirtshals Coast Cliff, which was described by A.-L. Andersen (1971). Furthermore, zones I and II in Skærumhede II show the same ecological succession as the upper three zones of the

Sandnes Clay in SW Norway described by Feyling-Hanssen (1966 and 1971).

Zone I in Skærumhede II (fig. 8) may be correlated with zone A of the Older *Yoldia* Clay in Hirtshals (A.-L. Andersen 1971), and also with zone 1 of the Sandnes Clay (Feyling-Hanssen 1971). The assemblages are arctic with a content of a few percent of boreal foraminifera. The slightly higher percentages of *Elphidium albiumbilicatum* and the more diluted faunas in zone I of the Skærumhede II boring may indicate a greater supply of fresh sediment-loaded meltwater into this area than into the Hirtshals and the Sandnes areas. Zone B in Hirtshals contains very few foraminifera, and it is supposed to have been deposited during unfavourable marine conditions (A.-L. Andersen 1971). This zone, which was correlated with zone 2 of the Sandnes Clay, can probably be correlated with the lower part of zone I in Skærumhede II (fig. 8).

Radiocarbon datings of the Sandnes Clay gave ages between 28,000 and 40,000 B.P., and Feyling-Hanssen (1971) supposed the deposits to belong to an interstadial of Middle Weichselian age, which he called the Sandnes Interstadial. It is thus of approximately the same age as the Swedish Götaälv Interstadial (Brotzen 1961), dated at about 26,000–30,000 B.P. and the Younger Dösebacka-Ellesbo Interstadial (Hillefors 1969), dated at 24,000–30,000 B.P.

Zone II in Skærumhede II can be correlated with zone C in Hirtshals and zone 3 in Sandnes. All three assemblages indicate high-arctic conditions, the Sandnes and Hirtshals faunas probably belonging to shallower water than the Skærumhede II fauna of this zone. A.-L. Andersen (1971) described a thinning-out of the fauna in the upper part of zone C in Hirtshals, and the same tendency is found in zone II of the Skærumhede boring (fig. 10).

Zone III in Skærumhede II contains an assemblage very close to the zone D assemblage in Hirtshals. The ecological indications of the faunas in these zones are similar, and show the transition from rather mild conditions to the high-arctic conditions of zone II and zone C, respectively.

In a Pleistocene silt at Holmstrup, Sjælland, Buch (Petersen and Buch 1974) has found a succession of foraminifera faunas, which seem to be correlatable with the faunas in zone III and the uppermost part of zone IV.

Zone IV in Skærumhede II, which is characterized by the rather strong boreal element in the faunas can be correlated with zones E and F in Hirtshals (fig. 8). The ecological indications of zone F in Hirtshals resemble those of the lower part of zone IV in Skærumhede II, whereas the fauna of zone E in Hirtshals seems to indicate shallower water than zone IV, probably less than 10 m (A.-L. Andersen 1971). Two radiocarbon datings made on material from zone E in Hirtshals gave ages of more than 35,000 years, and A.-L. Andersen (1971) suggested that zone E might belong either to an earlier part of the Middle Weichselian, or perhaps to the Brørup Interstadial at about 58,000 B.P. (S. T. Andersen 1961). As the boreal influence is rather strong, it seems most probable that zone IV in Skærumhede II, and also the zones E and F in Hirtshals, belong to the Early Weichselian Brørup Interstadial.

Zone V in Skærumhede II indicates high-arctic conditions and is not found in Hirtshals Coast Cliff. The same applies to the underlying zones VI–IX, described by Konradi in the present paper. The slight climatic amelioration, which is indicated by the *zone VI* assemblages, may suggest a correlation of this zone with the Early Weichselian Rodebæk Interstadial (S. T. Andersen 1961), whereas zone V mirrors the cold spell between this and the following Brørup Interstadial.

Mainly on the basis of sediments and mollusc faunas A.-L. Andersen (1971) correlated zones A-F in the Older *Yoldia* Clay of Hirtshals with the upper c. 30 m of the *Portlandia arctica* Zone and the lowermost part of the glacifluvial deposits in the old Skærumhede boring (Jessen *et al.* 1910). The present correlation of zones I–IV in the Skærumhede II boring with zones A–F in Hirtshals confirms A.-L. Andersen's correlation (fig. 8). The lowermost c. 12 m of the deposits which Jessen *et al.* (1910) considered glacifluvial are included in the marine sequence in the Skærumhede II boring.

Conclusions (Peter B. Konradi and Karen Luise Knudsen)

The chart fig. 8 shows an attempt at a stratigraphical correlation of the assemblage-zones I–IX in the Skærumhede II boring with other divisions of the Late Quaternary. Zones IX and VIII, which contain boreo-lusitanian to boreal faunas, are considered to belong to the Eemian Interglacial. These assemblages are followed by the arctic faunas of zone VII, probably indicating the first Weichselian cooling. The slight amelioration indicated by the foraminifera assemblage in zone VI can perhaps be correlated with the Rodebæk Interstadial, whereas zone IV with the stronger boreal influence in the fauna is suggested to belong to the Brørup Interstadial. The high-arctic faunas of zone V may thus represent the stadial period between the two Early Weichselian interstadials. The zone III assemblage shows the transition from the boreo-arctic zone IV to another stadial represented by the high-arctic faunas of zone II. The assemblage of the uppermost zone I again indicates slightly milder conditions, and this zone probably belongs to the Middle Weichselian Interstadial.

<table>
<tr><th></th><th>STAGES</th><th>SKÆRUMHEDE II</th><th>SKÆRUMHEDE I</th><th>HIRTSHALS</th></tr>
<tr><td rowspan="10">WEICHSELIAN</td><td>MAIN WEICHSELIAN STADIAL</td><td>GLACIFLUVIAL</td><td>GLACIFLUVIAL</td><td>RESIDUAL BOULDERS</td></tr>
<tr><td rowspan="2">INTERSTADIAL</td><td rowspan="2">ZONE I</td><td rowspan="9">PORTLANDIA ARCTICA ZONE</td><td>ZONE A</td></tr>
<tr><td>ZONE B</td></tr>
<tr><td rowspan="2">STADIAL</td><td>ZONE II</td><td>ZONE C</td></tr>
<tr><td>ZONE III</td><td>ZONE D</td></tr>
<tr><td rowspan="2">BRØRUP INTERSTADIAL</td><td rowspan="2">ZONE IV</td><td>ZONE E</td></tr>
<tr><td>ZONE F</td></tr>
<tr><td>STADIAL</td><td>ZONE V</td><td rowspan="5"></td></tr>
<tr><td>RODEBÆK INTERSTADIAL</td><td>ZONE VI</td></tr>
<tr><td>COOLING</td><td>ZONE VII</td></tr>
<tr><td rowspan="2">EEMIAN</td><td rowspan="2">EEMIAN INTERGLACIAL</td><td>ZONE VIII</td><td>ABRA NITIDA ZONE</td></tr>
<tr><td>ZONE IX</td><td>TURRITELLA TEREBRA ZONE</td></tr>
</table>

Fig. 8. Stratigraphical correlation of the assemblage-zones in the Skærumhede II boring.

The present correlations seem to indicate a complete marine succession in Skærumhede II from the Eemian and through the early and middle Weichselian. The Weichselian glaciers do not appear to have reached Vendsyssel until the main Weichselian advance, about 18,000–20,000 years ago.

Dansk sammendrag

I 1905 udførtes en undersøgelsesboring ved Skærumhede ca. 10 km vest for Frederikshavn (Jessen *et al.* 1910). Mellem to glaciale horisonter påvistes boreale og arktiske marine aflejringer, og forfatterne formodede, at den marine sedimentation havde fundet sted i den sidste interglaciale og begyndelsen af den påfølgende glaciale periode. Da denne antagelse siden da flere gange er blevet anfægtet, besluttede Danmarks geologiske Undersøgelse at udføre en ny boring med forbedret prøvetagningsteknik. Den nye boring blev udført i 1971–1972 med D.G.U.s 12"-boregrej, kun få meter fra det gamle borested.

Den forbedrede boreteknik ved Skærumhede II boringen gør det muligt, udelukkende på grundlag af lithologiske undersøgelser, at opdele de gennemborede jordlag i en række sediment-zoner. Sedimentationen synes ikke at være foregået uden afbrydelser, idet undersøgelserne viser, at der flere steder findes en pludselig forandring fra en sedimenttype til en anden. Disse ændringer antages at være opstået ved en skiften mellem sedimentation og erosion. Særlig voldsomme er ændringerne i et interval svarende til den nedre del af Skærumhede I boringens *Portlandia arctica* Zone. Afvekslende med fedt ler forekommer grus, sten og morænelersklumper, der antages at være transporteret hertil ved hjælp af isflager og isbjerge. En extrem ændring af stenselskabet midt i dette interval tyder på, at det sedimenterede materiale har haft forskellige oprindelsessteder.

Bearbejdningen af molluskerne i 241 prøver fra Skærumhede II viser at der fra de ældste aflejringer bestående af et *Turritella communis* blødbundssamfund kan følges en udvikling til et arktisk samfund i et miljø med drivis aflejringer.

Portlandia arctica Zonen som påvistes i den gamle boring er blevet inddelt i, fra neden at regne: *Turritella erosa, Balanus crenatus* og *Macoma calcarea* zonerne.

Indenfor *Balanus crenatus* Zonen er der fundet et fragment af *Zirphaea crispata.* Men dette anses ikke for tilstrækkeligt bevis for en boreal udvikling, således at molluskerne på basis af dette skulle kunne støtte den af mikropalaeontologerne fremsatte tanke om korrelation til Brørup Interstadialet.

Forskellen mellem den boreo–lusitanske fauna i Skærumhede seriens nedre del (i den nye boring), og den som kendes fra det typiske Eem i det sydlige Danmark, anses for at kunne være betinget af en facies forskel.

Der er foretaget en kvantitativ analyse af fossile foraminiferfaunaer fra Skærumhede II boringen. På grundlag af forskellige faunaselskaber er den marine lagserie mellem c. 45 m og 122 m's dybde blevet inddelt i 9 fauna-zoner (I-IX). Faunaerne er sammenlignet med recente og fossile faunaselskaber, og på dette grundlag er der forsøgt palæoøkologiske og stratigrafiske tolkninger af zonerne.

Zone IX, som er den dybeste, indeholder en sydlig boreal til boreo-lusitansk foraminiferfauna, mens faunaen i zone VIII er boreal med et indslag af enkelte koldere arter. Disse to zoner menes at kunne henføres til Eem Interglacialtiden. Sammenlignet med de marine zoner, som er beskrevet fra den første Skærumhede boring (Jessen *et al.* 1910), synes zone IX at kunne korreleres med den allerøverste del af *Turritella terebra* Zonen, mens zone VIII menes at svare til *Abra nitida* Zonen.

De øverste 7 zoner i Skærumhede II boringen indeholder arktiske til boreo-arktiske faunaselskaber, og kan korreleres med *Portlandia arctica* Zonen og den nederste del af de formodede glaciofluviale aflejringer i den første Skærumhede boring (Jessen *et al.* 1910). Faunaen i zone VII er arktisk, og afspejler sandsynligvis den første kolde periode i Weichsel-istiden. Zone VI indeholder en fauna, som står meget nær faunaen i zone VII, men et borealt indslag indicerer, at zone VI muligvis kan korreleres med Rodebæk Interstadial. Efter et nyt stadial med højarktisk foraminiferfauna, repræsenteret ved zone V, følger zone IV med et stærkt borealt indslag i faunaen. Zone IV kan muligvis henføres til Brørup Interstadial. Faunaen i zone III er arktisk med et svagt borealt indslag, og viser overgangen fra den boreo-arktiske fauna i zone IV til et nyt stadial, repræsenteret af det højarktiske zone II faunaselskab.

Faunaen i zone I indicerer igen mildere forhold, og denne zone synes at tilhøre et interstadial i det mellemste Weichsel, svarende til bl. a. Sandnes Interstadialet på Jæren, dateret til c. 28,000–40,000 BP (Feyling-Hanssen 1971), og det svenske Götaälv Interstadial, c. 26,000–30,000 BP (Brotzen 1961) og Yngre Dösebacka-Ellesbo Interstadialet, c. 24,000–30,000 BP (Hillefors 1969).

Den marine lagserie i Skærumhede II boringen synes således at indeholde dels aflejringer fra Eem Interglacial tiden, dels en marin lagserie fra Weichsel, omfattende 3 interstadialer og 3 stadialer. På grundlag af undersøgelser af foraminiferselskaberne i Skærumhede II boringen, synes Weichsel Istidens gletschere ikke at have nået frem til Vendsyssel før under hovedfremstødet for c. 18,000–20,000 år siden.

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Dislocated tills with Paleogene and Pleistocene marine beds. Tectonics, lithology, macro- and microfossils

Kaj Strand Petersen and Arne Buch

Petersen, Kaj Strand and Buch, Arne: Dislocated tills with Paleogene and Pleistocene marine beds. Tectonics, lithology, macro- and microfossils. *Danm. geol. Unders., Årbog 1973*, pp. 63–91, pls. 8–10. København, 4. oktober 1974.

Paleogene and Pleistocene marine beds in a dislocated till sequence at Holmstrup have been correlated by their macro- and microfossil content. By means of tectonic investigations and statistical evaluation of rock components and derived microfossils, the till has been differentiated into four characteristic groups. It has been attempted to make a correlation of the tills on this basis. The Paleogene part is considered to be an Upper Paleocene deposit with agglutinating foraminifera. A faunistic analysis of foraminifera in the Pleistocene beds is believed to indicate a Weichselian interstadial.

The Holmstrup clay pit, fig. 1, is situated about 500 m west north west of Holmstrup village. The area belongs to the dominating cirque ridges as an elevated part of the southwestern moraine around the till plain near Kundby to the north east. To the south east the large bog "Aamosen" has its outfall south of the area to the "Lille Aamose", a former tunnel valley west of the area. During the late Weichselian glaciation the mouth of this tunnel valley lay to the north, forming the big *sandur* near Bregninge and Saltbækvig. At this time the waters of Storebælt were occupied by another glacier lobe moving towards the north, so that the *sandur* originated in an interlobate area.

The Paleogene deposits form the base of the Quaternary series and often occur as floes, well known from exposures along the southern coast of the peninsula of Røsnæs. Within the Røsnæs area the Eocene plastic clay has been utilised by the firm A/S Leca for the production of "leca-klinker". The authors' work at Holmstrup started when the firm opened a new pit at this locality.

The attractive geological factor of the locality at Holmstrup was that it offered the rare situation in which Quaternary glacial deposits, including a thick marine series, were exposed and resting upon a Tertiary marine clay.

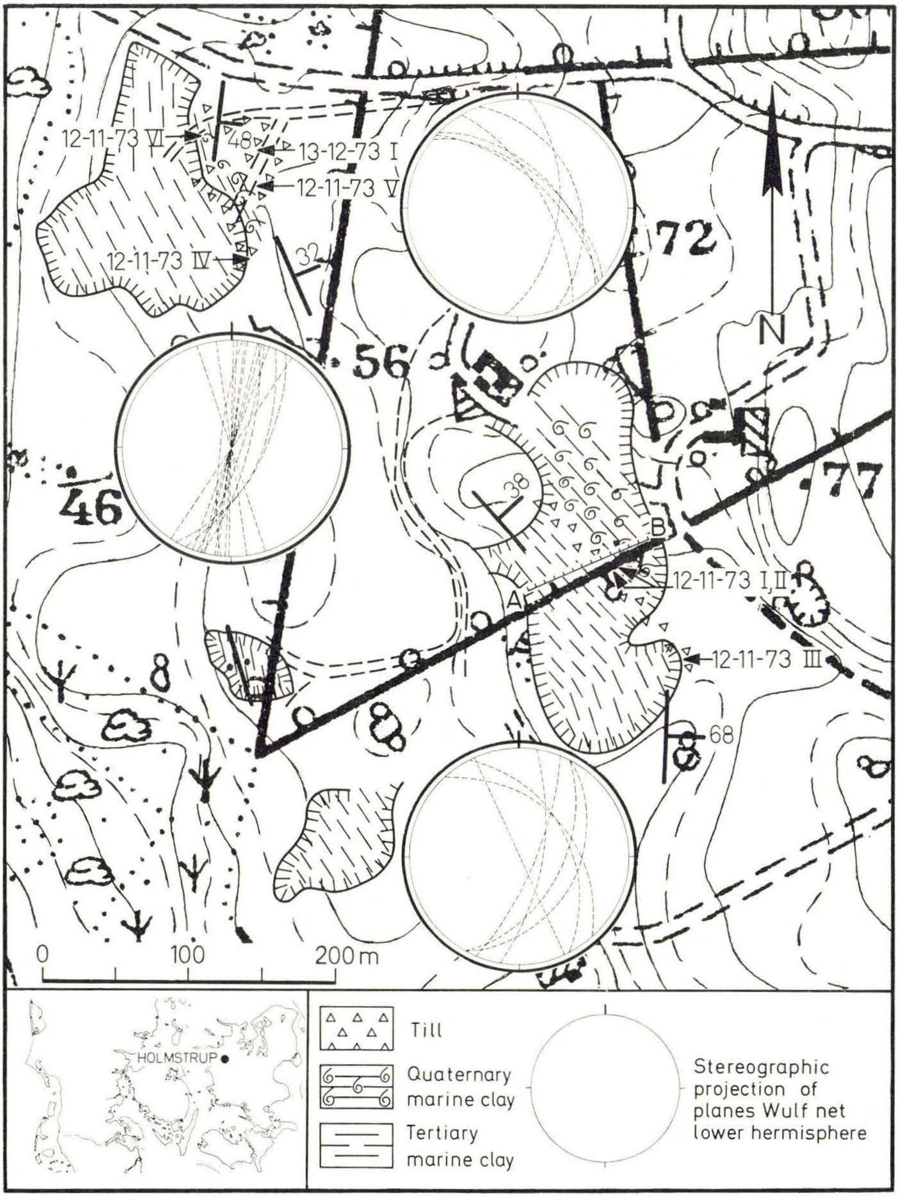


Fig. 1. Map of the Holmstrup clay pit. A–B marks the main profile (near center of map) with indication of sampling in 1968. The combined numbers refer to supplementary sampling in 1973. The level is indicated in meters by figures and contour lines with equidistance 2.5 m. Strike and dip of the sequence is figured.
Authorized reproduction.

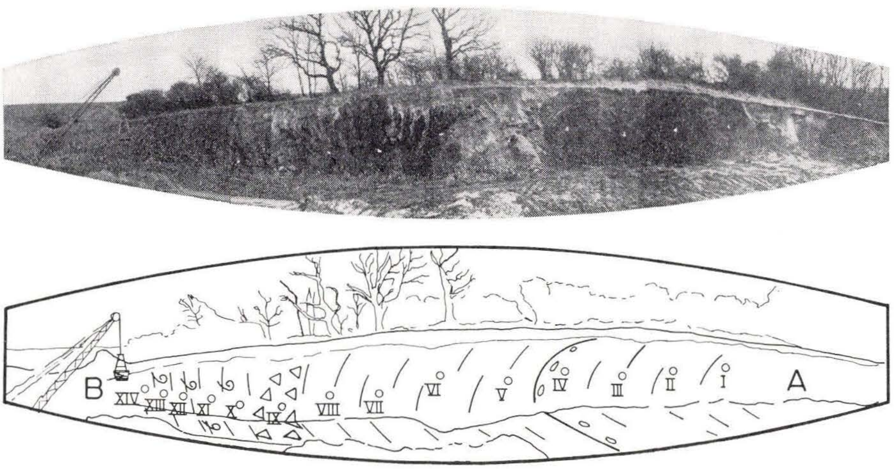


Fig. 2. The main profile viewed from the north. Composition of 4 photos. B–A: N100°–N200°, length 90 m. I–VIII: Paleocene, IX: Till a_1, and X–XIV marine Pleistocene. Phot. KSP. 8.4.1968.

8– 4–68–I	4/1	dark gray
– –II	5–4/1	gray, dark gray, partly 8/6, yellow
– –III	4/1	dark gray, partly 8/8, yellow
– –IV	4/1	dark gray
– –V	5–4/1	gray, dark gray
– –VI	4–3/1	dark gray, very dark gray
– –VII	4/1	dark gray
– –VIII	5/3	brown
– –IX	6–5/2	light brownish gray, grayish brown
– –X	3/1	very dark gray
– –XI	4/1	dark gray
– –XII	4/1	dark gray
– –XIII	4–3/1	dark gray, very dark gray
– –XIV	3/1	very dark gray
12–11–73–I	5/4	yellowish brown
– –II	5/4	yellowish brown
– –III	6/4–6	light yellow brown, brownish yellow
– –IV	5/2	grayish brown
– –V	6/4	light yellowish brown
– –VI	5–4/1	gray, dark gray
13–12–73–I	5/4–6	yellowish brown
– –II	7/2	light gray, partly 7/6, yellow
– –III	5/4–6	yellowish brown

Table 1: The colours of the 23 ground-moist samples from the Holmstrup clay pit. Symbols according to the Munsell Soil Color Charts, 1954, Hue 10 YR.

The marine Quaternary series should make it possible to correlate the different parts of the glacial sequence.

In accordance with the morphological features of the area (Langås) shown on the map fig. 1, the strike of the strata is north-south. To the east and southeast the strata show a dip to the east. The photo, fig. 7, p. 79, shows the contact between the transgressive till c and the underlying strata of dislocated sand and till b which may indicate ice pressure from the east. The designation of the tills has no relationship to similar designations of earlier authors; it is introduced only for the purpose of clarity.

The profile on fig. 2, indicated on the map fig. 1 A–B runs nearly normal to the strike. The colours of all the samples treated are recorded on table 1. Comments on the methods used for the presentation of tectonics, stone counts, and granulometry have been made in a previous paper (Petersen, 1973a) and by Bahnson (1973, pp. 93–94).

Microfossils

Arne Buch

Introduction

The quantitative content of foraminifera and oligostegina has been investigated by a series of analyses of samples from the exposures at Holmstrup. The aims of this investigation were to characterize the different types of sediments in relation to their origin and age.

The survey was initiated with the intention of making an analysis of the foraminifera in the marine Quaternary sediments for comparison with already described sections in Denmark. As a very limited molluscan assemblage was encountered in these layers, it was found necessary to make a supplementary study of the content of foraminifera. During this investigation it was noted that a gradual development existed in the relationship between the pre-Quaternary and Quaternary constituents of the microfossils through the series of samples No. 8–4–68–X–XIV of the main profile. In consequence, our interest in determining the content of derived microfossils in the till, which formed the basis for the marine Quaternary part of the main profile, initiated an investigation. As the results were promising, the next step was to examine larger samples of tills from different places in the exposures especially near to contacts with layers of marine Quaternary sediments. To fulfil the survey, an attempt was made to include the Tertiary marine series in the studies of the microfossils.

Techniques

The treatment of samples for the extraction of the microfossil content follows the standards applied by the micropaleontological laboratory of the Danish Geological Survey, developed during the last twenty years. With a few exceptions the method follows the description in Feyling-Hanssen *et al.* (1971). For disintegration of the sediments the samples were soaked with petroleum and subsequently boiled in water. In this way the chemical damage was avoided which often occurs if the hydrogen peroxide (H_2O_2) method is used. The two sieves used in the washing procedure had mesh diameters of 2 mm for the upper screen and 0.063 mm for the lower screen. It is our experience that especially many foraminifera of a pre-Quaternary origin have diameters just a little below 0.1 mm. The finer mesh is therefore used to make certain that such microfossils will also be extracted. The weight of the samples from the main profile varied between 235 g (sample 8–4–68–XII) and 47 g (sample 8–4–68–VIII). During the investigation this material was supplemented by 718 g of sample 8–4–68–I and by 725 g of sample 8–4–68–VIII, both from the main profile (A–B, fig. 1). Examination of the different layers of till outside the main profile was based on six samples, each of about 1 kg.

Marine Tertiary clay

General description (Kaj Strand Petersen)

The only macroscopic features of the Tertiary clay are the septarian nodules, approximately 1 m long, and two yellow coloured bands occurring as shown on fig. 2. Together they form a trace horizon through the pit. As the appearance of these yellow bands is much like an ash bed, fig. 3, two samples have been examined microscopically for ash particles, but with a negative result. Chemical analyses of these two samples, 19–6–73–I–II and the samples from the main profile, 8–4–68–I–VIII, have been made by the DGU laboratory staff, table 2, and commented upon by senior geologist H. Kristiansen as follows: "For the samples with a positive reaction for sulphur the content has been separately determined by a modification of Eschka's method. The chemical composition of the material is quite uniform and shows the ordinary composition of clay. Sample No. 8–4–68–III, however, gives a relatively high amount of Fe_2O_3; the content of S is probably derived from iron sulphate, Jarosite, in accordance with the higher amount of K_2O and probably also Na_2O". The chemical composition differs from the composition of various strata, including the Røsnæs Clay of a Lower Eocene age, exposed at Røsnæs (Petersen 1973b, fig. 6).

Fig. 3. Part of yellow band in Tertiary marine clay. Chemical analyses: 19–6–73–I–II. Phot. KSP. 19.6.1973.

The grain size analyses, fig. 4, show that the Tertiary clay at Holmstrup has a component of silt.

Foged (1974, personal communication) has analysed a sample of dark grey tertiary marine clay from the northern clay pit. The granulometric curve shows 85 % < 2 μ, median diameter $d_{50} \sim 0.2$ μ and 1 % > 10 μ. A semiquantitative clay mineral analysis on the clay fraction shows ~ 80 % montmorillonite, ~ 20 % illite and trace of kaolin, chlorite, and quartz.

Of macrofossils a single placoid scale, tiny shark teeth, and fragments of teleosteans occur. They are all in such a state of preservation that further determination is not possible.

The microfossil content (Arne Buch)

A series of eight samples, 8–4–68, I–VIII, from the main profile has been studied. Two of the washed residues show a content of foraminifera. The preservation of the fossil material was bad, and no $CaCO_3$ constituents were found. The presence of crystals of gypsum, $CaSO_4$, is understood as to indicate a transformation of all calcareous material in the sediment into gypsum, as a result of post-sedimental chemical activity. Thus one can not

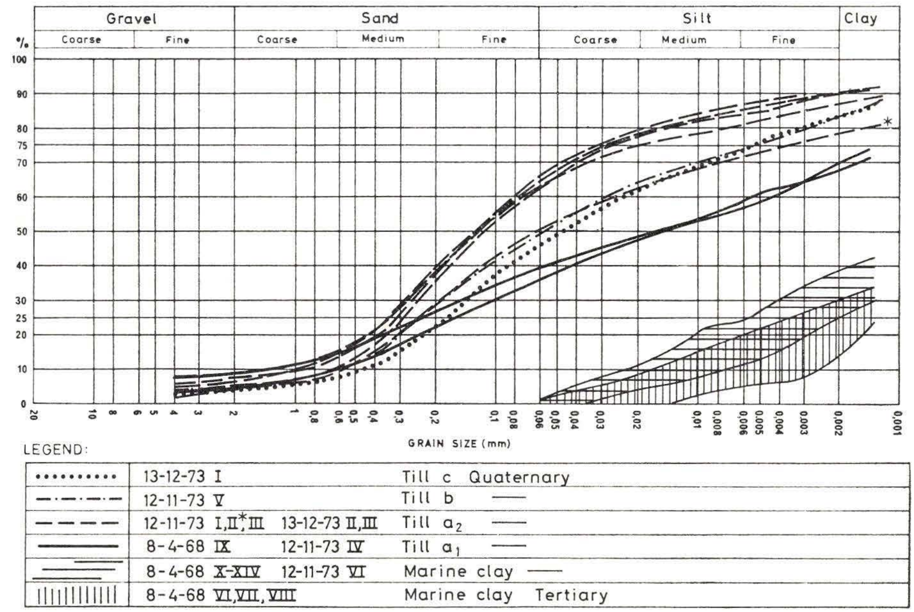


Fig. 4. Diagram of the granulometry of the samples. The curves for till a_1 (in contact with the Tertiary) show higher content of clay than the remaining till samples. One sample from till a_2 (marked with+) incorporates a smear of Tertary clay. Analyses by Henner Bahnson, D.G.U.

Sample No.	8-4-68 I	8-4-68 II	8-4-68 III	8-4-68 IV	8-4-68 V	8-4-68 VI	8-4-68 VII	8-4-68 VIII	19-6-73 I	19-6-73 II
% by weight of dry matter										
Insoluble + SiO_2	83.9	84.6	71.2	83.6	84.1	84.3	84.7	85.0	84.0	85.0
Fe_2O_3	2.39	2.06	8.68	2.37	2.42	2.03	1.92	1.83	1.89	1.52
Al_2O_3	1.7	1.8	2.3	2.3	2.2	1.9	1.8	1.9	1.3	1.7
P_2O_5	0.066	0.044	0.12	0.094	0.077	0.083	0.11	0.031	0.098	0.075
CaO	0.33	0.33	0.43	0.50	0.51	0.45	0.41	0.50	0.42	0.40
MgO	0.31	0.30	0.32	0.38	0.39	0.34	0.41	0.51	0.40	0.40
MnO	0.0038	0.0036	0.0044	0.016	0.0072	0.0054	0.0067	0.017	0.011	0.016
Na_2O	0.27	0.33	0.44	0.27	0.23	0.22	0.24	0.23	0.63	0.48
K_2O	0.52	0.57	1.4	0.62	0.58	0.58	0.47	0.50	0.14	0.27
Loss on ignition 1000^0	9.57	9.23	12.6	8.66	8.66	9.29	8.85	8.70	9.16	9.18
S - total	0/tr.	0.03	1.5	0/tr.	0.06	0/tr.	0.09	0.09	1.3	0.69

Table 2: Results of chemical analyses of the samples from the Tertiary part of the main profile, fig. 2, p. 65, and of two samples, 19–6–73–I–II, from the yellow band, fig. 3. The analyses have been made on component soluble after 2 hrs boiling with aqua regia (⅓ HNO_3 + ⅔ HC_l).

hope for the presence of species of foraminifera with calcareous tests. The obviously fragmental state of the original foraminiferal content does not allow an attempt to make a quantitative evaluation of the assemblage. The foraminifera found in samples 8–4–68–I and VIII all possessed an agglutiated test and represented the following species: *Glomospira charoides* (Jones & Parker); ten Dam 1944, p. 77, *Glomospira gordialis* (Jones & Parker); ten Dam 1944, p. 77, *Glomospira woodi* Haynes 1958, p. 58–59, *Involutina pyrotecnica* Haynes 1958, p. 58–59, and *Involutina cretacea* (Reuss); Haynes 1958, p. 58. (See pl. 9, fig. 5–15).

The differentiation of species within the genera *Glomospira* and *Involutina* as well as the separation from the genus *Glomospira* of another genus *Glomospirella* does not seem to be justified by the variation within the material from this study, which comprises numerous specimens. Further discussion of this question on nomenclature, however, falls outside the scope of this article.

All eight residues contained fragments of plants; samples 8–4–68–VII and VIII furthermore contained some fragments of macrofossils. A greater part of the washed residue of sample 8–4–68–VIII is composed of spicules from *silicispongia*.

The above description of the microfossils of the marine Tertiary clays gives no clue for a precise identification of the stratigraphical horizon of these sediments. Nevertheless, the content of the agglutinating genera and species indicates that the age is most probably Upper Paleocene. The species *Glomospirella woodi* and *Involutina pyrotecnica* were both first described by Haynes (1958) from the Paleocene Pegwell Marls in Kent, England, referred to the Thanetian. *Glomospira gordialis* and *Glomospira charoides* are both mentioned by ten Dam (1944) from the Paleocene of Holland. In Northwest Germany a similar biofacies has been published from Upper Paleocene sediments in cores from boreholes close to Hamburg (Staesche & Hiltermann 1940; Wick 1943).

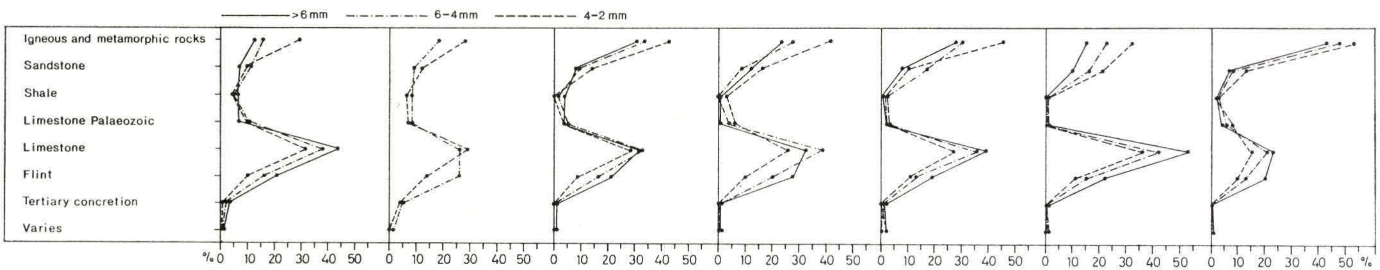
The Quaternary sequence

General description and macrofossils (Kaj Strand Petersen)

The Quaternary part of the profile, fig. 2, starts with a till a_1 (8–4–68–IX). Three supplementing samples have been taken to the south, as in-

Table 3: Stone counts for till samples, Holmstrup. (Figures in brackets indicate weight of sample before splitting. The corresponding N-value refers to a single part after splitting). Graphical representation of the stone-counting results of each fraction within the samples is shown at the bottom.

Till-sample number	12-11-73-IV			8-4-68-IX			12-11-73-I			12-11-73-II			12-11-73-III			12-11-73-V			13.12-73-I		
Fraction	> 6 mm	6-4 mm	4-2 mm	> 6 mm	6-4 mm	4-2 mm	> 6 mm	6-4 mm	4-2 mm	> 6 mm	6-4 mm	4-2 mm	> 6 mm	6-4 mm	4-2 mm	> 6 mm	6-4 mm	4-2 mm	> 6 mm	6-4 mm	4-2 mm
Weight of sample, grams		6980			1880			9724			7730			9185			9488			11120	
Weight of stones, grams	380.6	103.1	(144.7)	100.3	30.5	27.5	677.0	152.7	(191.7)	432.1	102.5	(125.1)	484.5	158.0	202.0	1089.0	133.8	(154.2)	265.0	(124.5)	(179.0)
Number of stones : N	123	307	430	24	110	677	173	334	299	150	270	565	204	375	410	185	321	314	159	304	440
In % of N																					
Igneous and metamorphic rocks	13.0	16.0	29.8		18.2	28.0	31.2	33.6	42.5	24.0	27.8	42.0	28.4	29.8	45.8	14.6	23.1	31.5	42.8	48.4	52.8
Sandstone	6.5	10.7	10.2		9.1	11.8	8.1	9.0	14.4	12.0	0.5	11.9	8.3	16.5	9.7	9.7	15.9	21.4	6.9	8.2	12.5
Shale	5.7	5.2	5.3		8.2	6.2	3.4	2.1	0.0	1.3	0.3	3.1	0.0	1.6	1.4	0.5	1.2	0.0	1.8	3.2	2.2
Limestone Palaeozoic	6.5	10.1	10.7		8.2	7.2	3.4	5.4	4.0	0.6	3.7	5.5	1.9	2.4	3.4	0.5	0.9	0.6	4.4	5.9	7.5
Limestone	43.9	38.1	31.6		25.5	28.7	31.7	33.2	29.4	32.6	38.9	26.0	39.2	35.7	27.3	52.5	42.4	34.5	22.6	21.0	14.5
Flint	21.1	15.6	10.2		26.4	13.4	20.8	16.2	9.0	28.0	19.6	10.2	19.1	13.0	10.5	22.2	15.2	11.1	20.2	12.5	9.7
Tertiary concretion	2.4	3.5	1.1		3.6	4.3	0.5	0.3	0.3	0.6	0.7	0.3	0.9	0.8	0.2	0.0	0.3	0.6	0.0	0.0	0.0
Varies	0.8	0.6	0.9		0.9	0.4	0.5	0.3	0.3	0.6	0.3	0.8	1.9	0.2	1.4	0.0	0.9	0.3	1.2	0.6	0.6
Stone-count quotient	1.62	0.97	0.34		1.39	0.48	0.67	0.48	0.21	1.17	0.71	0.24	0.67	0.44	0.23	1.52	0.66	0.26	0.47	0.26	0.18



dicated on the map, fig. 1, called: 12–11–73–I–III. The stone content is figured in table 3, and shown as a graphical representation of the fraction 4–6 mm on fig. 5. Because of a higher content of igneous and metamorphic rocks, and a lower proportion of shale and Paleozoic limestone in the upper part of this till (12–11–73–I–III), this has been figured separately as till a_2, and (8–4–68–IX) as till a_1 (see fig. 5). This difference is probably only the result of the successive deposition of the till. The smaller content of Tertiary concretions found in till a_2 compared with till a_1 reflects that till a_2 was less in contact with the pre-Quaternary surface than was till a_1. The granulometric composition reflects this difference in the clay content, fig. 4. To complete the description it is worth mentioning the occurrence of fragmental material of molluscs from the Paleocene, from which a gastropod, *Cylichna discifera,* is shown on pl. 10, fig. 3 in till a_2, sample 12–11–73–III.

The Quaternary marine clay (samples 8–4–68–X–XIV) has a granulometric composition (fig. 4) not very different from the Upper Paleocene marine clay, so that both might be characterized as silty clay. Small concretions also occur. In a fresh profile it is quite difficult to distinguish between these two clays with respect to their colour (table 1, p. 65). On drying, the Quaternary marine clay takes on a greenish tone. This could be the reason why part of such a Quaternary marine clay from the old boring at Nordruplund, north east of Slagelse, was first referred to the Tertiary (Ødum 1933, p. 10).

The five samples 8–4–68–X–XIV all contain shell material totally dominated by *Macoma calcarea,* which is found in abundance in certain layers, plate 10, fig. 5. All the specimens are fractured but pairs of valves are still in their original position, fig. 6, p. 77. Ophiuroidean vertebrae and arms are found in samples X and XIV. A dominance of *Macoma calcarea* is known from the nearby locality of Høve (Milthers 1900).

In the material ⟩ 0.5 mm, used for the study of macrofossils, the inorganic component represents 0.5 ‰, slightly higher in the two samples next to the till a_2: 0.9 ‰ and 1.6 ‰. This shows that the sedimentation has not been influenced by ice-rafted material, as is the case in part of the marine sequence at the borehole Skærumhede II (Bahnson *et al.* 1974).

The microfossil content (Arne Buch)

Till a_1. Sample 8–4–68–IX of the main profile represents a till (a_1) which separates the marine Tertiary clays from the layers of marine Quaternary sediments.

The total microfossil content was 1085 specimens of foraminifera in 212.70 g of sediment, equal to 510 specimens per 100 g of sediment.

	number	percent
Quaternary foraminifera:		
Elphidium excavatum clavatum	11	1
Cassidulina crassa	2	0.2
Protelphidium orbiculare	1	0.1
Bulimina marginata	1	0.1
	15	1.4
Upper Cretaceous foraminifera:		
Heterohelix spp.	205	19
Globigerinidae	about 120	about 11
	about 340	about 31.5

Of the remaining 744 specimens, about 100 were Globigerinids of supposed Paleocene age. A total numerical analysis was not carried out, but to give an impression of which genera and species were encountered the following derived forms are listed:

Of Upper Cretaceous origin – *Pseudouvigerina cristata*
Bolivinoides delicatula
Guembelitria sp.
Pyramidina sp.
Bulimina spp.
Polymorphinidae
Tappanina-group
Nodosariidae

and of Paleocene origin – *Bulimina midwayensis*
Bulimina trigonalis
Bulimina spp.
Praeglobobulimina ovata
Bolivinoides peterssoni
Pulsiphonina sp.
Gavelinella lellingensis

The ratio between Cretaceous and Paleocene foraminifera might be estimated to about 60 to 40. In the light of the composition of the microfossil content in other Quaternary samples to be described in the following text it must be emphasized that the residue of sample 8–4–68–IX did not contain any Oligostegina (see p. 85). The derived foraminifera of Paleocene origin listed here are probably an indication of material older than the sediments (8–4–68–I–VIII) stratigraphically basal to the till a_1 (8–4–68–IX) in the main profile (fig. 1, A–B). Finally, attention is drawn to the element of derived foraminifera of marine Quaternary origin, which indicates that the basal till (a_1) incorporates some reworked material, presumably from a marine Pleistocene deposit older than the marine Holmstrup Pleistocene.

Marine Quaternary clay. The remaining part of the samples from the main profile (fig. 1, A–B), i.e. 8–4–68–X–XIV, were collected from the marine clays resting upon the till (a_1). The washed residues showed that the faunal composition of the foraminifera in the five samples was rather uniform, with *Elphidium excavatum clavatum* and *Cassidulina crassa* together making up the dominating part (77.9 %) of the assemblage and with *Nonion labradoricum* as a designating attending species. All of the samples show an admixture of pre-Quaternary microfossils, predominantly of Upper Cretaceous origin. In sample 8–4–68–XIV the following distribution was encountered:

Quaternary species:	number	percent
Cassidulina crassa	246	46.4
Elphidium excavatum clavatum	167	31.5
Quinqueloculina stalkeri	15	2.8
Polymorphinidae	14	2.6
Virgulina sp. 1	9	1.7
Virgulina schreibersiana	7	1.3
Eoponidella laesoeensis	7	1.3
Elphidium sp. (very small specimens)	6	1.1
Nonion labradoricum	4	0.7
Quinqueloculina seminulum	4	0.7
Triloculina trihedra	4	0.7
Epistominella cf. takayanagii	4	0.7
Elphidium asklundi	3	0.5
Protelphidium orbiculare	3	0.5
Nonion labradoricum	2	0.4
Islandiella teretis	2	0.4
Elphidium subarcticum	1	0.2
Elphidium cf. subarcticum	1	0.2
Elphidium incertum	1	0.2
Buccella frigida	1	0.2
Bulimina marginata	1	0.2
Virgulina fusiformis	1	0.2
Lagena distoma	1	0.2
Oolina melo	1	0.2
Parafissurina fusiliformis	1	0.2
Fissurina danica	1	0.2
juvinile forms	3	0.5
fragments non det.	20	3.8
	530	99.6

Derived pre-Quaternary microfossils of an Upper Cretaceous origin (number of specimens in parenthesis): *Oligostegina* (93), *Heterohelix striata* group (24), *Guembelitria spp.* (6), *Pseudotextularia elegans* (1), *Globigerinidae* (19), *Pyramidina sp.* (3), other foraminifera (12). Number of derived microfossils: 158. In sample 8–4–68–XIII the distribution of microfossils was as follows:

Quaternary species:	number	percent
Elphidium excavatum clavatum	465	73.3
Cassidulina crassa	128	20.2
Protelphidium orbiculare	11	1.7
Buccella frigida	8	1.3
Nonion labradoricum	5	0.8
Polymorphinidae	4	0.6
Elphidium albiumbilicatum	3	0.5
Elphidium incertum	3	0.5
Elphidium subarcticum	3	0.5
Elphidium asklundi	2	0.3
Eoponidella laesoeensis	2	0.3
	634	100.0

Derived microfossils of Upper Cretaceous origin:		
Oligostegina	53	
Foraminifera	74	127
Total of microfossils counted		761

Observations outside the main profile

Kaj Strand Petersen

Further exploitation in the pit revealed that the sequence described above is repeated to the north west within the area shown on map fig. 1, but it occurs at a lower level so that according to the stratification planes (see stereograms fig. 1) it might belong to another sequence within an imbricate structure. In this floe, the Quaternary marine clay series is squeezed, exposing a slickenside in the contact with the sand and till deposits. As the exploitation worked through its first level it appeared that part of the Quaternary sequence had moved upon the Palaeocene marine clay from east to west, and therefore parts of the Quaternary marine clay were found in the contorted beds near the surface.

As shown by the colours, table 1, the samples 12–11–73–V and 13–12–

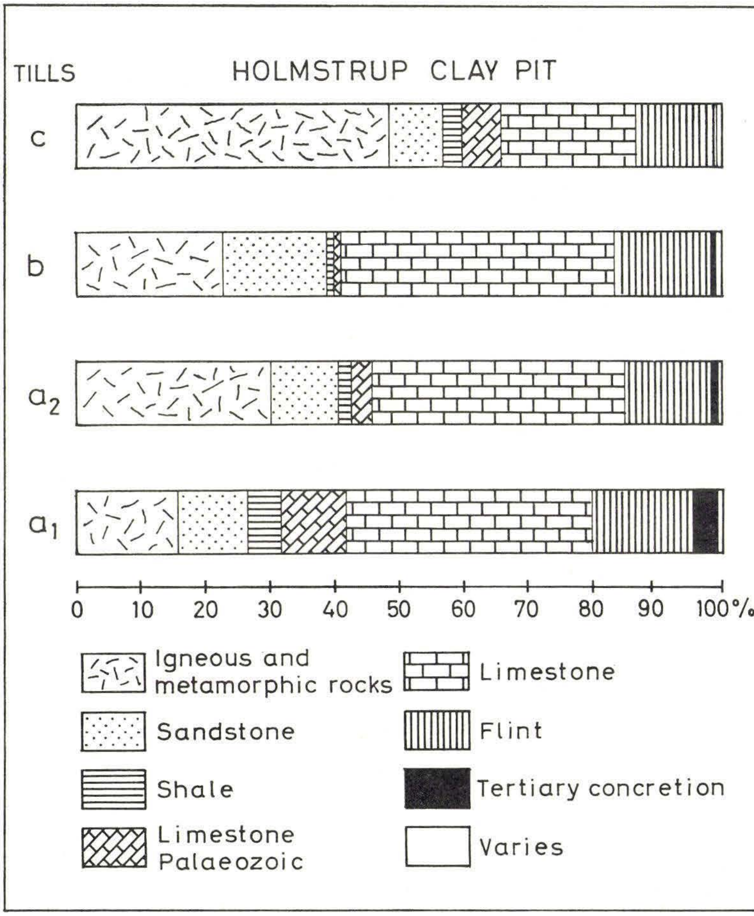


Fig. 5. Graphical representation of the figures in table 3 of the stone counts in the till samples, fraction 4–6 mm; til a_1, represented by one sample (12–11–73–IV), till a_2 by the average of three sample values (12–11–73–I–III), tills b and c each by one sample. Arrangement in accordance with their stratigraphic interrelation.

73–I belong to this elevated part, characterized by some iron disintegration, while the samples 12–11–73–IV and VI have been taken from a lower level in the pit.

The trenches through the area made by the exploitational activities give fine exposures, and it has been possible to combine observations from the opposing walls in the trenches, giving good information on the stratification. So although, as mentioned above, the Quaternary marine clay within

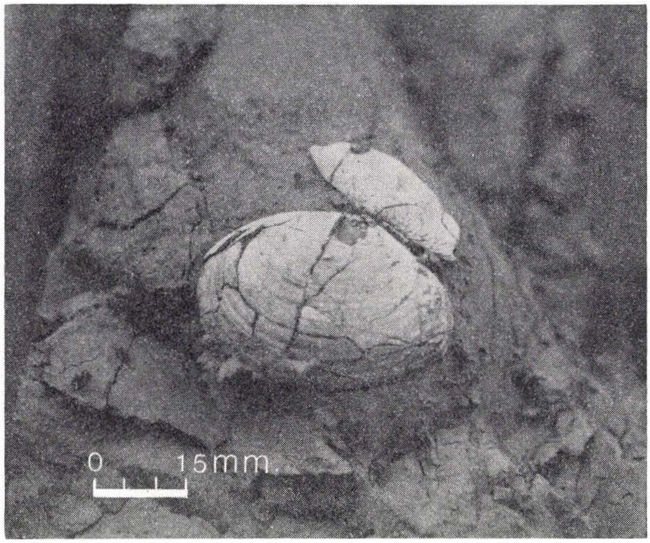


Fig. 6. Fragmented specimen of *Macoma calcarea* photographed in situ in the marine Pleistocene clay of the main profile. Holmstrup. The fragments have remained in their original position. Phot. KSP. 2.4.1968.

this part of the pit is exposed with a lesser thickness, nothing is found to indicate a repetition of strata within each sequence formed during dislocation.

In order to make a correlation with the main profile, samples were taken as shown on the map fig. 1, 12–11–73–IV, close to the Paleocene marine clay, and supplementing samples were taken from the Quaternary marine clay 12–11–73–VI.

The till sample 12–11–73–IV gives a good basis for correlation with 8–4–68–IX, see table 3, and it is conspicuous by its content of Tertiary concretions. Although macrofossils in a better state of preservation are some of the rarer constituents of a till, it should be noticed that *Cancellaria angulifera,* bored by a naticid (Adegoke *et al* 1974), plate 10, fig. 2, from the Paleocene, and echinoidspines of *Tylocidaris abildgaardi* from the Danian, plate 10, fig. 4, occur within this till a_1 (12–11–73–IV). Among the Tertiary concretions some fragmentary burrows with coproliths, plate 10, fig. 1, are found. They occur frequently in Lower Eocene deposits on Røsnæs (Petersen 1969).

The content of Palaeozoic Limestone and Shale is high, up to 10 ‰, compared with the percentage found in the other tills, table 3 and fig. 5, and as demonstrated by Bahnson (1973, fig. 13) this may characterize a deposit from a glacier moving through the Baltic Depression. This is confirmed by the occurrence of a high percentage of this Limestone in the tills on Røsnæs where they belong to the ice advance from the south, as deduced from the ice pressure (Petersen 1973a). It has been demonstrated on the basis of 46 stone counts from tills on the southern coast of Røsnæs (Petersen, unpublished) that the distribution of Shale and Palaeozoic Limestone vary in equal proportions.

In the following discussion of the correlation to profiles outside this area, the information on ice movements, stone composition, and stratigraphic horizons will be combined.

The Quaternary marine clay in this part of the pit (12–11–73–VI) is dominated by *Macoma calcarea; Leda pernula* and *Nucula tenuis* (in a concretionary state of preservation) are also represented. Furthermore, fragments of *Ophiuridea, Echinoidea* and *Cirripedia* were found. The Cirripedes (*Balanus crenatus ?*) show signs of transportation. The percentage weight of washed residue coarser than 0.5 mm was 0.6–0.2; this is equal to the percentage found in the samples from the Quaternary marine clay in the main profile. Sixteen kilograms of marine clay from the locality, represented by 12–11–73–VI, were analyzed. As seen from fig. 4, the same granulometric composition was found as that of the main profile. Furthermore a sample of Quaternary marine clay from the same clay pit (location 12–11–73–VI) has been analysed by Foged (1974, personal communication). The granulometric curve shows 67 % $< 2\ \mu$, median diameter $d_{50} \sim 0.8\ \mu$ and 3 % $> 60\ \mu$. A semiquantitative clay mineral analysis on the clay fraction shows ~ 30 % montmorillonite, ~ 45 % illite, ~ 10 % kaolin and ~ 5 % chlorite, and ~ 10 % mixedlayer. Associated with the clay minerals there are calcite, quartz, and traces of feldspar.

The sparse molluscan fauna indicates boreo-arctic conditions and it is tempting to make a correlation to the nearby locality Nordruplund (Ødum 1933). Here the sticky marine clay, which incorporates no stones and little sand, is found at a depth of 10–27 m below sealevel, probably overlain in situ by two tills. Another marine deposit is found at Holbæk (Ødum 1933). This contains a fauna more prolific in species but with a similar dominance of forms as found at Holmstrup. In addition, boreo – lusitanian faunas are known from deposits occurring as floes in the tills at Høng (Ødum 1933) and Røsnæs (Petersen 1973) as well as in situ at Strandegaards Dyrehave (Petersen & Konradi 1974); these have all been referred to the Eemian.

Fig. 7. Part of exposure at point 13–12–73–I (see map, fig. 1) viewed in the direction of the strike N340°. Dip measured; 32°E. – Contorted beds of sand below the transgressive till c. Phot. KSP. 13.12.1973.

The position of till b (12–11–73–V), indicated on the map fig. 1, leads to the conclusion that it is a till younger than the marine sequence at Holmstrup. Till b and till a_2 have much in common in their main lithological components, but till b carries less than 1 percent of Shale, Palaeozoic Limestone and Tertiary concretions, see table 3. The most significant character, however, is shown in the content of derived microfossils from the marine sequence, and their higher quantity than in the other tills (p. 84).

The till c (13–12–73–I) shows a dominance of Igneous and Metamorphic rocks and up to 7.5 percent of Palaeozoic Limestone. No Tertiary concretions are found, see table 3 and fig. 5. In the granulometric composition it resembles till b, see fig. 4. In the profiles it rests on contorted beds of sand superjacent to till b, as demonstrated on fig. 7.

Microfossils in samples outside the main profile (Arne Buch)

From different parts of the Holmstrup clay pit a total of seven samples were subsequently analyzed: 12–11–73–I–VI, and 13–12–73–I. Sample 12–11–73–VI represents marine Pleistocene clay interbedded between two till beds: samples 12–11–73–IV and V.

The marine clay (12–11–73–VI) contained:

Quaternary species:	number	percent
Elphidium excavatum clavatum	350	78.8
Cassidulina crassa	61	13.7
Quinqueloculina stalkeri	9	2.1
Epistominella cf. takayanagii	5	1.1
Nonion labradoricum	3	0.7
Protelphidium orbiculare	3	0.7
Virgulina schreibersiana	2	0.5
Eoponidella laesoeensis	2	0.5
Buliminella elegantissima	1	0.2
Elphidium subarcticum	1	0.2
Parafissurina lateralis carinata	1	0.2
non. det.	6	1.5
	444	100.2

Upper Cretaceous derived microfossils:

Oligostegina	10	
Globigerinidae	14	
Pyramidina sp.	2	
Heterohelix spp.	11	
Rotaliformes	11	
Buliminidae	2	
non. det.	3	53
Total of microfossils counted		497

The total content of microfossils in sample 12–11–73–VI was evaluated to about 1200 specimens. The weight of the analyzed sample was 38.1 g, so the frequency amounts to a value of about 30000 specimens/100 g sample – the largest value obtained in this investigation (table 4).

The remaining six samples each represent 1000 g of Quaternary till.

Sample 12–11–73–IV was collected in the till (a_1) situated between the Tertiary clay and the marine Pleistocene clay (sample 12–11–73–VI) just described.

The total content of microfossils was evaluated to about 30000, equal to 3000/100 g. This figure is based upon a count of 729 foraminifera, which represent the Upper Cretaceous, Paleocene and Pleistocene.

Upper Cretaceous derivates:	
Bolivinoides delicatula	few
Pseudotextularia elegans	few
Heterohelix spp.	170
Guembelitria	41
Upper Cretacous and Paleocene derivates:	
Globigerinidae	209
Paleocene derivates:	
Bulimina trigonalis	few
Robulus sp.	few
Dentalina sp.	few
Marginulina sp.	few
Gavelinella lellingensis	few
Pleistocene derivates:	
Elphidium excavatum clavatum	1
Cassidulina crassa	2
Apart from the foraminifera were found	
Oligostegina	28
Triceratium sp.	21

Remarks: The Upper Cretaceous derived elements show a predominance of *Heterohelix* and *Globigerinids*. The numerical representation of Oligostegina is very low. The Paleocene foraminifera consist partly of relatively large specimens of the above-mentioned species and partly of very small specimens, mainly of rotaliforme genera. *Triceratium sp.* is a diatom which is known to be distributed in Paleocene and Eocene strata in England, Germany and Denmark. The Pleistocene element comprises only 3 specimens, too low a number to be of any significance.

Sample 12–11–73–V originates from a till (b) resting upon the marine Pleistocene clay (sample 12–11–73–VI) so that the three samples: 12–11–73–IV, VI and V together represent a continuous Quaternary sequence, No. IV being the stratigraphically oldest element, and No. V the youngest.

Examination of the washed residue of 12–11–73–V revealed a material consisting of the following microfossils:

Upper Cretaceous derivates:

Oligostegina
Heterohelix spp.
Globigerinids
Gavelinella pertusa
Bolivinoides draco
Robulus rotulatus

Paleocene derivates:

Quadrimorphina halli
Pulsiphonina elegans
Anomalinoides nobolis
Spiroplectammina laevis
Bolivinoides peterssoni
Gavelinella grosserugosa

Pleistocene derivates:

Elphidium excavatum clavatum	abundant
Cassidulina crassa	3
Bulimina marginata	3
Ammonia batavus	2
Elphidium subarcticum	2
Elphidium incertum	2
Protelphidium orbicularis	1

The total number was evaluated to about 15500 microfossils or 1550/100 g. The Oligostegina have a frequency of about 3 %.

Sample 12–11–73–I represents a till (a_2) in a position close to 8–4–68–IX in the main profile. The results of the examination for microfossil derivates were as follows:

Cretaceous elements dominate. About 1/3 of the total number counted were Oligostegina equal to about 28 %. Paleocene foraminifera were next in frequency, about 10 % of the total count, and Pleistocene foraminifera about 4 %.

Sample 12–11–73–II was collected from the same till (a_2) as sample 12–11–73–I but in a position closer to the marine Pleistocene clay in the main profile. The total number of microfossils in sample 12–11–73–II was evaluated to about 3300, equal to a relative representation of 330/100 g sample. The Cretaceous element consists of 126 foraminifera and 144 Oligostegina, the Paleocene of 25 foraminifera and the Pleistocene of 6 foraminifera.

Sample 12–11–73–III represents a till (a_2) exposed close to the main profile. The microfossil content shows a predominance of Upper Cretaceous derivates. Oligostegina represent about 8 ⁰/₀ of the count. There is a very low frequency of derived Paleocene and Pleistocene foraminifera. The Pleistocene component is dominated by *Elphidium excavatum clavatum; Cassidulina crassa* obviously has a much lower but still significant frequency. *Eoeponidella laesoeensis* is present but forms below 1 ⁰/₀ of the total number counted. The microfossil content is evaluated to a total of 8000 specimens in the sample, equal to 800/100 g sample.

The last supplementary sample in this survey, 13–12–73–I, was collected in the trangressive till (c) superposed on the till b (sample 12–11–73–V) which again rests upon the marine Pleistocene clay (sample 12–11–73–VI). A total number of 8300 microfossils was evaluated; thus the representation is 830/100 g sample. The derived microfossils are dominated by Upper Cretaceous elements, 40 ⁰/₀ Oligostegina, 55 ⁰/₀ foraminifera. The Pleistocene element amounts to 5 ⁰/₀.

The arrangement of the samples in table 4 corresponds to the stratigraphical order present in the main profile and it is in accordance with the results of the structural analyses described by Kaj Strand Petersen in this paper. The designations of the different tills are those given on the basis of the percentage distribution of incorporated rock material (further in Strand Petersen's contribution). The frequencies of microfossils are expressed in number per 100 g of the original sample. A marked difference in these values separates the tills from the marine part of the section, with two exceptions. The general tendency for the tills seems to be that they have a dispersion of below 1000 microfossils per 100 g while the marine series shows a gradual increase in these values from 1600/100 g in the stratigraphically lowest sample up to a maximum of 30000/100 g in the uppermost marine sample. The two exceptions are formed by the sample 12–11–73–IV (till a_1) with 3000/100 g and sample 12–11–73–V (till b) with 1500/100 g sample. They are widely separated both in the constructed profile and in their actual position in the outcrop, No. IV coming from a till placed between the marine Paleocene and the marine Pleistocene (12–

Sample No.	Designa-tion	Microfossils in 100 g sample	Frequency in per Cent				
			Upper Cretaceous			Paleocene	Pleistocene
			Oligostegina	Foraminifera	Total	Foraminifera	Foraminifera
13-12-73-I	till c	800	40	55	95	0	5
12-11-73-V	till b	1500	3	47	50	40	10
12-11-73-VI	marine silt	30000	2	9	11	0	89
8- 4-68-XIV	-	15000	13.5	9.5	23	0	77
8- 4-68-XIII	-	8000	7	10	17	0	83
8- 4-68-XII	-	6000	4	11	15	0	85
8- 4-68-XI	-	2000	13	36	49	9	42
8- 4-68-X	-	1600	28	21	49	6	45
12-11-73-II	till a_2	300	48	42	90	8	2
12-11-73-I	till a_2	800	28	58	86	10	4
12-11-73-III	till a_2	800	8	dom.	dom.	low	low
12-11-73-IV	till a_1	3000	4	ab.60	ab.64	ab.35	0.4
8- 4-68-IX	till a_1	500	0	66	66	32.5	1.5

Table 4: Constructed profile.
The samples of Quarternary tills and marine clay arranged in stratigraphical order, group of numbers 8–4–68 in accordance with their interrelations in the main profile. Groups of numbers 12–11–73 (supplementary samples) in reference to their structural relationships.

11–73–VI), and No. V from above the same marine Pleistocene deposit (12–11–73–VI). The two tills (12–11–73–IV and V) have in common a content of Paleocene derivate foraminifera of about 40 %, and a content of Upper Cretaceous derived microfossils of about 64 % in No. IV and 50 % in No. V. A difference exists in the representation of Pleistocene derivate foraminifera which in the older till (12–11–73–IV) amounts to 0.4 % while the corresponding value for 12–11–73–V is 10 %. The figures for the proportion of Paleocene elements show similarities, but this gives a false impression of similarity of origin, as is demonstrated when the specific constituents are considered. The older till (a_1) (12–11–72–IV) incorporates derived Paleocene foraminifera in a combination characterized by relatively large specimens of *Robulus sp., Dentalina sp., Marginulina sp.* and *Gavelinella lellingensis,* while the younger till (b) (12–11–73–V) contains quite another mixture of Paleocene species: *Quadrimorphina halli, Pulsiphonina elegans, Gavelinella grosserugosa, Anomalinoides nobilis, Bolivinoides peterssoni* and *Spiroplectammina laevis.* The Pleistocene derivate foraminifera in the lower till (a) (12–11–73–IV) are of negligible frequency i.e. three specimens. The upper till (b) (12–11–73–V) includes a characteristic combination of Pleistocene species (for details, see p. 82). This combination leaves little doubt that a part of the underlying marine

Pleistocene has been incorporated in the till (b) (12–11–73–V) during the glaciation in which it was deposited.

The marine part of the section. The tendency demonstrated by the increasing number of microfossils/100 g, which was commented upon above, is also reflected by the percentage frequency of microfossils within the different stratigraphic groups of the Upper Cretaceous, Paleocene and Pleistocene (table 4). The Upper Cretaceous part comprises two columns: Oligostegina and Foraminifera. The Oligostegina have been incorporated in an attempt to test whether the frequencies of this element might prove useful in the distinguishing of different tills.

Oligostegina Kaufmann (1865) (see pl. 8, fig. 1–4) is a name provisionally used for calcareous spheres, *ca. 0.05 mm in diameter,* with one circular perforation of varying size which in reflected light very often appears as a slit. The Scanning Electron Micrographs, pl. 8, fig. 2–3, clearly show that the slitlike appearance is produced by an irregularly formed protursion of matrix – presumably calcareous like the remaining part of the sphere. The Oligostegina dissolve totally in 10 % HCl. The surface of the body shows a neat pattern of triangular elements with concave sides, a structure that leaves no doubt as to the organic origin of the sphere. This surface pattern is not recognisable in the light microscope under the normal procedure, but this is probably the explanation for the special light effect that makes the Oligostegina spheres easy to distinguish from other spheres of the same size. According to Glaessner (1967) they are abundant in Albian and Upper Cretaceous deposits from different parts of the world. In many earlier papers Oligostegina has been considered to be a foraminifer, named *Orbulina* e.g. by Plummer (1931, pp. 112–118), *Fissurina* by Sujkowski (1931) and *Orbulinaria* Rhumbler in Beschoren (1926, 1927) and Voigt (1929). Brotzen (1936) gives a short comment on their rôle as facies-constructing elements in certain parts of the Upper Cretaceous Chalk of Europe and North America. So-called "White spheres", with a surface pattern greatly resembling that of Oligostegina as revealed here (pl. 8, fig. 3), have been described by Hansen & Andersen (1969) from the Danish Paleocene Upper Selandian. In several other cases, abundant Oligostegina have been observed by the author in certain horizons of the Maastrichtian Chalk from ditch samples from borings for oil prospecting. It may be stated conclusively that the Oligostegina found in the samples from the Holmstrup exposures are microfossils originating from Upper Cretaceous Chalk, and that they represent a facies different from the wellknown Heterohelix-Globigerinid facies from the same limestone unit, where species of these two groups are totally dominating in number. The variations in the percentage frequencies of Oligostegina (table 4) show a notable agreement with the subdivision of the tills based on the rock distribution. One exception to this general trend is seen in the Oligostegina percentage of 8 % in 12–11–73–III, which is supposed to represent till a_2 according to the relative stone content. The estimates for the Upper Cretaceous and especially for the Paleocene foraminifera in 12–11–73–III are in accordance with the similar frequencies in 12–11–73–I and II. To get a basis for a better interpretation, however, the estimates need to be replaced by a quantitative examination. If the Oligostegina frequencies are followed upwards through the marine Pleistocene silt a steady decrease is noted. This tendency has one exception, 8–4–68–XIV, where the frequency reaches 13.5 %. The described development gives a picture of a marine environment which, during a period of sedimentation, is gradually losing elements supplied by erosion.

The percentage frequencies of the foraminifera presented in table 4, p. 84, show a gradual decrease of Upper Cretaceous elements through tills a_1 and a_2 and the marine clay series. The two tills above the marine Pleistocene have a greater representation, till b, 12–11–73–V 50 % and till c, 13–12–73–I as much as 95 %. The Paleocene foraminifera have a more irregular variation through the sequence. A notable difference exists in the tills so that each of the groups a_1, a_2, b and c has a characteristic Paleocene frequency. In the lower part of the marine Pleistocene, three samples have low Paleocene frequencies (6–9 %) and in the remaining four samples there are no Paleocene representatives at all.

Within the marine Pleistocene part of the profile, a combination of the variation in the frequencies of derived microfossils, described above, together with the gradual increase in their numbers per 100 g of sediment, demonstrates a similar gradual increase in biological productivity, which is also demonstrated by the augmentation of the frequencies of Pleistocene foraminifera.

The foraminiferal assemblage in the marine Pleistocene clay. From the results of an examination of the numerical variation in the Pleistocene foraminifera species, it was found that all six samples were characterized by the same distribution of dominating and accessory species. Five samples showed a dominant frequency of *Elphidium excavatum clavatum* and a prominent but lower frequency of *Cassidulina crassa.* One sample, 8–4–68–XIV, differed from this pattern, showing a predominance of *Cassidulina crassa* with *Elphidium excavatum clavatum* as the next in frequency. A total analysis of the percentage frequency pattern of three samples (8–4–68–XIII, XIV and 12–11–73–VI) was made (pp. 75, 74, 80) to form a basis for correlation with similar investigations of the Danish marine Pleistocene.

Correlation of the marine Pleistocene clay

Arne Buch

The assemblages of marine Pleistocene foraminifera in the Holmstrup sequence show a percentage frequency pattern with affinities to the results published from Vendsyssel by Feyling-Hanssen *et al.* (1971), Knudsen (1973) and Konradi & Knudsen (1974). In the analyses of faunas from the Older *Yoldia* Clay at Hirtshals, Andersen (1971 *in op. cit.* p. 159–184) describes faunas from the Hirtshals Zones A–F which show affinities with the Holmstrup faunas from the three samples totally analyzed. In this succession an inversion of the relationship between the frequencies of the two dominating species *Elphidium clavatum* and *Cassidulina crassa* takes place through the zones F, E, D and C so that in the older zones, F and E, *Elphidium clavatum* is the more abundant of the two; in zone D, *Cassidulina crassa* is the dominant, and *Elphidium clavatum* number two in frequency, and finally in zone C *Elphidium clavatum* dominates over *Cassidulina crassa.* A similar inversion of this relationship is found in the Holmstrup section. As mentioned above, sample 8–4–68–XIV showed *Cassidulina crassa* as dominating, and *Elphidium excavatum clavatum* (synonymous with *E. clavatum*) as the next in frequency. Among the accessory species *Nonion labradoricum, Elphidium asklundi, Islandiella teretis, Virgulina schreibersiana* and others are represented in both localities. The assemblages, however, are not in full accordance, so further study and especially examination of a greater number of samples from Holmstrup is needed to fulfil the correlation.

A comparison with the Lundergård Clay of Vendsyssel described by Knudsen (1973) shows certain affinities such as the dominance of *Elphidium excavatum clavatum* and *Cassidulina crassa,* the presence of *Quinqueloculina stalkeri* represented by 2.8 % in Holmstrup sample 8–4–68–XIV, of *Nonion labradoricum, Triloculina trihedra, Elphidium asklundi, Fissurina danica, Protelphidium orbiculare.* One of the characteristic species in the Lundergård Clay, *Elphidium ustulatum,* seems to be absent at Holmstrup.

The foraminifera from the Skærumhede II boring, Vendsyssel, have been analysed by Konradi & Knudsen (1974). A predominance of *Cassidulina crassa* (41 % – 49 %) and *Elphidium excavatum* (28 % – 32 %) characterizes their zone III, and the older zone IV has an *excavatum* representation of 43 % – 73 % with a *crassa* frequency of 5–25 %. In the Holmstrup sample No. 8–4–68–XIV, *Cassidulina crassa* comprises 46 % and *excavatum clavatum* 31.5 %, while sample 8–4–68–XIII, which is the older of the two, showed 73.3 % of *excavatum clavatum* and 20.2 % of *C. crassa.* With regard to the accessory species the two localities have a great deal in common, but as illustrated by the lists of foraminifera pp. 74–80 some differences exist. The similarities to the Older *Yoldia* Clay, especially the arctic part of the Skærumhede II section, might suggest that the Holmstrup marine Pleistocene clay correlates with a Weichselian Interstadial.

Concluding remarks

This investigation has revealed that the dislocated till sequence at Holmstrup can be divided into two units: the dislocated series, and the transgressive till from a glacier moving from the east.

The dislocated series is shown to be moved as one body. It consists of a sequence of strata recording a stratigraphical succession. The oldest element is a silty clay deposit representing the Upper Paleocene, superposed by a till (a_{1-2}), characterized by its content of Palaeozoic Limestone and Shale as well as Tertiary concretions. The series of marine Pleistocene clay, which is deposited upon this till, shows a gradual sedimentation with a decreasing content of elements from its substratum, till a_{1-2}. The marine silty clay has a boreo arctic fauna dominated by *Macoma calcarea*. On the basis of microfossils it has been correlated (p. 87) with a part of the marine sequence at Skærumhede (Bahnson *et al.* 1974) within the Weichselian glaciation.

On top the marine Pleistocene is cut off by a till (b) characterized by the sparse representation of Palaeozoic Limestone, Shale and Tertiary concretions; this till also carries microfossils from both the marine Pleistocene and the Paleocene. It can be shown that this Paleocene element represents deposits of a different composition from the Upper Paleocene silty clay at the base of the Holmstrup sequence.

Upon the dislocated series rests the transgressive till c, with microfossil constituents in quite a combination different from the underlying, dislocated tills, and with a lithological dominance of Igneous and Metamorphic rocks, a representation of Palaeozoic Limestone, but without any Tertiary concretions.

The Holmstrup sequence compared with known features of ice movements

Kaj Strand Petersen

The correlation of the marine sequence with the cold upper part of the marine series from Skærumhede II (Bahnson *et al.* 1974) indicates the tills above this marine horizon to be of mid Weichselian age.

The uppermost till, the transgressive till c, which forms part of the moraine bounding the till plain at Kundby, is characterized by an ice pressure from the east and by a content of Palaeozoic Limestone and Shale. These are suggestive of a Baltic origin for the corresponding glacier. The same is true for the younger tills at Røsnæs (Petersen 1973a) which were deposited during the Belt Advance, as was the younger till at Asnæs.

The sparse occurrence of Baltic elements in the underlying till b may indicate that this till represents a deposit from the North East Ice. No traces of ice movements, however, have yet been demonstrated from this particular till at Holmstrup. But to the west, at Asnæs, two glacial deposits have been distinguished (Berthelsen 1971, pp. 64–65), of which the elder has been an object for ice movement from the northeast, antedating the Belt Advance. Ice pressures from the northeast are also known from Strandegaards Dyrehave (Petersen & Konradi 1974); here the dislocated series includes tills and a marine deposit ascribed to the Eemian. This indicates a Weichselian age for this dislocation, supporting the above suggestion that till b at Holmstup belongs to the North East Ice deposits.

Dansk sammendrag

Fra en lergrav 500 m vestnordvest for Holmstrup på Sjælland beskrives en lagserie, der består af tertiære og kvartære lag. Man kan skelne mellem det dislocerede afsnit og en overlejrende moræne afsat af en dislocerende is fra øst.

Den dislocerede serie indledes med en aflejring, der umiddelbart ligner det eocæne, plastiske ler på Røsnæs. Analyser af aflejringens kornfordeling og kemiske sammensætning viser dog, at dette tertiære Holmstrup-ler har en afvigende karakter. Fund af agglutinerende foraminiferer af slægterne *Involutina* og *Glomospira* i selskab med talrige rester af kiselspongier gør det sandsynligt, at aflejringen er af øvre paleocæn alder. Moræneleret (a) afsat på paleocænlagene indeholder oparbejdet tertiært materiale samt, som fremtrædende fjerntransporterede elementer, palæozoiske kalksten og lerskifre. Denne morænelers nederste del er præget af paleocæne foraminiferer, medens den øvre del er præget af øvre-kretaciske foraminiferer og oligosteginer. I den overlejrende marine siltholdige lerserie aftager indholdet af omlejrende mikrofossiler gradvist opad i lagserien. Den domineres af kvartære foraminiferer, hvis fordeling er overensstemmende med foraminifer-fordelingen gennem de øvre, boreoarktiske afsnit i Skærumhede II boringen; dette afsnit tilskrives en tidlig Weichsel-interstadial. Molluskfaunaen, der særlig er præget af *Macoma calcarea,* bliver sammenlignet med tilsvarende faunaer i andre marine aflejringer beskrevet fra denne egn. Øverst i den dislocerede serie, overlejrende det marine ler, findes en moræneler (b), der i sit stenselskab stort set adskiller sig fra moræneleren (a) under den marine serie ved sit ringere indhold af palæozoiske kalksten og skifre samt af tertiære konkretioner. Denne moræneler (b) indeholder tillige omlejrede foraminiferer fra øvre kridt, paleocæn og det umiddelbart underliggende marine kvartær.

Moræneler-aflejringen (c) fra den dislocerende is er i sit stenindhold præget af eruptiver og krystallinske skifre samt af et indhold af palæozoisk kalk og skifer. Tertiære konkretioner er ikke fundet i denne moræneler. Hovedparten af de omlejrede mikrofossiler er øvre kridt former, såvel foraminiferer som oligosteginer, en sammensætning helt anderledes end i den underliggende moræneler. Der findes ingen paleocæne former, som i den ældre moræneler, og mængden af omlejrede kvartærformer er tydeligt mindre.

Dele af den kvartære lagserie i Holmstrup forsøges indplaceret i en isstrømskronologi gennem sammenligninger med kvartære lagserier på andre, nærtliggende lokaliteter, hvor isbevægelsesretningerne er kendte.

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C–14 chronology of Late- and Post-glacial marine deposits in North Jutland

Harald Krog and Henrik Tauber

Krog, Harald and Tauber, Henrik: C–14 chronology of Late- and Post-glacial marine deposits in North Jutland. *Danm. geol. Unders., Årbog 1973*, pp. 93–105. København, 4. oktober 1974.

C–14 dates of mollusc shells from marine Late- and Post-glacial deposits, mainly from Vendsyssel, North Jutland, are presented. The *Zirphaea* beds, which were formerly referred to the Alleröd oscillation, are now correlated with the Bölling oscillation, and the beach deposits from Borgbakke and from Råholt are included in the *Zirphaea* beds. The dates of the *Dosinia* beds fall within the first half of the Sub-boreal, pollen zone VIII, and perhaps the end of the Atlantic, pollen zone VII. A number of recent shell samples were measured as a control.

Series of mollusc shells from marine deposits in North Jutland, especially in Vendsyssel, and from the island of Læsö have been collected and dated in an attempt to establish a chronology of the most important events in the Late- and Post-glacial marine sequence of the area. Special emphasis was placed on getting as broad a representation as possible from the different Late-glacial marine deposits and from the Post-glacial *Dosinia* beds, but no effort was made to cover the whole Post-glacial sequence.

Our knowledge of the marine deposits of the area is based mainly on investigations and observations made at the end of the last and the beginning of this century (Jessen 1899; Nordmann 1904). As several of the sites from that time are no longer accessible, a few samples have been taken from shells collected at that time and kept since then in the specimen collections of the Geological Survey. The rest of the fossil samples originates from new field collections made from 1962 to 1968 by Sigurd Hansen and Harald Krog from the Geological Survey, partly assisted by Ib Marcussen and Erna Nordmann. The recent control samples, K–330 to K–339, were kindly placed at our disposal from the specimen collections at the Zoological Museum. A number of the dates have previously been published in date lists (Tauber 1966 a, 1966 b). A list of the samples dated after the 1966 lists is found at the end of this paper.

A survey of the shell dates in the present date list and in the lists of

1966 is given in Table 1. Stratigraphical divisions and the terminology applied in the table and in the date lists are mainly those used by Jessen (1936) and followed by Hansen (1965) and Krog (1968). The shell layers from Borgbakke and from Råholt have, however, been placed in a stratigraphically uncertain group, Upper *Saxicava sand/Zirphaea* beds, because opinions have differed as to the proper stratigraphical position of these deposits. The Post-glacial deposits are only divided into two groups, *Tapes* deposits *s.l.* and *Dosinia* deposits, because the material presented here is too sparse to allow a more detailed subdivision. Two samples, K–1248 and K–1469, have not been included in the table because of uncertainties as to what is actually represented by the sample material.

The samples in the first two groups in Table 1, Lower *Saxicava* sand and Late-glacial *Yoldia* clay, have all been collected from layers in a supposed primary position and are considered reliable. The samples in the two groups thus date deposits from the Late-glacial *Yoldia* sea and are chronologically correlated with Daniglacial time and pollen zone I a.

It has not been possible to get shell samples from stratigraphically certain deposits of Upper *Saxicava* sand, which is usually supposed to represent the end phase of the Late-glacial *Yoldia* sea.

The shell layers at Borgbakke and Råholt, here placed in the uncertain group Upper *Saxicava* sand/*Zirphaea* beds, have previously been referred to the *Zirphaea* beds (Jessen 1899), to Upper *Saxicava* sand (Jessen 1936), and to a separate transgression between the *Yoldia* sea and the *Zirphaea* sea (Hansen 1965). It follows from Table 1 that the three samples chronologically fall within the age range of the true *Zirphaea* beds. On the basis of the C–14 dates they should therefore be referred to the *Zirphaea* beds, as was tentatively done by Krog (1968).

The samples representing *Zirphaea* beds were collected partly from shells in reliable primary positions, partly from shell banks and similar deposits where redeposition is likely to occur. It should be noted, however, that all species dated are members of the *Zirphaea* fauna and are not represented in deposits from the previous periods. They are therefore reliable as time markers for the *Zirphaea* beds, even when found in rebedded positions. The dates in this group are spread relatively evenly over about 800 years and hardly allow any subdivision into different stages as was done by Mörner (1969, p. 174). Pollen analytically the *Zirphaea* beds have previously been referred to the Alleröd oscillation (Iversen 1947). However, all the C–14 dates, except three that are older, fall within the range of dates for the Bölling oscillation. The present dates therefore very strongly indicate that the *Zirphaea* beds should be correlated with the Bölling oscillation, as was also accepted by Iversen (1967, 1973). The three somewhat older dates, among these one made directly on shells of *Zirphaea crispata,* may suggest that the climatic amelioration that is reflected both by the *Zirphaea* fauna and by the terrestrial Bölling oscillation was registered slightly earlier in the sea than by the terrestrial plant communities.

Opinions have differed somewhat as to the chronological position of the Post-glacial *Dosinia* beds. Hansen (1965) has correlated them with the Sub-boreal, pollen zone VIII. The dates presented here suggest that the correlation should rather be with the first half of the Sub-boreal, perhaps with a beginning already at the end of the Atlantic as suggested by K–1237 and K–1238. However, as stated in the sample descriptions, these two samples are not considered fully reliable as they originate from a shell bank. However, the fact that the two dates, from the upper and the lower part of the shell bank respectively, are almost identical supports the idea that all shells in the bank, and among these are shells of *Dosinia exoleta,* are likely to be of the same age. It should be emphasized that the number of samples and dates from *Dosinia* beds is too small for an exact chronological delimitation of this group.

The samples referred to *Tapes* deposits *s.l.* have not been systematically collected to give a broad representation and need only little comment. The samples from Melholt must all be considered to belong to the same beach deposit, and the age differences between the dates for these samples may perhaps be explained as due to contamination from rebedded older shells. The youngest date in Table 1, K–1246, grouped under *Tapes* deposits *s.l.,* is interesting because it refers to a deposit found only 300 m from a *Dosinia* bed and at the same level as this, but stratigraphically it deviates from the *Dosinia* beds by not being deposited on the stony surface of Older *Yoldia* clay like these, but in marine sand. Deposits similar to the one represented by K–1246 are rather common within the area of the *Dosinia* beds, but their chronological position is uncertain.

C–14 dating of marine shells poses some special problems. While the atmosphere of each hemisphere is well mixed within months and thus ensures a uniform C–14 activity of contemporary terrestrial plant material, the turnover of water masses in the oceans is a slow process that gives rise to considerable differences in C–14 activity within the oceans. The mean residence time of water masses in the deep oceans, i.e. below the thermocline, varies from ocean to ocean. In the Atlantic it is of the order of 600 to 700 years (Broecker *et al.* 1960). During this time C–14 atoms in the deep oceanic bicarbonate will gradually decay. In areas of upwelling of deep ocean water, i.e. around the Antarctic and in restricted areas with divergent surface currents, oceanic bicarbonate is therefore depleted in C–14 activity relative to equilibrium conditions. Due to exchange of carbon dioxide between the atmosphere and the oceans the C–14 activity of upwelling deep water will gradually increase again as the water masses are mixed into the upper mixed layers, and on the rate of exchange of carbon dioxide between way an equilibrium, mainly depending on the rate of turn-over between the deep ocean and the upper mixed ocean, on the mean residence time in the upper mixed layers, and on the rate of exchange of carbon dioxide between the atmosphere and the oceans, tends to be established. With the present circulation pattern a fairly constant C–14 activity, corresponding to a depletion in C–14 activity of about 4–5 ‰ or an apparent age of surface water bicarbonate of about 300–400 years, is attained in areas well away from the centres of upwelling. In the Atlantic sector this relative constancy prevails in the North Atlantic and the adjacent seas (Broecker *et al.* 1961, Mangerud 1972), perhaps with the exception of the East Greenland Current where outflow of water from the icecovered Arctic ocean may give a local depression in C–14 activity corresponding to about 100–200 years (Östlund and Fonselius 1959; Hjort 1973).

Another effect also influences the age calculations. When atmospheric carbon dioxide is absorbed in the oceans an isotopic fractionation takes place and, under equilibrium conditions, gives rise to an enrichment of 4–6 ‰ in the C–14 activity of oceanic bicarbonate relative to that of terrestrial plant material. At the present rate of ocean circulation the enrichment in C–14 due to fractionation and the depletion in C–14 due to ocean circulation almost cancel. In the upper mixed layers of the North Atlantic, and in the adjacent seas with a pronounced marine influence, the C–14 activity of ocean bicarbonate, and of marine shells, therefore broadly equals the C–14 activity of contemporary organic terrestrial material.

The uniformity or near-uniformity in C–14 activity of terrestrial plant material and of marine shells is shown in the measurements of the recent shell samples K–433, K–892, and K–893 (Tauber 1966a, 1966b), and the series K–330 to K–339 in the list below. The molluscs in the last mentioned series had been collected as live animals between 1840 and 1934. The C–14 activity of the shells has been corrected for decay between the time of collection and 1950, and expressed in percentage of the international modern standard (0.95 times the activity of the NBS oxalic acid standard), which is also used as a standard in age calculations of organic terrestrial material. The average activity of 11 recent samples that were living before large-scale nuclear testing began is 99.9 ‰ of the modern terrestrial value, with a scatter slightly exceeding what is normally expected statistically.

Calculated with this standard and with no correction for isotopic fractionation, dates of marine shells are thus directly comparable with C–14 dates of organic terrestrial material, provided that the circulation pattern in the oceans has not changed significantly. No further "sea correction" should therefore be applied to these dates, as was erroneously done in a recent discussion of the Late-glacial (Mörner 1969, pp. 174, 380, and 385; cf. Tauber 1970, p. 180). In this connection it may be noted that two Scandinavian C–14 stations, Uppsala and Lund, in the age calculations of marine shells apply a correction for the isotopic fractionation that occurs in the absorption of carbon dioxide in ocean water, and disregard the effect of ocean circulation. In this way they arrive at dates for shell material that are about 400 years older than those presented below.

Shell material is liable to post-depositional contamination due to exchange with bicarbonate of marine water or of percolating ground water. To avoid errors from this effect the surface layers of the shell samples, or about 10–20 % of the total sample weight, were removed with acid prior to dating. Finally it should be noted that the shell dates listed below are given in "conventional" C–14 years B.P. (before 1950). Dates in approximately absolute years may be obtained, at least as far back as 7300 B.P., by a calibration with the American bristlecone pine chronology (Suess 1970; Damon *et al.* 1973). In the middle of the Post-glacial this calibration amounts to a correction of the conventional C–14 dates by about 800 years. In the Late-glacial and the early Post-glacial conventional C–14 dates approximate the revised Swedish varve chronology and therefore, perhaps, may need no correction (Tauber 1970). However, this question is still disputed and will not be finally decided before the bristlecone pine chronology has been extended further back in time.

Table 1. Late- and Post-glacial shell dates from North Jutland and recent samples from the North Atlantic sector.

Lower Saxicava sand			
K–858	Lönstrup Klint	*Saxicava arctica*	13,900±220 B.P.
Late-glacial Yoldia clay			
K–1051	Gölstrup	*Saxicava arctica*	14,280±240 B.P.
K–1052	–	– –	14,080±240 – –
K–1049	Læsö	– –	13,770±130 – –
K–1053	Skeen Möllebæk	– –	13,610±220 – –
K–887	Dybvad	– –	13,180±200 – –
K–903	–	– –	13,010±190 – –
K–894	Læsö	– –	12,910±180 – –
K–1050	–	– –	12,850±210 – –
K–891	Bindslev	*Mya tr., Sax., Mac. calc.*	12,650±180 – –

Upper Saxicava sand/Zirphaea beds

K–1688	Råholt	*Mytilus edulis*	12,400±180 B.P.
K–859	Borgbakke	– –	12,030±130 – –
K–1687	–	– –	12,020±180 – –

Zirphaea beds

K–1468	Vangen	*Zirphaea crispata*	12,770±190 B.P.
K–898	Skeen Möllebæk	*Mya truncata*	12,770±160 – –
K–897	– –	*Mytilus edulis*	12,520±180 – –
K–1318	Kjul Å	*Zirphaea crispata*	12,460±190 – –
K–1357	– –	*Macoma baltica*	12,370±190 – –
K–862	Skeen Möllebæk	– *calcarea*	12,360±150 – –
K–899	– –	*Mytilus edulis*	12,240±180 – –
K–860	– –	*Mya truncata*	12,230±170 – –
K–861	– –	– –	12,190±170 – –
K–1681	– –	*Mytilus edulis*	12,120±180 – –
K–1320	Kjul Å	*Mac. bal., Zir., Cypr.*	12,130±190 – –
K–1470	Tværsted Å	*Cyprina islandica*	11,980±190 – –
K–1471	– –	*Zirphaea crispata*	11,950±190 – –
K–1319	Kjul Å	*Mytilus edulis*	11,950±190 – –

Tapes (Littorina) deposits s.l.

K–895	Tværsted Å	*Cardium edule*	8280±140 B.P.
K–1472	– –	– –	8250±130 – –
K–1054	– –	– –	7820±140 – –
K–906	Melholt	*Ostrea edulis*	6110±120 – –
K–890	–	*Card. ed., Ost., Cypr.*	6090±120 – –
K–907	–	*Cardium edule*	5940±140 – –
K–888	–	*Ostrea edulis*	5620±140 – –
K–889	–	*Cardium edule*	5560±140 – –
K–902	–		5550±140 – –
K–866	Lille Vildmose	*Ostrea edulis*	5580±150 – –
K–864	Gettrup	*Ostrea ed., Myt. ed.,* etc.	4150±140 – –
K–865	–	*Littorina litt.*	4010±120 – –
K–1241	Glomstrup Vig	*Ostrea edulis*	3050±100 – –
K–1246	Frederikshavn	*Cardium edule*	2440±100 – –

Dosinia deposits

K–1237	Frederikshavn	*Ostrea edulis*	5240±120 B.P.
K–1238	–	– –	5180±150 – –
K–900	Strandby	*Dosinia exoleta*	4470±140 – –
K–1039	–	*Ostrea edulis*	4290±130 – –
K–1038	–	*Dosinia exoleta*	3990±130 – –
K–1236	Frederikshavn	*Ostrea edulis*	3980±140 – –

Recent samples			% of modern
K–331	Middelfart, Denmark, 1861	*Mytilus ed.*	101.8±0.8 %
K–332	Horsens Fj., Denmark, 1934	– –	100.5±0.8 %
K–333	Limfjorden, Denmark, 1886	– –	99.0±0.6 %
K–334	Sörvåg, Faroe Isl., 1905	– –	99.6±0.8 %
K–330	Faxebugt, Iceland, 1840	– –	101.0±0.6 %
K–335	Thorshöfn, Iceland, 1913	– –	98.0±0.6 %
K–336	Godthåb, Greenland, 1887	– –	98.3±0.6 %
K–337	Jacobshavn, Greenland, 1898	– –	100.3±0.8 %
K–338	Disco, Greenland, 1902	– –	101.1±0.8 %
K–339	Disco, Greenland, 1906	– –	98.9±0.6 %
K–433	Limfjorden, Denmark, 1952	*Ostrea ed.*	100.7±0.5 %
K–892	Kujegrund, Denmark, 1962	*Cardium ed.*	100.8±0.5 %
K–893	Sæby, Denmark, 1962	*Mya aren.*	101.9±0.5 %

Sample descriptions

14,280±240 B.P.
K–1051. Gölstrup, DGU 291 12,330 B.C.

Shells (*Saxicava arctica*) from clay pit at the brick-works Gölstrup Teglværk (57°25′N Lat, 9°49′E Long), Vendsyssel. Found in Late-glacial *Yoldia* clay, ca. 3 m below ground level.

14,080±240 B.P.
K–1052. Skeen Möllebæk, DGU 292 12,130 B.C.

Shells (*Saxicava arctica*) from Skeen Möllebæk, E of Skeen Möllegård (57°33′N Lat, 10°07′E Long), Vendsyssel. Found in Late-glacial *Yoldia* clay, 3 m below the top of the clay.

13,610±220 B.P.
K–1053. Skeen Möllebæk, DGU 293 11,660 B.C.

Shells (*Saxicava arctica*) from same locality as K–1052. Found in the uppermost 30 cm of he Late-glacial *Yoldia* clay, just below shell-free *Zirphaea* sand, 3 m above sample K–1052.

13,770±230 B.P.
K–1049. Læsö, Byrum, DGU 289 11,820 B.C.

Shells (*Saxicava arctica*) from Late-glacial *Yoldia* clay, Byrum, Læsö, S of the farm Storehave (57°15′N Lat, 10°59′E Long). Found ca. 1½ m below ground level, ca. ½ m below the clay surface.

12,850±210 B.P.
K–1050. Læsö, Byrum, DGU 290 10,900 B.C.

Shells (*Saxicava arctica*) from Late-glacial *Yoldia* clay, Byrum, Læsö, just N of the farm Storehave (57°15′N Lat, 10°58′E Long). Found ca. 1½ m below ground level in the top part of the clay.

13,250±160 B.P.
K–1469. Vangen, DGU 386 11,300 B.C.

Shells (*Macoma calcarea*) from clay pit ca. 200 m W of Vangen Bro abt. ½–1 km SSW of Nr. Bindslev (57°32′N Lat, 10°12′E Long), Vendsyssel. Found in lower part of clayey sand on top of Late-glacial *Yoldia* clay, altitude ca. + 15 m. The layer was clearly referred to the *Zirphaea* beds, but it was evidently disturbed by solifluction processes and already when taking the samples we had a suspicion that part of the shells might be reworked from the underlying shell-rich *Yoldia* clay. From the results of the date it is concluded that the shells originate from the *Yoldia* clay. Date is average of two measurements: 13,490±200 and 13,010±200.

12,770±190 B.P.
K–1468. Vangen, DGU 385 10,820 B.C.

Shells (*Zirphaea crispata*) from same locality as K–1469. Most of the shells were found in the same sand layer (*Zirphaea* bed) as the shells from K–1469, but a few of them were found in their burrows in the upper 10–15 cm of the *Yoldia* clay. Altitude ca. + 15 m.

12,460±190 B.P.
K–1318. Kjul Å, DGU 343 10,510 B.C.

Shells (*Zirphaea crispata*) from *Zirphaea* bed, Kjul Å, abt. 150 m N of Helligkilde (57°35′N Lat, 10°01′E Long), Vendsyssel. Found partly in a small shell bank, 1–5 cm thick, on top of Older *Yoldia* clay, partly in their burrows in the upper 10–15 cm of the *Yoldia* clay below the shell bank. Altitude ca. + 6½– + 7 m.

12,370±190 B.P.
K–1357. Kjul Å, DGU 348 b 10,420 B.C.

Shells (*Macoma baltica*) from *Zirphaea* bed, same locality and same layer as K–1318.

11,950±190 B.P.
K–1319. Kjul Å, DGU 344 10,000 B.C.

Shells (*Mytilus edulis*) from *Zirphaea* bed, Kjul Å, ca. 130–140 m N of Helligkilde (57°35′N Lat, 10°01′E Long), Vendsyssel. Found in shell rich silt layer, 10–30 cm thick, on top of Older *Yoldia* clay. Almost all shells were juvenile. Altitude ca. + 5½ m.

12,130±190 B.P.
K–1320. Kjul Å, DGU 345 10,180 B.C.

Shells (*Macoma baltica, Zirphaea crispata,* and *Cyprina islandica*) from *Zirphaea* bed, same locality as K–1319. Found in a small shell bank, ca. 5 cm thick, ca. ½ m above surface of Older *Yoldia* clay, and separated from K–1319 by shell-free sand layer. Altitude ca. + 6 m.

11,710±180 B.P.
K–1248. Kjul Å, DGU 330 9760 B.C.

Shells (*Mytilus edulis*) from Kjul Å, abt. 200 m S of Helligkilde (57°35′N Lat, 10°01′E Long), Vendsyssel. Found in sand layer ca. 75 cm above surface of Older *Yoldia* clay. Altitude ca. + 6½ – + 7 m. The sequence above the *Yoldia* clay consists of Late- and Post-glacial marine gravel and sand layers without any distinguishable limit. The layer from which the shells are collected was originally believed to be a *Zirphaea* bed. The same layer contained lumps of organic material which by pollen analysis proved to be of very young Post-glacial age. Thus the shells may be of mixed origin.

11,980±190 B.P.
K–1470. Tværsted Å, DGU 387 10,030 B.C.

Shells (*Cyprina islandica*) from *Zirphaea* bed, Tværsted Å, W of Nr. Tværsted (57°35′N Lat, 10°11′E Long), Vendsyssel. From gravel layer rich in fragmented shells. Altitude ca. + 3 m.

11,950±190 B.P.
K–1471. Tværsted Å, DGU 388 10,000 B.C.

Shells (*Zirphaea crispata*) from *Zirphaea* bed, same locality and same layer as K–1470.

12,120±180 B.P.
K–1689. Skeen Mölle, DGU 414 10,170 B.C.

Shells (*Mytilus edulis*) from clay pit N of Skeen Mölle (57°33′N Lat, 10°07′E Long), Vendsyssel. Type site for *Zirphaea* beds. Found in gravel layer on top of Late-glacial *Yoldia* clay, covered by 3–5 m of stratified sand. Coll. V. Nordmann 1904.

12,400±180 B.P.
K–1688. Råholt, DGU 415 10,450 B.C.

Shells (*Mytilus edulis*) from Råholt (57°27′N Lat, 10°31′E Long), Frederikshavn, Vendsyssel. From gravel rich in shell fragments. In the literature this deposit has been referred both to the Upper *Saxicava* sand and the *Zirphaea* beds. Altitude ca. + 25 m. Coll. V. Nordmann 1904.

12,020±180 B.P.
K–1687. Borgbakke, DGU 416 10,070 B.C.

Shells (*Mytilus edulis*) from Borgbakke (57°27′N Lat, 10°31′E Long), Frederikshavn, Vendsyssel. From gravel rich in shell fragments. Like K–1688 this deposit has been referred to both the Upper *Saxicava* sand and the *Zirphaea* beds. Altitude ca. + 20 m. Coll. V. Nordmann 1904.

7820±140 B.P.
K–1054. Tværsted Å, DGU 294 5870 B.C.

Shells (*Cardium edule*) from cliff at the river Tværsted Å (57°35′N Lat, 10°11′E Long), Vendsyssel. Found in Post-glacial marine sand below *Cardium* clay. See comment to K–1472.

8250±130 B.P.
K–1472. Tværsted Å, DGU 389 6300 B.C.

Shells (*Cardium edule*) from cliff at the river Tværsted Å, same locality as K–1054. From sand layer in lower part of marine series on top of thin peat layer. The Post-glacial marine transgression is marked in the profile by transition from peat to marine clay gyttja and by pollen analysis it is dated at the transition between pollen zones V and VI. Altitude of shell layer + 6.0 m. Samples K–1054 and K–895 (see Table 1) must be referred to this layer too.

5240±120 B.P.
K–1237. Frederikshavn, DGU 318 3290 B.C.

Shells (*Ostrea edulis*) from Skippergade in Frederikshavn (57°27′N Lat, 10°32′E Long), Vendsyssel. From uppermost part of a more than 1 m thick shell bank. Surface of shell bank (and sample level) ca. 40 cm below ground level, altitude ca. + 1.3 m. Referred to *Dosinia* beds as shells of *Dosinia exoleta* were present, but not enough for a date. Most of the shells in the shell bank were fragmented. Date is average of two measurements: 5380±150 and 5100±150.

5180±150 B.P.
K–1238. Frederikshavn, DGU 319 3230 B.C.

Shells *(Ostrea edulis)* from lower part of same shell bank as K–1237. Altitude ca. + 0.3 m. Two fragmented shells of *Dosinia exoleta* were found in this layer. As it must be assumed that the shells in the shell bank have been redeposited, the shells of *Dosinia* and of *Ostrea* may be of different origin and age. Accordingly it is uncertain if K–1237 and K–1238 really date *Dosinia* beds.

3990±130 B.P.
K–1038. Strandby, DGU 287 2040 B.C.

Shells (*Dosinia exoleta*) from Strandby (57°29'N Lat, 10°30'E Long), Vendsyssel. Found in layer of clayey shell gravel, ca. 25 cm thick, on top of Older *Yoldia* clay. Altitude ca. + 4 m.

4290±130 B.P.
K–1039. Strandby, DGU 288 2340 B.C.

Shells *(Ostrea edulis)* from same layer as K–1038. *Dosinia* bed.

3980±140 B.P.
K–1236. Frederikshavn, DGU 317 2030 B.C.

Shells *(Ostrea edulis)* from *Dosinia* bed, near Flade Engvej N of Frederikshavn (57°28'N Lat, 10°31'E Long), Vendsyssel. Found in thin shell-rich sand layer on top of Older *Yoldia* clay. Altitude ca. + 4 m. Shells of *Dosinia exoleta* were present but not sufficient for a date.

2440±100 B.P.
K–1246. Frederikshavn, DGU 328 490 B.C.

Shells *(Cardium edule)* from place ca. 300 m N of K–1236, near Flade Engvej N of Frederikshavn (57°28'N Lat, 10°31'E Long), Vendsyssel. From small shell bank of *Cardium* shells in otherwise shell-free sand, at approximately same level (+ 4 m) as K–1236. Date is average of two measurements: 2480±110 and 2400±110.

3050±100 B.P.
K–1241. Glomstrup Vig, DGU 322 1100 B.C.

Shells *(Ostrea edulis)* from shell bank near Glomstrup Vig S of Tissing Huse (56°43'N Lat, 8°38'E Long), island of Mors, North Jutland. From fossil "oyster bank" covered by marine mud. In the layer were found 3 different species of *Tapes* which during *Tapes* time *(Littorina* time) lived in Danish waters. Coll. V. Nordmann 1903. Date is average of two dates: 2920±120 and 3180±120.

101.0±0.6 %
K–330 Faxe Bugt of modern

Shells *(Mytilus edulis)* from Faxe Bugt (ca. 64°20'N Lat, ca. 22°00'W Long), Iceland. Collected in 1861 as live animals and preserved in the Zoological Museum, Copenhagen.

K–331 Middelfart Sund — 101.8±0.8 % of modern

Shells *(Mytilus edulis)* from Middelfart Sund (55°31′N Lat, 9°42′E Long), Denmark. Collected in 1861 as live animals and preserved in the Zoological Museum, Copenhagen.

K–332 Vorsø, Horsens Fjord — 100.5±0.8 % of modern

Shells *(Mytilus edulis)* from Vorsø, Horsens Fjord (55°52′N Lat, 10°01′E Long), Denmark. Collected in 1934 as live animals and preserved in the Zoological Museum, Copenhagen.

K–333 Fur Sund, Limfjorden — 99.0±0.6 % of modern

Shells (*Mytilus edulis*) from Fur Sund, Limfjorden (56°48′N Lat, 9°00′E Long), Denmark. Collected in 1886 as live animals and preserved in the Zoological Museum, Copenhagen.

K–334 Sørvåg, Vågø — 99.6±0.8 % of modern

Shells *(Mytilus edulis)* from the beach at Sørvåg, Vågø (62°04′N Lat, 7°20′W Long), Faroe Islands. Collected in 1905 as live animals and preserved in the Zoological Museum, Copenhagen.

K–335 Thorshöfn — 98.0±0.6 % of modern

Shells *(Mytilus edulis)* from Thorshöfn (66°15′N Lat, 15°19′W Long), Iceland. Collected in 1913 as live animals at a depth of 0–6 m and preserved in the Zoological Museum, Copenhagen.

K–336 Godthåb — 98.3±0.6 % of modern

Shells *(Mytilus edulis)* from Godthåb (64°12′N Lat, 51°45′W Long), Greenland. Collected in 1887 as live animals at a depth of 4–9 m and preserved in the Zoological Museum, Copenhagen.

K–337 Jacobshavn — 100.3±0.8 % of modern

Shells *(Mytilus edulis)* from Jacobshavn (69°13′N Lat, 51°08′W Long), Greenland. Collected in 1898 as live animals and preserved in the Zoological Museum, Copenhagen.

K–338 Disco — 101.1±0.8 % of modern

Shells *(Mytilus edulis)* from Disco (ca. 69°15′N Lat, ca. 53°30′W Long), Greenland. Collected in 1902 as live animals and preserved in the Zoological Museum, Copenhagen.

K–339 Mudderbugten, Disco — 98.9±0.6 % of modern

Shells (*Mytilus edulis*) from Mudderbugten, Disco (69°41'N Lat, 52°00'W Long), Greenland. Collected in 1906 as live animals and preserved in the Zoological Museum, Copenhagen.

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Dansk sammendrag

En række C–14 bestemmelser på molluskskaller fra sen- og postglaciale marine aflejringer, hovedsagelig fra Vendsyssel, fremlægges. De fleste prøver er indsamlet 1962–1968, men enkelte stammer fra indsamlinger foretaget i begyndelsen af dette århundrede. En del af dateringerne er tidligere publiceret i dateringslister (Tauber 1966a, 1966b), de øvrige findes i slutningen af denne afhandling. Dateringerne er oversigtligt samlet i Table 1, opdelt i stratigrafiske grupper efter A. Jessens terminologi (Jessen 1899, 1936). Som vigtigste resultater skal fremhæves, at *Zirphaea*-lagene, der tidligere var henregnet til Allerödtid, ifølge disse dateringer tilhører Böllingoscillationen. Stranddannelserne fra Borgbakke og Råholt har hidtil været stratigrafisk usikkert placeret, men må ifølge C–14 dateringerne henregnes til *Zirphaea*-lagene, og dermed Böllingoscillationen. Dateringerne af skaller fra *Dosinia*-lagene falder indenfor første halvdel af subborealtid og måske i slutningen af atlantisk tid. En række recente skalprøver er blevet målt til kontrol af de ovennævnte dateringer.

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Scanning electron micrographs of pollen from two *Tilia* species

Jens Stockmarr

Stockmarr, Jens: Scanning electron micrographs of pollen from two *Tilia* species. *Danm. geol. Unders., Årbog 1973,* pp. 107–109, pls. 11–14. København, 7. oktober 1974.

Pollen grains from *Tilia platyphyllos* Scop. and *Tilia cordata* Mill. have been studied in a scanning electron microscope for further description of the structure and sculpture of the exine.

The structure and sculpture of *Tilia* pollen grains have in recent years been treated by Chambers and Godwin (1961, 1971), Praglowski (1962) and Andrew (1971) and the main problems are now solved. In particular the scanning electron micrographs published by Chambers and Godwin in 1971 give a good impression of the so-called bacula-centric reticulation with more or less hollow bacula that forms funnels towards the surface of the grain. The funnels have minute lateral channels which connect the void in the exine with the surface of the funnel.

Both *Tilia cordata* Mill. and *Tilia platyphyllos* Scop. have been studied in a JEOL scanning electron microscope model S 1 at the Geological Survey of Denmark.

The *Tilia cordata* pollen is from tree No. 1504 in section 386 of Draved forest, Southern Jutland, and the *Tilia platyphyllos* pollen is from tree No. 1 on the island in Brændegård lake, Funen. Both collections seem to be representative for the species. The pollen has been treated by acetolysis, coated with coal and gold, and photographed with an accelerating voltage of 10 kV. The magnifications were x 2,000, x 10,000 and x 30,000, while in the plates the magnifications are x 1,500, x 7,500 and x 22,500.

Some pollen grains are heteropolar with rougher sculpture on the distal pole than on the proximal pole (i.e. the pole nearest to the center in the tetrad). The furrows or the pores may also be dislocated a little towards the proximal pole. This heteropolarity is seen in most *Tilia* (plate 11, No. 6, plate 12, No. 6 and plate 14, Nos. 2 and 5) and *Ulmus* pollen grains (Stockmarr, in press), and may also occur in other species. Another feature, in *Tilia* pollen, which is not often seen under the light microscope is that the proximal pole is often divided by three smooth ridges, which match the space between the three other grains in the tetrad. When the pollen grains collapse it is often the proximal pole that falls in, due to the weakness in this end of the pollen grain.

The polar and equatorial views of *Tilia platyphyllos* and *Tilia cordata* are seen in plates 11 and 12. It is seen that funnels with lateral openings are found in both species, but that the funnels are more irregular in *Tilia platyphyllos* than in *Tilia cordata.* On the distal pole, funnels without visible lateral openings are most common in *Tilia cordata.* The funnels on the proximal pole are almost exclusively of the simple type without visible lateral openings in *Tilia cordata,* while in *Tilia platyphyllos* this sculptural type is only found on the proximal pole in a minor part of the grains, as also pointed out by Miss Andrew (l.c.). Unfortunately the micrographs from the proximal pole are not the best ones.

In the light microscope it can be seen that there is a relationship between the sculpture on the two poles, so that grains with a relatively rough distal pole have a relatively rough proximal pole, too, and a similar relationship is found in grains with fine sculpture. It should therefore be sufficient to compare either distal or proximal poles for separating the two species.

In plates 13 and 14 some fractures are shown. Plate 13, Nos. 1 and 3 are from the intercolpium near the furrow and so is No. 5 on the same plate, but from another grain. As *Tilia platyphyllos* has the roughest sculpture, this species has been preferred for the structural studies.

In plate 13, No. 3 are shown two bacula, which in the upper part divide into several branches that together form a funnel, not with lateral channels, but with space between the branches of the bacula. The spaces thus act as channels between the funnel surface and the void. The top of some of these branches are united with the branches of the neighbouring bacula, forming a tectum in a reticuloid pattern which could be called an inter-reticulum. No. 4 in the same plate shows the same feature but from the distal pole and here is seen a short and thick single bacula, the branches of which occupy the main part. No. 5 shows a cut through a bacula with the central channel reaching the foot-layer. This can also be seen in the transmission electron micrographs, and the model, of Chambers and Godwin (1961).

The structural elements may be described as a group of unequally sized columns which are partly fused into a tube-like form in the lower part and a funnel-like form in the upper. No principal difference in structure between *Tilia platyphyllos* and *Tilia cordata* occurs, only a difference in size of the bacula, which may derive from the number of columns that are fused. Some bacula have a long tube and almost no funnel due to a total fusion of the columns.

Acknowledgements. The photographic developing and printing has been carried out by the photographers at the Geological Survey, *O. Neergaard Rasmussen* and *Irma Christiansen*.

Litterature

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Sedimentological and geochemical features of Weichselian tills and pre-Quaternary sediments in Denmark

Knud Binzer

Binzer, Knud: Sedimentological and geochemical features of Weichselian tills and pre-Quaternary sediments in Denmark. *Danm. geol. Unders., Årbog 1973,* pp. 111–131. København, 7. oktober 1974.
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Tills and pre-Quarternary sediments have been analysed. The results of the sedimentological analysis show that the granulometrical composition of the tills is very uniform. With a few exceptions they can be characterized as clayey tills. The chemistry of the tills also shows homogeneity in composition, except in two localities where more than one till is present. Comparison with analyses of pre-Quarternary clays and calcareous sediments shows that the analysed tills have probably inherited most of the element content from local pre-Quarternary sediments.

To provide values from which the heavy-metal contamination of soils can be evaluated, a project supported by Statens teknisk videnskabelige Fond was initiated at the Geological Survey of Denmark and the Mineralogical Institute (Technical university of Denmark) to analyse Weichselian tills, collected from localities all over the country. Besides this pollutional aspect, the aim was to estimate to what degree it is possible to distinguish between tills deposited by glaciers moving from different directions. A further aim was to try to make out from what source the trace element content in the tills was derived.

On the map (fig. 1) the sample localities are shown. Among the investigated localities where tills occurred there have been 4 with more than one till observed and investigated (7: Hven, 9: Feggeklit, 12: Ristinge and 13: Halk Hoved).

Regional geology

The basement for the Quaternary deposits in Denmark consists mostly of soft unconsolidated sediments. In contrast, the pre-Quaternary rocks in Scandinavia consist of hard metamorphic and igneous rocks, but the

Quaternary deposits reveal geological relationships with the neighbouring countries to the north, east and south. A continuation of the Quaternary deposits can be followed from Scandinavia through Denmark to Poland, Germany and Holland. These deposits witness the erosion, transport and sedimentation during the Glacials. Although these deposits do not form a continuous and homogeneous cover, there is good evidence of a common origin.

In Denmark the stratigraphical age of the pre-Quaternary sedimentary series at the base of the Quaternary becomes younger from northeast to southwest (Sorgenfrei and Buch 1959). This distributional pattern of the pre-Quaternary sediments can be explained as an erosional cut through the stratigraphic column by the glaciers. "Pockets" with Cretaceous and Paleocene sediments in Swedish basement rocks (Halland and Scania) show that the borders of the pre-Quaternary sedimentary basins at least sometimes have been more to the northeast than the borders between the sediment series show today.

Quaternary Geology

Geological processes in the Weichselian have been important agents in forming the Danish landscape. Mainly on evidence from indicator boulder analyses (Milthers 1909) and stone countings (Madsen 1928) a hypothetical glacial stratigraphy of the country has been established (K. Milthers 1942, V. Milthers 1948, Hansen 1965). This hypothesis includes glacier advances from different directions at different times in the Weichselian resulting in till-deposits with characteristic stone content. Milthers (1942) tried to divide the tills into three main types, characterised by a stone-content from Norway, Sweden and the Baltic, respectively. The till-types should thus represent glacier movements from north, east and southeast respectively. Lately doubt has arisen as to whether the indicator boulders and stone countings are sufficient basis for the hypothesis of a Weichselian glacial stratigraphy (Marcussen 1973, 1974).

Besides the stone content, tectonic analysis of dislocated cliffs with tills have contributed to the establishment of supposed icepressure directions (Hartz, Madsen and Nordmann 1908, Rosenkrantz 1944, Jessen 1930, Gry 1940, Aabo Rasmussen 1973 and Strand Petersen 1973).

Depositional environment of the tills

The tills were probably deposited in a cold and moist environment. Water has been important as a transporting agent especially in the deglaciation period. The dispersed calcareous material in the tills suggests that the pH of the depositional environment was relatively high. Measurements in unaltered tills show pH-values between 7 and 8 (W. Christensen pers. comm.). The cold and moist depositional environment probably did not increase a chemical alteration that could lower the pH. This suggests that the pH in the environment was alkaline or neutral during the deposition of the tills.

Weathering

The surface deposits have been subject to weathering and soil-forming processes. Under the soil profile the weathering can be seen as a red colouring due to oxidation of the iron compounds in the sediments. Besides the oxidation the sediments are often washed out by percolating rainwater. The calcareous material and to some degree also the iron and manganese are normally washed out to a certain depth under the surface. It is possible to measure within a narrow horizon to what depth the calcareous material has been washed out by the shift from low pH-value to a high pH-value between upper layers without calcareous material and underlying layers rich in calcareous substance. This horizon has been called the "acid front" (W. Christensen 1962).

Material

The analysed samples have been taken from two groups of deposits. One group consists of Weichselian tills and the other of pre-Quaternary sedimentary rocks. The till samples chosen were as little altered as possible by secondary processes (weathering and soil-forming processes). From the tills present at the localities up to 5 samples were taken of 5 kg each. The pre-Quaternary samples were taken in sediment series which had been touched by the glacial erosion and thus constitute the basement of the Quaternary deposits. From each of these sediment series up to 7 samples were taken.

All the samples were collected in cliffs or in open pits, and were taken with a plastic spoon and kept in plastic bags until further treatment. The sediment types and sample localities are shown in fig. 1. The numbers of the different types of sediments which are analysed are listed in table 1.

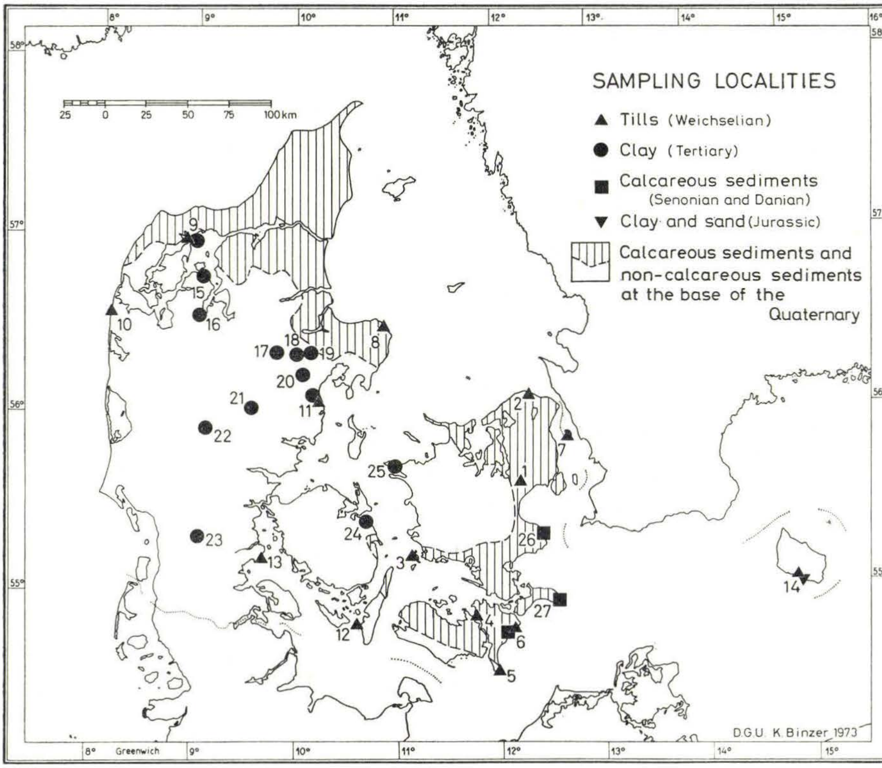

Fig. 1: All sampling localities, except loc. 22 and 23, are placed within the Weichselian glaciated area.

Names of localities: 1 Hedehusene (W), 2 Gilleleje (W), 3 Agersø (W), 4 Alstrup (W), 5 Gedser (W), 6 Pomle Nakke (W and Senonian), 7 Hven (W), 8 Gjerrild (W), 9 Feggeklit (W and Eocene "Moler"), 10 Bovbjerg (W), 11 Århus (W and Eocene), 12 Ristinge Klint (W), 13 Halk Hoved (W), 14 Bornholm (W and Jurassic), 15 Branden (Oligocene), 16 Gammelgård (Eocene), 17 Sofienlund (Oligocene and Miocene), 18 Hinge (Eocene), 19 Ølst (Eocene), 20 Grundfør (Eocene and Oligocene), 21 Salten (Miocene), 22 Brande (Miocene), 23 Gram (Miocene), 24 Lundsgård (Paleocene), 25 Ulstrup (Eocene), 26 Stevns (Senonian and Danian), 27 Møn (Senonian).

"W" indicate Weichelian tills.

Table 1.

No. of samples	Sediment type
72	till
23	Tertiary clay
5	Danian and Senonian limestone
2	Jurassic clay and sand
102	

Methods

The flow-sheet diagram of the analytical procedure of the tills is shown below:

Sample
|
fractionation

separation	grain size analysis
0.032 mm	1.40 – 6 mm
chemical analysis	stone countings

To avoid contamination of the fraction finer than 0.032 mm for the chemical analysis, this fraction was obtained by wet sieving with distilled water through an 0.06 mm nylon sieve and by sedimentation and decanting. The separated fraction for the chemical analysis was dried at 100° C.

The stone countings

After grain size analysis the 1.4–6 mm fraction of the sieved till samples was used for stone counting analysis. The procedure described by Bahnson (1973) was followed, and the analyses were carried out by Sedimentlaboratoriet, D.G.U.

Grain size analysis

The grain size analysis was carried out on the till samples after removal of the material coarser than 2 cm. The grain size distributions for the material bigger than 0.064 mm were found by sieving. The distribution of the smaller fractions was determined by hydrometer analysis. These analyses were also carried out by Sedimentlaboratoriet, D.G..U

Chemical analyses

The major elements Al, Fe, Ca and Mg and the trace elements Mn, Sr, Cr, Ni, Zn, Cu, Co, Li and Pb were determined by atomic absorbtion spectrophometry employing a Perkin-Elmer A.A.S. model 303. TiO_2 was determined by spectrophometry with a Beckman DB spectrophometer. Na_2O and K_2O were determined on an EEL Flame Photometer. SiO_2 was determined by gravmetrical analysis. The rock samples were evaporated with

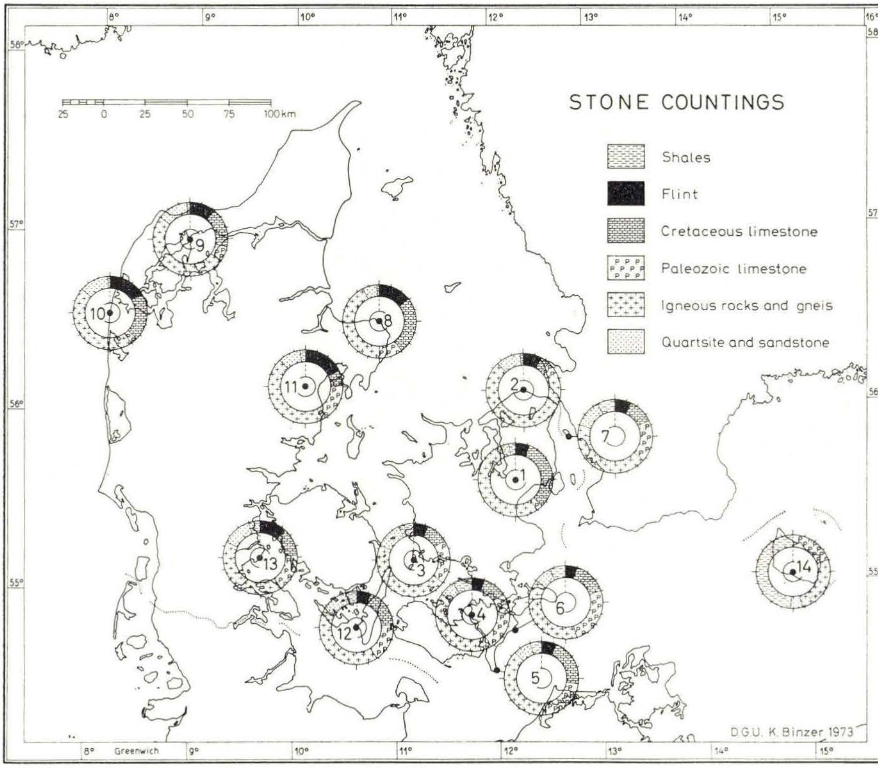

Fig. 2: Each circle represents the relative frequency of six rock types, expressed in percent. The shown distributions are averages from several countings in samples from the localities. In cases of more than one till (loc. 7, 9, 12 and 13), only countings from the uppermost till are shown.

a mixture of HF and $HClO_4$. The residue left, after fuming to dryness, was dissolved in dilute HCl. All the analyses were carried out at the Mineralogical Institute, Technical university of Denmark.

Statistical analysis

The values of the trace-element content and the figures for content of $CaCO_3$ and content of 0.032 mm fractions in the till-samples were analysed statistically by a program edited by J. Thuesen, 1973. The program is written in UNIVAC ALGOL *V*, version NUALGOL, and processes principal component analysis.

Results and discussion

Stone countings

Stone counting analyses primarily provide information about the rock content of the tills. In fig. 2 the results of the analyses are summarised. The rocks have been divided into 6 types and the content of each type is recalculated as percentage of the total counted stones.

Except for locality 14 (Bornholm) there is a suprisingly uniform content of the rock types on the localities. However, Paleozoic limestone, shales and clay-ironstones show a distributional pattern with decreasing content from southeast toward northwest, in accordance with the so-called baltic-ice hypothesis (Milthers 1909, Madsen 1928).

The very high shale content in locality 14 comes from the nearby Paleozoic and Mesozoic sediments in the basement. The content of shales and clay-ironstone in the samples from the localities in the southern part of the country (3, 4, 5, 6, 12 and 13) can be derived from the Tertiary sediments north and northeast of the localities and thus indicate glacier movements from northeast as well as from southeast.

The content of Cretaceous calcareous sediments in tills shows variations that seem to be related to the thickness of the Quaternary deposits at the locality and/or the distance from the locality to Cretaceous sediments at the base of the Quaternary. On fig. 1, the borders between calcareous sedimenι and non-calcareous sediment at the base of the Quaternary are shown. At the localities 1, 5, 6 and 8 the content of Cretaceous sediments is relatively high, in accordance with the thin Quaternary deposits (25–50 m) resting on Cretaceous sediments (fig. 1). At localities 2 and 7 the content is relatively low and here the Quaternary deposits resting on Cretaceous sediments are very thick (more than 75 m). Localities 9 and 10 have high contents, relating to nearby Cretaceous sediments north of the localities and to the ice-pressure direction or glacier movement from north to south (Gry 1940, Nørregaard 1912). At localities 11, 12 and 13 the Quaternary deposits rest on non-calcareous sediments and are situated far from Cretaceous sediments, which results in a relatively low content of these sediments in the tills. At locality 14 there have not been found any Cretaceous calcareous sediments among the stones counted.

The content of Cretaceous sediments in the tills from localities 3 and 4 are unexpectedly low, considering the thin Quaternary deposits (less than 25 m) resting on the Cretaceous. A possible explanation can be that the tills are deposited by glaciers moving from north and north-east across large areas with Tertiary non-calcareous sediments. This suggestion is in opposition to the distributional pattern of Paleozoic limestones, which show spreading from south-east. However there is no evidence against the possibility that the different limestones in the same till can show distributional patterns that reflect glacier movements from north-east as well as from south-east.

The importance of the stone content for evaluation of the chemical Analyses.

In this investigation the grain-size (Søndergaard 1959) and the number of stones counted (Lundquist 1952) should ensure that the apparent tendency of distributions of the rocks in the tills is reliable. Only limestones and shale- and clay-ironstones show regional variations. It has been shown that limestones contribute trace-elements at a level below the analytical precision worked with (Binzer 1973). The content of shale- and clay-ironstones are very low (less than 10 %) with one exception (locality 14) and can be ignored.

The stone content in the tills can thus be regarded as being so uniform that no essential source of variation in the element content has been excluded by analysing chemically only the 0.032 mm fraction of the tills.

Grain size distribution

The till samples were grain size analysed and the distribution curves are summarised in fig. 3. The figure shows that only two samples contain less than 10 % clay. For the comparability of the chemical analyses it is important to know how much the fraction less than 32 μ constitutes of the tills. In fig. 4 the distribution of the ÷ 32 μ fraction of the samples is shown. The samples can be divided in three groups and it appears that in most of the samples the ÷ 32 μ fraction constitutes about 50 % of the tills.

Besides granulometrical distribution the grain size curves also provide information of a change in nature of the tills from dominance of rock fragments to dominance of mineral grains. (Beaumont 1971). In this investigation this change appears in the grain size range 0.1–0.7 mm as a break of slope in the grain size curves. Another break of slope appears at 0.064 mm and is ascribed to difficulties in connecting the results of the sieve analysis with the results of the hydrometer analysis. Examples showing breaks of slopes in the curves at different grain sizes are shown in fig. 5.

The grain size analyses have shown that all the samples except 2 are clayey tills, that the chemically analysed fraction (÷ 32 μ) constitutes about

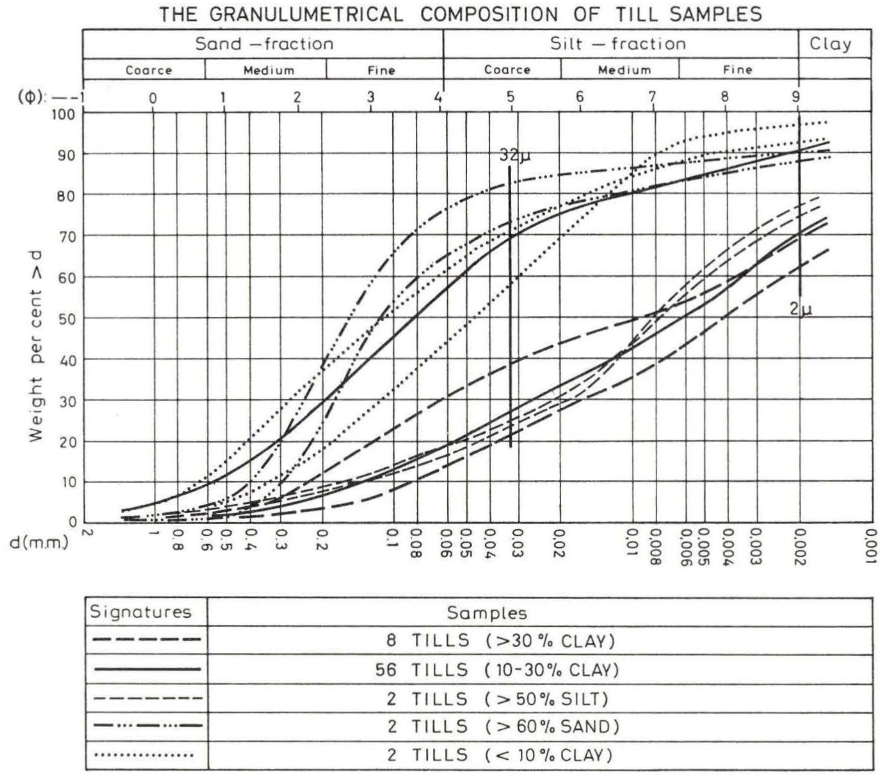

Fig. 3: The full lines show the area within which run distributional curves for 56 samples. The same applies to 8 samples within the thick dashed lines.

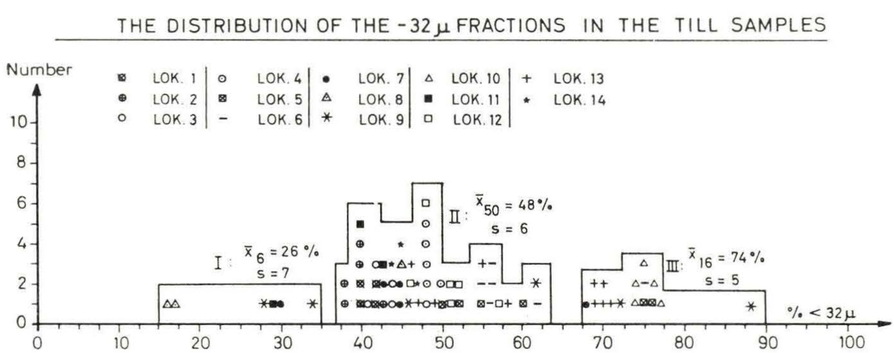

Fig. 4: The diagram shows the proportion of the till samples constituted by the fraction less than 0.032 mm. It is seen that the fraction less than 0.032 mm constitutes more than 40 % of most of the samples.

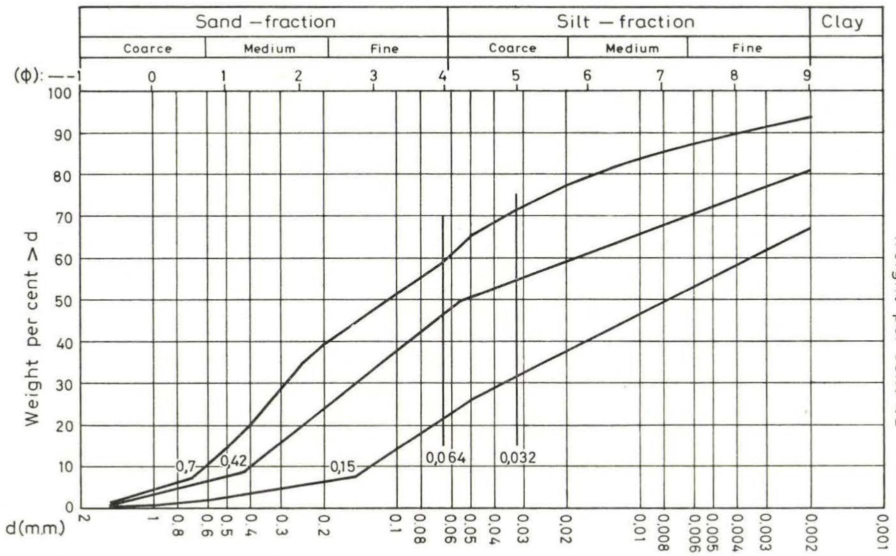

Fig. 5: Distributional curves with breaks of slope for 3 samples from loc. 7, shown as examples. The breaks in the coarse end are ascribed to a change in nature of the tills from dominance of rock fragments to dominance of mineral grains. The breaks of slope around 0.064 mm are ascribed to difficulties in connecting sieve analyses with hydrometer analyses.

50 % in most of the samples, and lastly that this fraction will be free of rock fragments.

Chemical analyses

The results of the chemical analyses are given in table 2. In table 3 the average composition of the tills for major elements is shown. The average trace element content of the tills, recalculated on $CaCO_3$ free basis, and the average contents of the pre-Quaternary formations are given in table 4.

Major elements. The figures from table 2 for K_2O, Na_2O, MgO, Fe_2O_3 and Al_2O_3 have been recalculated and plotted in triangular diagrams (fig. 6 and 7) to facilitate comparison. All the chemical data plotted are recalculated to mol percentages of basic oxides.

In fig. 6, besides Danish tills, Norwegian till analyses (E. Roaldset 1972) have been recalculated and plotted. Furthermore, analyses of Swedish basement rocks (granite and gneiss), Bredvad porphyry (Törnebohm 1901), and Rapakivi porphyry (Sahama 1945) are plotted together with mineral analyses (Deer, Howie and Zussman 1966), an earthcrust average (Krauskopf 1967) and the mean values of Norwegian loams (Goldschmidt 1954).

The Danish tills (except one analysis) plot within an area (the rhomboidal figure) of less than 2 percent of the triangular diagram and thus vary negligibly. The Norwegian tills are more scattered, and except for three analyses plot outside the Danish tills. The rock analyses plot outside the rhomboidal area, though the granite and gneiss lie closer than the porphyries. The earthcrust average (E on the figure) and the Norwegian loams (G on the figure) also plot outside the rhomboidal area, but lie among the Norwegian tills.

The analysis of the clay fraction (sample OlB) of one of the till samples plots close to the middle of the rhomboidal figure showing no difference in chemical composition between the clay fraction and the $-32\ \mu$ fraction of the till. This is consistent with studies on factors affecting the composition of argillaceous sediment (Englund and Jørgensen 1973), which concluded that moderate variations in grain size distribution have only a small effect upon the bulk chemistry. Among the mineral analyses plotted it is noteworthy that illite (7 in the figure) plots close to the till analyses and within the rhomboidal area.

In the triangular diagram fig. 7 the rhomboidal figure, the granite- and gneiss analyses and the earthcrust average from fig. 6 are shown together with plots of the analyses of the pre-Quaternary samples.

World averages of analyses of carbonate rocks (C), basalts (B), sandstones (S), granite (G) and shales (Sh) taken from Krauskopf (1967) are shown. The average of 68 analyses of Danish tills are also plotted (▲).

The plots of the analyses of the pre-Quaternary samples are more scattered than the till analysis, but three groups can be distinguished. One group of 5 samples, to the left of the till analyses, consists of 2 samples from loc. 17 and 20 containing glauconite; one sample from loc. 19 contains volcanic ash, and 2 samples from loc. 9 consist of marine diatomit (Moler). Another group of 6 samples to the right of the till analyses consist of 2 samples from Jurassic limnic sediments in loc. 14, 2 samples of limnic sediments from loc. 17 and 21 and 2 samples from loc. 22 taken outside the Weichselian glaciated area. In general most of these samples are taken from layers with a small stratigraphic or regional distribution.

The last group of 14 samples lies close to or inside the rhomboidal figure containing the till analyses. The samples consist of marine clay sediments taken from localities within the Weichselian glaciated area, with the exception of 2 samples from loc. 23. It seems from these plots that the till analyses resemble the pre-Quaternary analyses, with respect to the elements

Table 2 Chemical composition of tills and pre-Quaternary sediments. Major elements in percent and trace-elements in p.p.m.

TILL SAMPLES Loc.	Smp.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	CO_2	Li	Cr	Mn	Co	Ni	Cu	Zn	Sr	Pb
1	1A	43.00	0.42	9.00	4.06	1.24	20.92	0.87	1.80	17.79	17	45	374	< 5	30	18	32	505	39
	1B	30.00	0.56	12.00	3.89	1.74	22.65	0.93	2.28	18.94	31	71	438	10	37	29	83	504	46
	80	43.97	0.56	11.52	4.15	1.96	17.84	1.10	2.31	13.88	39	67	443	17	52	28	82	328	28
	81	45.28	0.55	10.72	3.82	2.07	18.44	1.14	2.29	13.98	26	66	486	8	51	27	65	313	20
	82	43.91	0.59	10.95	3.86	1.92	18.13	1.16	2.47	14.12	26	60	458	34	39	27	73	332	21
	83	42.08	0.55	11.30	4.20	2.01	18.26	1.09	2.47	14.72	28	67	535	28	47	30	70	334	29
2	75	52.48	0.70	14.25	5.48	1.43	8.51	1.47	2.90	7.08	32	65	509	20	35	29	20	221	35
	77	56.48	0.74	13.51	4.80	2.14	9.25	1.77	2.63	6.57	33	75	431	17	35	31	97	206	31
	78	55.31	0.72	14.50	5.26	2.21	8.62	1.57	3.25	6.16	36	76	404	15	31	33	106	197	15
	79	55.56	0.74	13.51	3.42	1.56	8.62	1.67	2.80	6.46	33	71	425	16	41	29	77	194	15
3	4	39.71	0.46	10.27	3.70	1.77	20.33	0.88	2.16	17.30	24	48	319	7	25	22	87	353	15
	7	39.81	0.49	10.32	3.73	1.72	20.17	0.83	2.14	17.20	23	44	365	10	28	23	26	316	25
4	9	36.37	0.49	11.03	4.13	1.48	20.37	0.73	2.22	17.90	25	57	351	5	29	23	51	314	20
	10	36.00	0.53	12.00	3.66	1.62	20.62	0.69	2.30	17.94	23	63	366	< 5	23	27	71	299	55
	11	47.25	0.61	13.36	4.95	1.76	12.21	0.92	2.52	10.74	27	60	377	10	31	26	63	226	15
	12	37.63	0.49	11.01	4.10	1.71	19.87	0.78	2.27	17.38	28	41	333	18	30	26	51	330	30
5	13	40.50	0.69	11.50	3.08	1.86	17.93	0.81	2.30	15.08	25	62	373	5	28	25	56	268	38
	14	42.50	0.57	11.50	3.71	1.18	17.77	0.84	2.40	15.46	26	33	332	9	22	24	64	287	45
	15	42.50	0.75	11.00	2.96	2.07	17.45	0.83	2.36	13.83	26	69	414	4	27	22	64	266	30
	16	43.00	0.53	11.00	3.69	1.66	16.49	0.89	2.36	13.99	24	59	355	5	21	30	91	235	50
	17	44.50	0.63	11.50	3.72	1.99	15.12	0.91	2.42	15.08	26	68	386	5	28	28	67	263	37
6	18	43.00	0.64	12.00	4.70	2.13	17.76	0.88	2.54	13.83	30	63	388	9	16	25	62	300	45
	19	46.00	0.64	12.00	4.49	2.36	18.05	0.77	2.53	14.32	32	58	427	9	22	25	65	286	50
	20	43.50	0.62	11.50	4.21	1.96	15.60	0.83	2.40	13.96	28	54	430	5	17	31	90	264	57
	21	43.00	0.56	11.50	3.72	2.19	21.53	0.80	2.42	15.08	28	64	443	4	23	24	56	251	43
	22	47.00	0.68	11.50	3.64	2.30	13.47	0.80	2.48	12.82	27	67	531	8	27	21	58	199	43
	25	43.00	0.63	11.50	4.05	2.07	18.14	0.75	2.44	15.58	28	67	505	4	34	24	60	314	-
7	70	45.50	0.60	12.00	3.62	1.53	14.76	0.87	2.33	12.20	25	68	405	12	24	23	77	407	-
	71	41.00	0.66	12.50	3.96	1.54	16.26	0.63	2.26	12.82	21	86	346	6	24	23	81	391	-
	72	41.00	0.67	12.00	3.45	1.66	15.89	0.90	2.21	12.68	20	75	319	< 5	28	16	90	194	-
	73	55.88	0.77	14.77	5.72	1.79	5.85	1.41	3.12	5.53	38	70	474	14	38	25	34	167	20
	74	50.00	0.74	15.50	4.75	1.55	7.44	1.37	3.15	5.46	36	90	652	21	39	26	89	505	-
8	39	36.00	0.73	12.50	4.26	3.20	20.47	0.63	2.53	17.06	34	71	468	< 5	30	29	59	316	40
	40	39.50	0.54	10.50	3.75	2.21	25.41	0.73	1.97	20.74	25	59	418	< 5	19	26	56	414	25
	41	20.78	0.26	5.32	1.36	0.93	37.51	0.30	0.93	30.35	15	40	260	19	24	20	47	819	41
	42	29.50	0.49	8.00	3.75	1.14	25.41	0.52	1.44	22.68	18	63	399	< 5	15	18	37	616	50
9	26	66.50	0.87	14.50	5.83	1.68	0.81	0.86	1.93	0	33	42	381	11	21	44	181	156	40
	27	61.89	0.86	15.76	7.15	1.67	0.35	1.16	2.82	0	30	62	518	12	44	43	128	119	30
	28	60.00	0.96	15.50	7.66	2.03	0.94	1.26	2.74	0	35	76	450	21	37	61	162	136	40
	29	59.50	0.96	17.00	9.00	1.65	0.98	1.17	2.25	0	39	79	532	23	48	57	103	130	65
	30	47.00	0.92	13.00	5.22	2.18	15.55	1.08	2.28	11.22	33	63	427	< 5	28	38	69	300	45
	31	40.00	0.51	14.50	5.23	2.09	17.60	0.77	3.12	13.22	40	70	545	9	27	32	78	342	200
10	34	46.00	0.69	11.50	4.46	2.20	18.56	0.88	2.66	11.45	34	82	469	8	43	29	70	294	36
	35	46.00	0.72	14.00	5.23	2.36	14.80	0.93	2.63	11.40	42	68	497	< 5	34	28	59	340	55
	36	45.50	0.92	14.00	5.23	2.40	14.80	0.88	2.58	11.06	37	74	570	< 5	39	34	79	314	55
	37	45.50	0.83	14.00	5.23	2.36	14.80	0.93	2.64	11.66	39	70	464	< 5	37	27	89	316	50
	38	48.00	0.75	13.50	4.85	2.45	14.80	0.91	2.65	10.52	35	66	557	< 5	31	26	66	334	45
11	44	59.00	0.98	19.00	7.99	2.36	0.85	1.07	3.15	0.08	40	107	850	< 5	62	51	190	96	20
	46	62.00	0.91	18.00	5.42	1.89	1.16	1.66	3.72	0.16	36	83	498	16	44	32	98	119	37
	47	51.70	0.68	14.50	4.71	1.99	11.69	0.87	2.38	10.14	38	85	877	14	56	34	98	225	37
12	48	37.50	0.57	12.00	3.91	1.99	18.56	0.64	2.36	16.02	29	73	412	< 5	34	26	68	339	51
	50	31.00	0.51	9.50	2.16	1.72	24.41	0.56	1.65	21.35	15	76	392	9	24	22	96	535	-
	52	35.50	0.75	9.00	2.23	1.79	25.87	0.62	1.45	20.24	11	74	362	6	13	10	99	334	-
	53	44.16	0.61	12.19	4.43	2.47	15.40	0.78	2.73	13.10	33	50	424	12	33	23	44	255	40
	54	44.47	0.58	10.88	3.89	2.19	15.36	0.84	2.61	13.26	27	58	440	16	28	21	65	279	35

Loc.	Smp.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	CO_2	Li	Cr	Mn	Co	Ni	Cu	Zn	Sr	Pb
13	55	56.49	0.90	17.55	8.71	1.81	0.56	0.80	2.88	0	55	109	978	29	88	38	51	108	25
	56	67.42	1.00	14.94	5.92	1.39	0.42	1.32	2.66	0.14	33	87	588	20	63	30	76	75	30
	57	38.00	0.73	10.50	3.17	1.33	19.88	0.53	1.46	17.32	18	74	1163	14	39	22	100	391	-
	58	33.64	0.56	10.28	4.03	1.03	20.31	0.57	1.74	17.21	28	63	365	13	40	29	23	370	25
	59	37.97	0.54	10.30	3.58	1.04	20.36	0.57	1.81	17.32	28	62	387	11	30	25	65	389	20
	60	39.00	0.61	10.50	3.20	1.33	19.34	0.60	1.72	17.06	25	67	1261	14	47	27	82	390	-
	61	38.00	0.67	11.00	3.50	1.34	19.29	0.57	1.67	17.14	22	66	1167	12	41	25	80	329	-
	62	31.50	0.59	10.50	2.67	1.61	22.64	0.51	1.70	19.67	22	64	398	12	28	14	67	384	-
	63	42.00	0.59	11.00	3.25	1.87	17.46	0.66	1.94	14.52	21	68	426	13	27	14	67	313	-
	64	39.00	0.59	10.50	3.32	1.77	19.98	0.60	1.96	17.64	27	63	447	19	32	15	63	378	-
14	65	47.50	0.87	13.50	4.55	2.17	12.12	0.97	2.59	8.00	22	85	473	16	41	26	100	216	-
	66	52.00	0.69	12.50	4.16	1.82	9.39	1.04	2.80	6.22	28	80	426	15	34	20	88	268	-
	67	51.00	0.81	14.00	4.75	1.77	8.09	0.97	2.74	6.22	25	92	420	15	36	29	101	185	-
TERTIARY																			
Loc.	Smp.																		
9	32	53.06	1.96	10.67	7.69	2.02	2.97	1.02	1.36	0	69	82	124	24	34	170	98	122	8
	101	58.80	2.37	12.73	10.73	2.12	1.78	2.01	1.21	0	62	74	99	20	20	220	125	83	< 5
11	43	32.62	-	10.66	4.29	1.07	-	0.24	1.66	-	64	93	377	39	116	50	198	756	-
15	102	59.71	0.83	17.00	7.31	1.84	1.39	0.60	2.71	0.52	63	105	110	16	56	19	58	114	10
16	103	57.95	0.83	17.46	7.51	1.82	0.81	0.87	4.12	0	46	137	102	21	40	20	101	168	15
17	104	56.34	1.19	26.79	3.22	0.98	0.15	0.35	2.46	0	62	87	59	16	50	15	48	67	35
	105	47.59	0.86	17.10	23.62	1.82	0.49	0.49	3.38	0	44	238	99	17	47	18	81	109	10
	106	65.13	0.84	11.98	6.55	1.84	2.32	0.87	2.12	0.63	26	101	225	26	45	18	105	135	10
18	110	54.04	1.23	14.73	9.35	1.97	0.42	0.56	2.69	0	39	84	98	21	25	175	104	806	10
	111	54.21	2.67	14.67	11.95	3.12	2.04	1.10	2.07	0	74	56	270	35	65	200	178	1213	10
19	107	53.76	0.84	20.66	10.07	2.32	0.73	0.47	3.18	0	59	108	593	54	136	49	139	239	15
	108	52.26	1.32	20.24	11.78	2.42	1.58	0.58	2.81	0.24	65	88	3832	52	171	80	131	299	10
	109	49.94	3.66	17.78	14.73	10.00	2.88	1.44	1.71	0.11	38	74	129	98	127	280	231	736	5
20	112	22.71	0.40	9.06	4.05	1.33	29.23	0.59	1.05	24.94	29	42	547	23	64	38	92	1033	10
	113	47.46	0.80	16.77	7.18	2.06	9.74	1.01	2.59	7.20	44	99	188	22	39	23	97	525	15
	114	45.96	0.64	13.01	19.71	1.68	0.46	0.85	3.60	0.10	36	200	181	25	62	10	80	96	30
21	115	33.64	1.02	17.95	6.01	1.08	0.28	0.26	2.50	0	42	77	185	11	44	17	47	41	15
22	116	48.63	0.96	27.99	6.22	1.06	0.15	0.37	2.09	0.20	79	80	148	18	67	28	65	48	30
	117	50.22	1.04	20.22	6.25	1.03	0.20	0.35	2.07	0	79	90	145	20	69	29	64	84	25
23	118	59.89	0.96	18.45	8.52	1.58	0.80	0.54	2.29	0.46	60	90	200	18	41	19	83	122	15
	119	55.28	0.98	21.94	8.81	1.58	0.99	0.57	2.31	0.52	70	98	208	23	50	21	80	157	15
24	120	14.80	0.06	6.32	1.94	0.76	40.26	0.42	0.47	33.91	5	24	932	14	27	16	31	992	25
25	122	45.84	1.05	19.31	11.71	2.27	5.67	0.81	2.47	4.34	73	66	5374	42	126	85	113	325	10
CALCAREOUS																			
Loc.	Smp.																		
6	24	1.22	-	0.21	0.02	0.31	-	0.09	0.11	-	2	< 5	261	< 5	< 5	6	16	615	-
26	Stevns 1	1.38	-	0.20	0.10	0.66	-	0.24	0.14	-	2	< 5	215	< 5	8	7	88	599	-
	Stevns 2	1.31	-	0.12	0.08	0.36	-	0.07	0.07	-	< 1	< 4	166	< 5	< 5	7	65	839	-
27	Møn 1	1.49	-	0.16	0.04	0.21	-	0.09	0.09	-	< 1	< 5	96	< 5	11	7	31	628	-
	Møn 2	1.37	-	0.11	0.04	0.19	-	0.09	0.07	-	< 1	< 5	94	< 5	< 5	6	26	698	-
JURASSIC																			
Loc.	Smp.																		
14	68	67.00	1.21	16.00	1.17	0.58	0.34	0.27	1.26	0	77	114	98	20	37	15	69	97	-
	69	90.00	0.68	3.00	0.27	< 0.05	< 0.05	0.12	0.25	0	4	41	41	< 5	10	< 5	26	37	-

Missing analyses are indicated by a stroke.

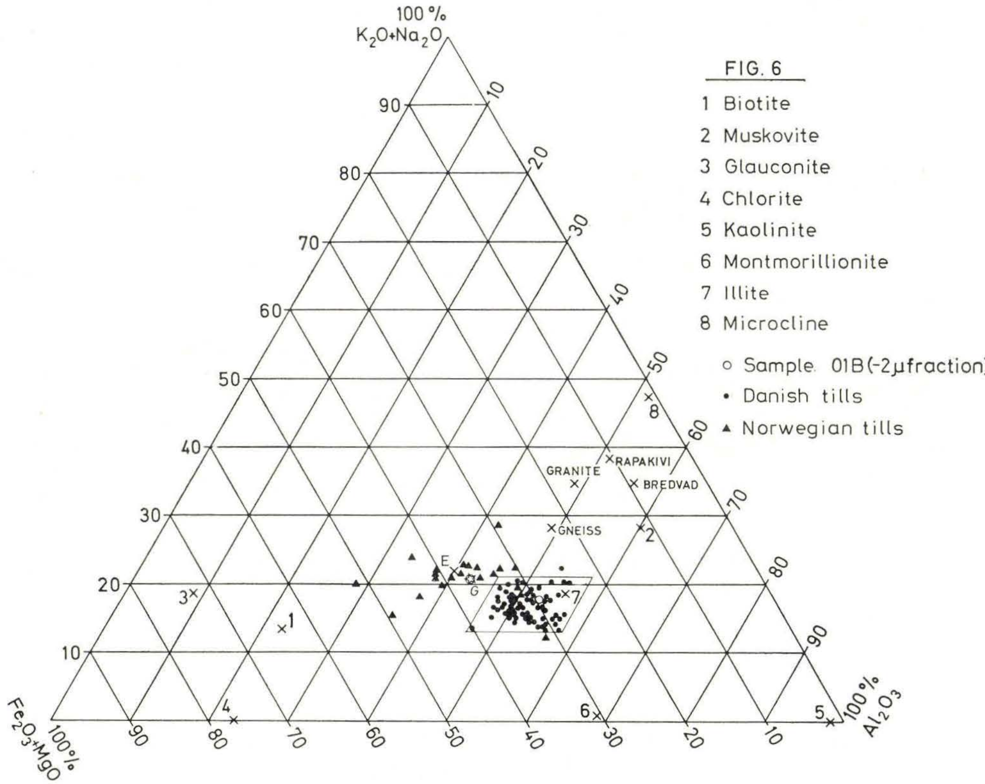

Fig. 6: The relative frequencies of the shown oxides reveals that the Danish tills (68 analyses) plot within a small area (the rhomboidal figure), while the Norwegian tills (22 analyses) are more scattered and plot outside the rhomboidal area. The mineral analyses, except illite, also plot outside the area. The rock analyses of granite, gneiss and Bredvad porphyry from Sweden and Papakive porphyry from Finland also plot outside, through the granite and gneiss lie closer to the rhomboidal figure. An earth-crust average (E) and Norwegian loams (G) also plots outside the area of the Danish tills.

used in the triangular diagram, more than they resemble Scandinavian basement rocks. Lastly it should be noted that the world average of shales lies within the area of the till analysis.

The major elements analysis has shown that the till samples analysed are very simiiar in composition and that the Weichselian tills in Denmark may be regarded as a chemically rather well-defined rock type. In table 3 the average composition of the tills has been calculated.

FIG. 7

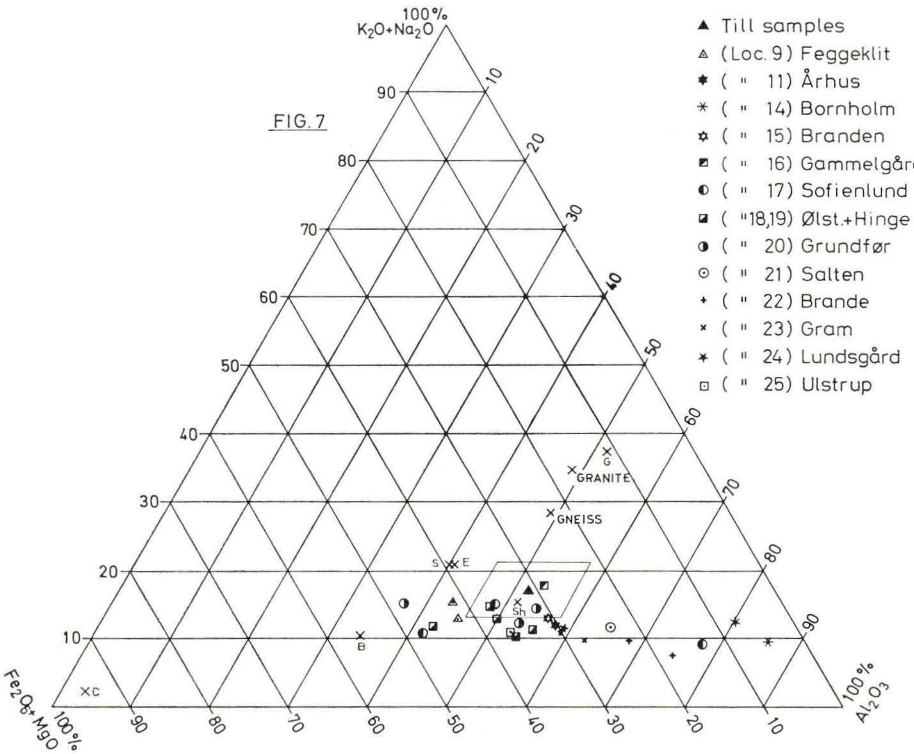

Fig. 7: The rhomboidal figure of the till analyses, the granite and geniss analyses and the earthcrust average from fig. 6 are shown together with world averages of carbonate rocks (C), basalts (B), granite (G), sandstone (S) and shales (Sh). The average of 68 analyses of Danish tills is also shown (▲).

The rest of the plots are pre-Quaternary local non-calcareous sediments. Roughly 3 groups of analyses can be distinguished: One group of 5 samples to the left, and another group of 6 samples to the right of the rhomboidal area. A larger group of 14 samples plots closer to or within the rhomboidal area and thus resembles the till analyses.

Table 3. Average composition of ÷ 32 μ fraction of the till samples.

	$\bar{X}_{68}$ %	s %
SiO_2	44.81	8.95
TiO_2	0.67	0.15
Al_2O_3	12.30	2.23
Fe_2O_3	4.28	1.37
MgO	1.84	0.40
CaO	16.54	10.94
Na_2O	0.89	0.30
K_2O	2.40	0.47
CO_2	12.50	6.31

From the figures in table 3 the content of calcite in the avarage till has been calculated to 28.4 %. On the basis of the Al_2O_3 and SiO_2 content of an illite analysis (Deer *et al.* 1966) the possible content of this mineral in the average till has been calculated. Based on these contents of calcite and illite the relative frequency of possible minerals of the tills has been estimated as follows:

Calcite	3
Illite	6
Quarts and other silicates	1

Illite seems to constitute an important part of the till; this is also indicated by the illite analysis shown in the triangular diagram fig. 6. Preliminary X-ray investigations of the clay fraction of the samples also show that clay minerals from the illite-group possibly form the major clay minerals in the tills.

Trace elements. The sedimentological investigations and the major element analyses have shown that the analysed till samples vary only little and that they constitute a uniform background on which regional and stratigraphical variations of the trace elements can be evaluated.

In table 4 are listed figures from table 2, showing the trace element content in Cretaceous (Møn 2) and Paleocene, and the average contents for Eocene, Oligocene and Miocene. The average trace element content of the tills recalculated on $CaCO_3$ free basis is also shown. This is done because the $CaCO_3$ content in most of the samples is high and variable, and it has been shown (Binzer 1973) that the pre-Quaternary calcareous sediments from which the $CaCO_3$ in the tills is predominantly derived do not contribute significantly to any of the trace elements analysed for, except for Sr. Furthermore it is expedient to exclude the $CaCO_3$ for the sake of comparisons with similar materials poor in $CaCO_3$.

The tendency of regional distribution of trace elements has previously been discussed (Binzer 1973) and it was shown that there is a little higher content of Li, Cr and Ni in the northern part of the country. It was also shown that in loc. 9 with more than one till the content of Co, Ni, Cu and Zn in the uppermost till was higher than in the underlying tills. Likewise in loc. 13 it was shown that the content of Mn and Ni in the one upper till present was significantly higher than in the lower till. The Cu content in the upper till was also slightly higher.

In fig. 8 the values from table 4 have been represented graphically to

Table 4

Avarage trace-element content in tills and pre-Quaternary sediments. Values in p.p.m.

		Li	Cr	Mn	Co	Ni	Cu	Zn	Sr	Pb x)
WEICHSELIAN TILLS N=68	max	67	122	1931	49	88	88	193	819	43
	$\bar{x}$	38	92	680	15	45	41	105	292	28
	s	8	19	279	9	13	19	32	113	8
	min	21	22	447	5	21	20	23	75	15
MIOCENE N=5	max	79	98	208	23	69	29	83	157	13
	$\bar{x}$	66	87	177	18	54	22	67	90	20
	s	13	7	26	3	11	4	12	44	6
	min	42	77	145	11	41	17	47	41	15
OLIGOCENE N=7	max	63	238	225	26	62	23	105	525	35
	$\bar{x}$	45	138	137	20	48	19	81	173	17
	s	12	54	55	3	7	2	20	146	9
	min	44	87	59	16	39	15	48	67	10
EOCENE N=8	max	74	108	5374	98	171	280	231	1033	15
	$\bar{x}$	54	74	1367	93	140	139	139	591	9
	s	19	19	1915	52	83	42	42	385	3
	min	29	42	99	21	25	38	92	83	5
PALEOCENE		5	24	932	14	27	16	31	992	25
CRETACEOUS		< 1	< 5	94	< 5	< 5	6	26	698	-

The values of the tills are recalculated on $CaCO_3$-free basis, except Sr.

x) Pb values of the tills are calculated on analyses of 30 samples.

show the trace element variation in the stratigraphic column from the Cretaceous to the Quaternary. It appears that the Tertiary includes formations which have a higher trace element content than the Quaternary tills. This together with the major element analyses, supports the idea, that the tills have inherited most of their element content from local Tertiary clay formations in the same way that they have inherited the $CaCO_3$ content from the local pre-Quaternary calcareous sediments (Binzer 1973).

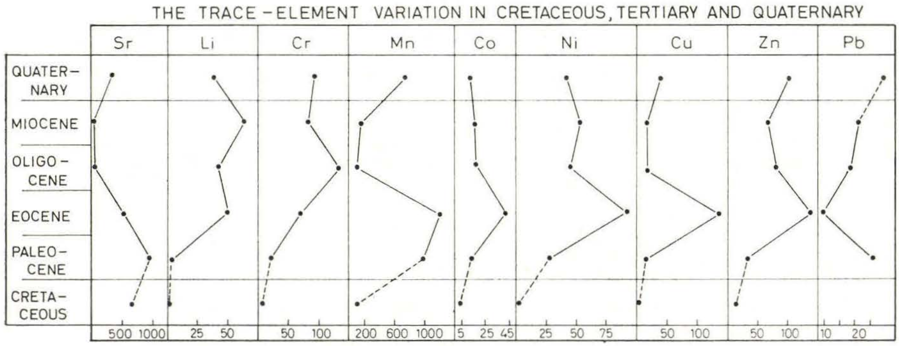

Fig. 8: The variation in the content of trace elements of the stratigraphic colum from Cretaceous to Quaternary is shown. It appears from the graph that the Tertiary includes formations with a trace element content higher than the Quaternary tills. Only Pb shows a slightly higher value in the Quaternary.

Summary of the chemical analyses. This investigation shows that the clayey tills analysed here have a surprisingly uniform chemical composition though the tills reveal a confusing mess in appearance as well as genetically. It appears furthermore that the Danish tills are to a great extent a sediment of local origin with only a low content of exotic material. This observation is consistent with analyses of clays from Fennoscandia (Soveri 1950) showing relationship between the local basement rocks and the clay mineral composition in the Quaternary clays.

Statistical analyses

The 9 trace elements analysed for (Sr, Li, Cr, Mn, Co, Ni, Cu, Zn and Pb), the $CaCO_3$ content and the -32 μ fraction of 67 till samples were statistically treated by correlation analysis. The strong correlation between Sr and $CaCO_3$ previously shown (Binzer 1973) was confirmed.

Acknowledgements. This work was carried out during the period August 1971 to February 1973. Statens teknisk videnskabelige Fond made it possible to make the investigations and is gratefully thanked.

I wish to express my graduate to prof. dr.phil. *H. Pauly* of the Mineralogical Institute, Technical university of Denmark and to director, dr.phil. *O. Berthelsen* of the Geological Survey of Denmark, who took personal interest in the project. A special word of thanks is due to lecturer, mag. scient. *Troels V. Østergård* for discussions and fruitful criticism during the work. I am also indebted to members of the staff of the Geological Survey of Denmark for help and suggestions, especially to State Geologist dr.phil. *Helge Gry.*

Dansk sammendrag

Sedimentologiske og kemiske undersøgelser er blevet udført på prøver af moræneler fra weichsel-istiden og prøver fra præ-kvartære aflejringer (se fig. 1). Undersøgelsens omfang og forløb er skitseret i diagrammet side 115.

De sedimentologiske undersøgelser bestod i stentællinger og kornstørrelsesanalyser. Resultaterne af disse undersøgelser er fremstillet grafisk i fig. 2, 3, 4, og 5. Det konkluderes at det undersøgte moræneler er af så ensartet beskaffenhed at det er tilladeligt at drage sammenligninger mellem kemiske analyser af prøverne.

De kemiske undersøgelser har omfattet analyser af morænelerets finfraktion (mindre end 0,032 mm) og, til sammenligning, af udvalgte prækvartære ler- og kalk aflejringer (se fig. 1). Følgende hovedelementer er blevet bestemt: Si, Al, Fe, Mg, Ca, Na, K samt følgende sporelementer: Sr, Li, Cr, Mn, Ni, Cu, Co, Zn og Pb (se tabel 2). I trekantdiagrammet fig. 6 er de relative mængder mellem K_2O, Na_2O, MgO, Fe_2O_3 og Al_2O_3 for hver af de analyserede morænelerprøver blevet indsat. Desuden er til sammenligning indsat analyser af norske morænelersanalyser og andre bjergarts- og mineralanalyser. Diagrammet viser at det danske moræneler ligger indenfor et område der udgør mindre end 2 % af hele trekantdiagrammet og de analyserede prøver må således siges at variere ubetydeligt. Det norske moræneler ligger udenfor det danske moræneler og mere spredt. De øvrige anførte analyser bortset fra lermineralet Illit (nr. 7 i diagrammet) ligger ligeledes udenfor. I trekantdiagrammet fig. 7 sammenlignes morænelersanalyserne med analyser af de prækvartære leraflejringer. Yderligere er der indsat analyser af andre bjergarter, bl.a. granit og gnejs fra det skandinaviske grundfjeldsområde. Det fremgår af diagrammet at der er større lighed mellem moræneleret og de lokale, danske præ-kvartære lersedimenter end mellem moræneleret og de skandinaviske bjergarter.

Den gennemsnitlige sammensætning af de analyserede morænelersprøver er anført i tabel 3. På grundlag af dette gennemsnit og på grundlag af en analyse af Illit er det mulige indhold af dette mineral blevet beregnet. Ligeledes er indholdet af $CaCO_3$ (Kalkspat) blevet beregnet. Forholdet mellem følgende mulige mineralsammensætning i moræneleret er derefter blevet estimeret til: Kalkspat 3, Illit 6, Kvarts og andre silikater 1.

Sporelementindholdet i moræneleret har vist sig at være meget ensartet, bortset fra et lidt højere indhold af Li, Cr og Ni i den nordlige del af landet. På lokalitet 9 og 13 kunne der vises en vis forskel i sporelementindholdet mellem 2 morænelersbænke. I fig. 8 er sporelement-variationen (taget fra tabel 4) i prøver taget i formationer der repræsenteter tidsrummet fra kridt til kvartær blevet grafisk afbilledet. Det fremgår heraf at tertiæret indeholder formationer, der har et højere sporelementindhold end moræneleret. Dette, sammen med hovedelementanalyserne, støtter tanken om at moræneleret har arvet det meste af sit sporelementindhold fra de lokale tertiære lerformationer.

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ESR investigations of humic acids

Jens Arne Pedersen and Arne Villumsen

Pedersen, Jens Arne and Villumsen, Arne: ESR investigations of humic acids. *Danm. geol. Unders., Årbog 1973,* pp. 133–140. København, 7. oktober 1974.

Investigations of humic acids (HA) extracted from fossil Danish peat and soil samples have confirmed that by the ESR method it is possible to distinguish between HA formed under acid conditions (raised bog peats, mor) and HA originating from more alkaline environments (fen peat, mull), as suggested by Atherton *et al.* (1967). An analogous classification for recent soils (mor and mull) does not seem to be possible in our case, however, presumably because the samples contain relatively simple organic molecules (originating from partly humified material) in addition to the HA fraction. – With the ESR technique no differences can be observed between different mor types (coprogenous mor, mycogenous mor), and variation in the degree of humification of raised bog peats seems only to influence the intensity of the ESR signal.

The term "humic acid" has been used with various meanings in the geological literature. The difficulty of precisely defining a humic acid (HA) has been the main reason for this confusion. By a humic acid we mean in the present context that portion of soil organic matter (humus) which is soluble in sodium hydroxide solution and which is precipitated by acidification of the alkaline extract with hydrochloric acid.

HA's are formed in nature in connection with the microbiological degradation (humification) of organic matter. Since the humification is most intense under aerobic conditions, the largest HA production generally takes place in the upper drained layers of peat bogs or on land. Under anaerobic conditions the HA production is quantitatively minor (Teichmüller & Teichmüller 1967). This explains why one often finds strongly humified fossil peat layers alternating with weakly humified ones (see f.ex. Bahnson 1968).

The chemical constitution of HA's is more or less unknown (Degens 1967) although new light has been shed on their composition from recent degradation studies (Schnitzer and de Serra 1973). Such studies have emphasized once more the complexity of HA's and made it obvious that a single HA structure scarcely exists.

One of the spectroscopic methods which in recent years has received increasing interest for characterization of HA's is the electron spin resonance (ESR) method.

Humic acids exhibit paramagnetism in the solid state, as was first observed by Rex (1960) using ESR spectroscopy. Steelink and Tollin (1962) noted ESR spectra of HA in solution. It was early accepted that the ESR signals originated from organic free radicals present in the HA core, and it was demonstrated that many solution spectra, in contrast to solid state spectra, contained resolvable hyperfine structures.

The ESR spectra of various HA's in solution appear to be almost identical or to consist of a very few slightly different types. Atherton *et al.* (1967) suggested a classification of the HA's based on resolution differences in the ESR spectra. The spectra obtained from acid boiled HA's (ABHA) originating in acid soils and peats (pH 2.8–4.3) showed a resolved four line structure (class I), whereas those obtained from ABHA produced in more basic soils (pH 4.0–7.2) showed almost structureless spectra (class II). It was later demonstrated that a pH-value of about 4.6 in the environment where HA is formed separates class I spectra from class II spectra (Cheshire & Cranwell 1972).

We have investigated a number of HA's by means of the ESR-technique with the following objectives:

1. To test the Atherton (1967) classification.
2. To examine whether it is possible to distinguish between humus from different mor types by means of the ESR technique.
3. To investigate whether the ESR signals from HA's extracted from raised bog peats are influenced by the degree of humification.

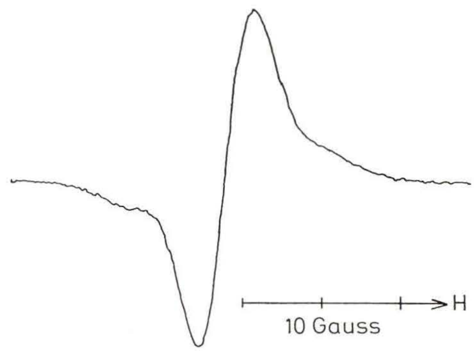
After a brief introduction of the ESR method, a discussion of the results obtained is given.

The ESR method

ESR spectroscopy detects unpaired electrons characteristic of paramagnetic species, such as organic free radicals, semiconductors, and transition metal ions as typical examples. The basic phenomenon underlying the ESR experiment is the Zeeman effect. By placing the paramagnetic sample in a static magnetic field the spin magnetic moments of the unpaired electrons are forced to align with or against the external field, the energy between the two spin states being

$$E = g\beta H_0 \qquad (1)$$

Fig. 1: Solid state ESR spectrum of a humic acid.



H_0 is the applied magnetic field, β is the Bohr magneton and g the spectroscopic splitting factor or g-value. Irradiating the sample with electromagnetic energy causes electrons in the lower state to absorb energy and jump to the upper state if the frequency (υ) of the radiation fulfils the condition

$$h\upsilon = g\beta H_0 \tag{2}$$

where h is Planck's constant. Equation (2) is called the resonance equation and is basic to all magnetic resonance experiments. For ESR spectroscopy one uses in practice a microwave radiation of about 9.5 GHz directed perpendicular to the magnetic field and sweeps the field through resonance (eqn. 2). For a "free" electron, resonance occurs at about 3400 Gauss and a single absorption line appears in the ESR spectrum. Additional lines are usually observed at the moment the unpaired electron is inherently a free radical. An interaction then arises between the magnetic moment of the electron and the magnetic moment of those nuclei having a moment different from zero. As an example, such nuclei are ^{1}H, ^{14}N, ^{17}O and ^{13}C, whereas ^{12}C and ^{16}O have magnetic moments of zero. Interaction with, say, a proton, causes the single line to split into a doublet, two chemically inequivalently positioned protons giving rise to a four line spectrum. The line pattern, or the hyperfine structure, as the pattern is called, is of immense value in elucidating structures of free radicals or processes in which free radicals take part. For more details of the hyperfine interaction see Pedersen 1969.

HA's in the solid state exhibit single line spectra (figure 1) with g-values around 2.0033. The four line spectra from HA's in solution (see figure 2) are composed of two splittings of 1.3 and 0.4 Gauss, respectively, from two inequivalent protons. The g-values and the hyperfine splittings as well as the

Table 1

Sample No.	Locality		Nature of soil	Age	ESR spectrum
Dr. 1	Draved Skov, Sønderjylland. The samples are taken in a vertical mor-profile, located close to Draved 381:8 (Iversen 1969, p. 38)		mycogenous mor	fossil	class I
Dr. 2			coprogenous mor	–	–
Dr. 3			yellowish pollen layer (mor)	–	–
Dr. 4			yellowish pollen layer (mor)	–	–
Dr. 5			humic sand	–	–
Dr. 6			humic sand	–	–
	Elevation (m)				
2218	31.56–31.54	Fuglsø Mose Djursland The samples are taken from profile 420 (Bahnson 1968)	raised bog peat	fossil	class I
2224	31.44–31.42		–	–	–
2228	31.36–31.34		–	–	–
2238	31.16–31.14		–	–	–
2243	31.07–31.05		–	–	–
4507	30.81–30.79		--	–	–
4511	30.73–30.71		–	–	–
4524	30.48–30.46		-	–	–
4528	30.40–30.38		–	–	–
4537	30.22–30.20		–	–	–
4546	30.03–30.01		–	–	–
4555	29.85–29.83		–	–	–
4559	29.77–29.75		–	–	–
El 1	Eldrup Skov, Djursland		mor	fossil	class I
El 3	Eldrup Skov, Djursland		humic sand below El 1	–	–
Ra 21	Randers Fjord area (Villumsen 1973)		fen peat	fossil	class II
Ra 23			– –	–	–
14703	Draved Skov, Sønderjylland		coprogenous (zoogenous) mor	recent	see text
14705			insectmull (initial stage of mor formation)	–	–
14706			insectmull	–	class II or I
14707			hydromull	–	class II or I
14708			mycogenous mor	–	see text
14713			mull	–	class II or I
14714			mull	–	class II or I

peculiar redox behaviour of the HA's in alkaline solutions (Atherton 1967) are strong evidence that the HA core contains radicals of the semiquinone type. No definite explanation for the unusual stability of the radicals or their actual structure has as yet been given, however.

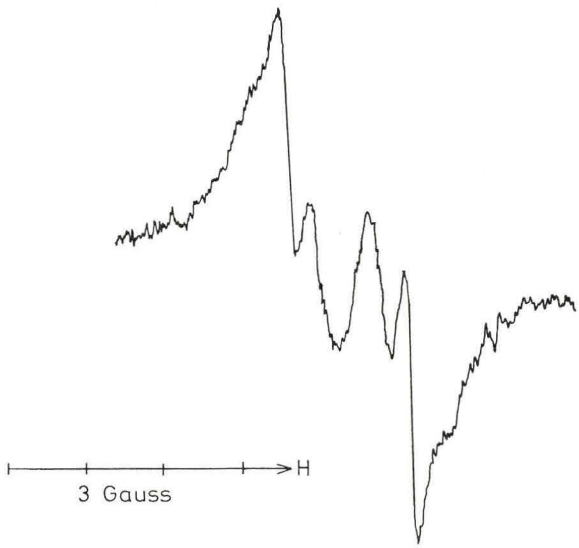


Fig. 2: Four line ESR spectrum of a humic acid in alkaline solution. (Class I spectrum).

Experimental details

The extraction of HA's and preparation of ABHA's were carried out according to the procedure described by Atherton *et al.* (1967). ESR spectra were obtained from solid samples of ABHA either using an E–3 or an E–15 Varian Associates ESR spectrometer. Solution spectra were obtained from 1 per cent solutions of ABHA's in 0.1 N NaOH. Careful air oxidation of the alkaline solution was performed by a circulation method (Pedersen 1973) in order to get reliable and fully resolved spectra. The best resolution was found to occur in the temperature range 30–60°C.

Results and Discussion

The present investigation has by and large confirmed the classification proposed by Atherton *et al.* (1967). As stated in table 1, listing all the results obtained, the series with sample Nos. Dr. 1 to Dr. 6, 2218 to 2243 and 4507 to 4559 all exhibit class I spectra with four clearly resolvable hyperfine lines (see figure 2). Identical line patterns are observed for the samples El 1 and El 3 although the resolution of the four lines is less pronounced for the spectra of those two samples. No hyperfine lines are

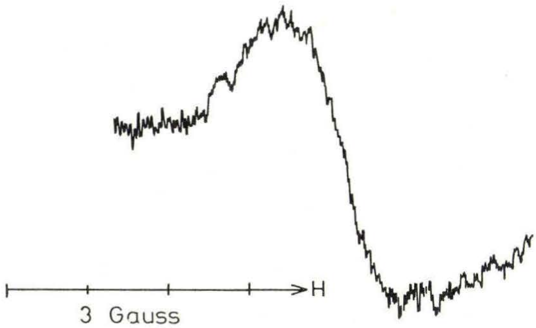
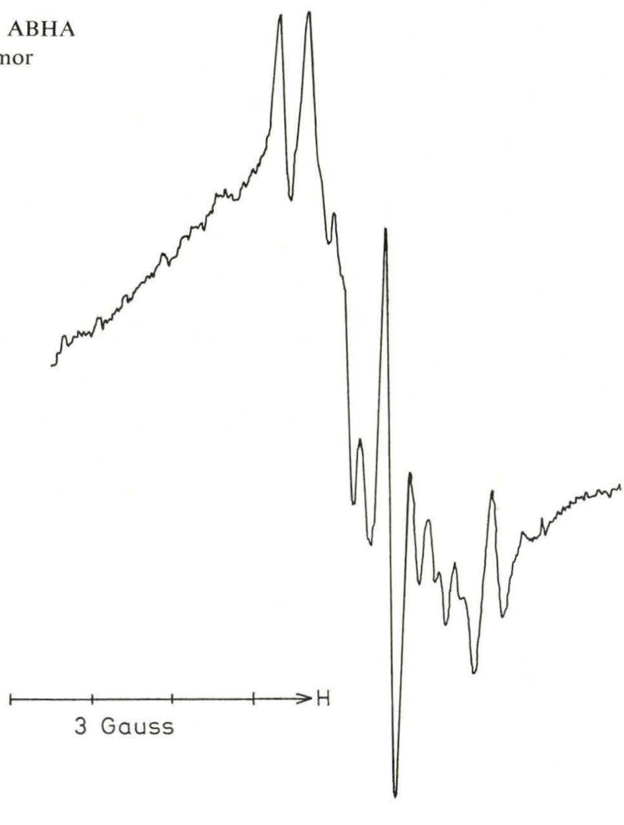


Fig. 3: Class II spectrum of a humic acid alkaline solution.

observed from the spectra of the fen peat samples Ra 21 and Ra 23 (see figure 3), the corresponding HA's thus belonging to class II as expected (mull type HA). From these results it seems possible to distinguish between mull and mor type HA's by the ESR method. For the more recent series with sample Nos. 14703 to 14714 some discrepances are observed. The

Fig. 4: ESR spectrum of ABHA extracted from a recent mor sample.



samples 14706, 14707, 14713 and 14714, all expected to give class II spectra (compare figure 3), thus exhibit a faint and distorted four line structure. The spectral resolution is quite poor, and whether the spectra are properly termed as class I or class II is an open question. Concerning the samples 14703, 14705 and 14708, expected to yield class I spectra, we obtain spectra containing 10–15 sharp lines as seen in figure 4. An explanation for this widely different result is that the samples in addition to the HA fraction contain residues of only partly humified matter consisting of relatively simple organic molecules. It is of interest to notice that no difference in the ESR spectra is observed regardless whether the HA is a result of a mycogenous mor-formation (sample No. 14708) or produced through a coprogenous process (sample No. 14703). For the fossil soil samples no differences between mycogenous and coprogenous mor could be observed by the ESR-method (samples Nos. Dr. 1 and Dr. 2).

We have investigated a series of raised bog peats in order to observe what effect a different degree of humification makes on the ESR spectrum. We observe only a change in signal intensity, i.e. samples with a humification larger than 50 % yield spectra with signals of strong intensity, whereas those less humified yield spectra with intensities of weak or medium strength. A qualitative correlation between degree of humification and ESR signal thus seems to exist.

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Dansk sammendrag

Electron spin resonans (ESR) undersøgelser har i de senere år haft stigende interesse for bl.a. undersøgelser af humussyrer (HA). Metoden har vist sig at være anvendelig til at skelne mellem HA, der er dannet under sure forhold (højmosetørv, mor) og HA, der er opstået i mere basiske miljøer (kærtørv, muld). Nærværende undersøgelse bekræfter denne klassificering af HA for fossilt materiale. For recent muld og mor er klassificeringen usikker, antagelig fordi der i den extraherede fraktion af prøvematerialet sammen med HA forekommer relativt simple organiske molekyler, stammende fra organisk stof, der endnu ikke er humuficeret. – HA stammende fra forskellige mortyper (mycogen mor, coprogen mor) giver samme ESR signal. – Undersøgelser af højmosetørv med forskellig humuficeringsgrad viser, at humuficeringsgraden kun påvirker ESR signalets intensitet.

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Annual report 1973

Translation by C. M. Robson

The Geological Survey of Denmark was established in 1888 in order to carry out the geological mapping of the country, to collect all relevant geological information concerning Denmark and the Faeroe Islands, and to process this material scientifically. The role of geology in the advancement of society has resulted in directed research also becoming a significant function, which now constitutes a large proportion of the work at the institute.

The Geological Survey of Denmark is led by a scientifically trained director, and immediately under him come the administrative, book-keeping, and similar functions. The remainder of the institute is divided up into 6 scientific departments, each under the leadership of a Chief Geologist.

Direction and administration

The director, dr. phil. Ole Berthelsen, controls all the administrative functions and supervises the scientific and practical work of the institute. He is chairman of the Danish Hydrological Decade Committee. The Danish Decade programme is part of a large international hydrological work programme, extending over a 10-year period and under the auspices of UNESCO.

At its general assembly in the autumn of 1972, UNESCO decided to follow up the Hydrological Decade programme with a long-term hydrological programme, to commence 1st Jan. 1975. The preparations for a possible Danish participation and the working out of the Danish contribution to the long-term programme have been supervised by the Decade Committee.

As a member of the Danish National Committee for Oceanology and as chairman of the Scandinavian Committee under the International Oceanographic Commission, the director has taken part in the discussions and preparatory work in connection with a planned oceanographic research programme, to extend over a period of 10 years.

The director is chairman of the Raw Materials Council set up by the Minister of Public Works, and in this capacity and as member of an interdepartmental working group set up by the Ministry of Public Works, he has taken part in the preparation of guidelines and directives regarding the administration of the Raw Materials Act. He has furthermore been responsible for the preparation of suggestions for the mapping of the country's raw material resources, both on land and on the territorial sea-bed.

As chairman of the Scandinavian Marine Geological Commission the director has taken part in the preparations for the Commission's next meeting, to be held in Denmark in April 1974.

The director has participated as member of two committees under the Danish Federation of Engineers in the preparation of guidelines for the establishment of water supply plant and sewage disposal plant conforming to the requirements of the new Water Supplies Act and the Environmental Protection Act. He has also given a number of lectures on water planning and the utilization of raw materials, and has been consultant in connection with the regional water planning programme for the Aalborg area.

The annual meeting of the directors of the Scandinavian Geological Surveys was held in Denmark in 1973, whilst the meeting of the directors of the Geological Institutes of Western Europe was held in London.

The Geological Survey of Denmark co-operates in the running of the Carbon-14 Dating Laboratory at the National Museum, and bears half of the operational costs of the laboratory.

Department of Quaternary Geology

The principal tasks of this department are to carry out the geological mapping of the country, and to advise in national and regional planning problems, including nature conservation and pollution problems. The department is also expected to perform work of applied geological nature (partly in the form of investigations and partly on the basis of archive material), to give advice regarding raw materials, i.e. sand, gravel, clay and lignite, and to make scientific investigations in this connection.

The institute's drilling equipment and personnel belong under this department.

The following geologists are employed in the department:

Chief geologist, dr. phil. Helge Gry, dr. phil. Viggo Münther, Bent Søndergaard, Erik Heller, Arne Vagn Nielsen, Ib Marcussen, Peter Konradi, Kaj Strand Petersen, and Henner Bahnson.

The systematic geological mapping of the country has been continued in a large number of districts. Thus Arne Vagn Nielsen has been in charge of the mapping of the Sakskøbing map-sheet, Henner Bahnson of the Stavnshoved map-sheet, Gunner Larsen (Århus University) of the Randers map-sheet, Arne Vagn Nielsen of the Nibe map-sheet, Erik Heller of the Daubjerg map-sheet, Viggo Münther of the Skjern map-sheet, Helge Gry (assisted by Kaj Strand Petersen) of the Løgstør map-sheet, and Helge Gry (assisted by Peter Konradi and Knud Binzer) of the Thisted map-sheet. In connection with the cartographic work the texture, structure, fossil content, etc. of the glacial deposits have been studied intensively.

On the basis of glacial-geological and morphological investigations, Ib Marcussen has constructed a map of the landscape structures in south-east Denmark. Per Baand has registered and described a great number of localities on the Daubjerg map-sheet showing periglacial phenomena. Kaj Strand Petersen has amongst other things collected molluscs in order to shed light upon the environmental conditions in the *Litorina* Sea.

Peter Konradi has investigated the foraminifera fauna from the Eem deposits at Stensig Bog. The material from the new borehole, Skærumhede No. II, has been prepared for publication; Henner Bahnson has described the lithology, Kaj Strand Petersen the macrofossils, and Karen Luise Knudsen (Århus University) and Peter Konradi the foraminiferal fauna.

The passing of the Raw Materials Act has placed new responsibilities upon the department. The work of planning and coordination in this respect has been led by Erik Heller and Arne Vagn Nielsen. The Act requires the department, among other things, to register all raw material excavation sites throughout the country, and to obtain information concerning the nature and quantities of the raw materials extracted.

The Raw Materials Act allows for control over the exploitation of raw materials, and in connection with this, Erik Heller has prepared maps showing easily accessible occurrences of raw materials in North Jutland and other areas.

The department has recorded profile diagrams and relevant geological information from a great number of sites around the country. Thus Arne Vagn Nielsen has taken profiles at major road works and excavations at e.g. Sdr. Tranders, Ålborg University, and the Rørdal cement factory (Ålborg). Mention must also be made of the investigations carried out (until his death on October 19th, 1973) by Sigurd Hansen on the marine Eem deposits in South Jutland, and on the distribution of glacial deposits in South and Mid-Jutland during the last Glacial.

Palaeobotanical Department

The department carries out research in the fields of vegetational history, biostratigraphy, palaeoecology, and palaeoclimatology, with especial reference to Quaternary and Tertiary deposits. Other areas of interest are sea level changes, forest ecology, soil evolution, pollen dispersal and pollen morphology, and the records of air pollution in raised bogs. The department advises on dating problems and conservation cases.

The following geologists are employed in this department:

Chief geologist, dr. phil. Svend Th. Andersen, Peter Ingwersen, Harald Krog, Inger Brandt, Jóhs. Jóhansen (stationed on the Faeroe Islands), Jens Stockmarr, and Bent Aaby.

The pollen analytical investigations of samples from the Upper Permian salt clay from DAPCO's oil test well Tønder By I have been continued. The photographic work has been completed, and descriptions of the fossil pollen types are in preparation (Peter Ingwersen).

The submarine bog from the Eem Interglacial outside Egernsund has now been fully investigated (Svend Th. Andersen). Work on the Late Glacial profile from Nørre Lyngby has also been completed (Harald Krog).

Pollen analytical examination of Late Glacial and Postglacial sediments from Elsborg Bog, Djursland, has been completed (Svend Th. Andersen and C. Vang Nielsen). Work has been started on the 43 m deep annually stratified, Late Glacial and Postglacial sediment series from the Gravlev valley in North Jutland; X-ray photographs have been made of the entire core, in co-operation with the Institute for Technical Geology, The Technical University of Denmark (Jens Stockmarr). The glacial sediments and mor layers in the research area in Eldrup Forest, Djursland, have been mapped (Svend Th. Andersen in co-operation with Henner Bahnson) and the pollen analytical examination of the mor layers has been commenced (Svend Th. Andersen). Pollen analytical investigations have been carried out in the raised bog Draved Kongsmose to shed light on the developmental history of the bog and on the Postglacial climatic changes – the latter in co-operation with the Carbon–14 Dating Laboratory. Peat layers under the shifting sand cover on Læsø have been investigated (Jens Stockmarr).

Continuous determinations are being made of the pollen sedimentation in Draved Forest to examine the changes in annual pollen production connected with climatic variations (Svend Th. Andersen), and the investigations of forest dynamics have been continued. The first 20-year observation period has now been completed and the material has been processed in part (Inger Brandt with the assistance of K. Havemann). Determinations are being made in the raised bog Draved Kongsmose of heavy metal fallout resulting from air pollution, and investigations of natural heavy metal fallout in pre-industrial times are in progress (Bent Aaby in co-operation with Arne Villumsen and the Isotope Centre).

Pollen morphological investigations have been carried out using the scanning electron microscope (Jens Stockmarr).

A natural stand of the elm species *Ulmus lævis* has been found on the Krenkerup Estate on Lolland; this species was not previously thought to grow wild in Denmark. It may possibly be a relic from the warm Postglacial period. The history of the stand is being investigated pollen analytically (Svend Th. Andersen).

Investigations have been made of bogs in South Jutland in connection with preservation cases (Bent Aaby). The department has also dated samples both for other departments of the institute, and as commissioned investigations.

The Carbon–14 Dating Laboratory has dated 54 samples for the Geological Survey of Denmark, and 14 samples for the Geological Survey of Greenland.

Department of Subsurface Geology

The chief tasks of this department are as follows:

1) Geological supervision and contact with the prospecting activities of the concessionaire (Dansk Undergrunds Consortium) for oil and natural gas in Denmark and on the Danish part of the continental shelf.
2) Scientific analysis of the biostratigraphical conditions in the Prequaternary in Denmark.
3) Systematic mapping of the Danish Prequaternary – both the individual formations and the present-day Prequaternary surface relief.
4) Advisory and research work in connection with major construction works affecting Prequaternary strata, such as activities in salt domes, preliminary studies for major bridge and tunnel construction, etc.
5) Archiving and ordering of sample material, etc., arising from the activities of the Dansk Undergrunds Consortium and from important boreholes penetrating the Prequaternary, made in connection with geotechnical pilot studies.

The following geologists are employed in this department:

Chief geologist, dr. phil. Leif Banke Rasmussen, Arne Buch, Arne Dinesen, Inger Bang, Erik Stenestad, Fritz Lyngsie Jacobsen, Ole Bruun Christensen, Finn Nyhuus Kristoffersen, Olaf Michelsen, Finn Bertelsen, Johannes Carl Baartman, Svend Erik Henriksen, and Lars Madsen.

The lithological and technical description of the Dansk Nordsø P–1 borehole has been made by Finn Bertelsen. Preliminary biostratigraphical investigations of the oil test wells drilled by the Dansk Undergrunds Consortium are being carried out by the eight micropalaeontologists in the department (A. Buch, A. Dinesen, I. Bang, E. Stenestad, O. Bruun Christensen, F. Nyhuus Kristoffersen, O. Michelsen, and F. Bertelsen). The results of these investigations are confidential at present, since in accordance with the agreement between the concessionaire and the State, the material received from the concessionaire must not be made public until 5 years after the date of receipt.

17 reports have been published in 1973 containing the research results from one of the deep boreholes made by the Consortium (Nøvling No. 1). Leif Banke Rasmussen has prepared a description of five North Sea boreholes for publication in 1974.

Work has been carried out on Lower Carboniferous microfloras (Finn Bertelsen), and Lower Carboniferous and Permian ostracods (Ole Bruun Christensen).

Work on the ostracod faunas from Triassic, Upper Jurassic, and Lower Cretaceous has been continued (Ole Bruun Christensen). The description of the Lower Jurassic ostracoda has been completed, providing a foundation for a biostratigraphical subdivision of the series (Olaf Michelsen). The microflora from the Haldager Formation (Middle Jurassic) has been studied in material from the older deep boreholes, and in foreign type collections (Finn Bertelsen). The foraminifera faunas from the Upper Cretaceous in the deep boreholes are still under investigation, and work on the samples from Arnager and from Hvidskud on Møn has been continued (Erik Stenestad).

Analyses of the foraminifera from the Danian-Selandian have been continued, and include extensive electron microscopy work and phylogenetic-taxonomic studies (Inger Bang). Description of the Eocene foraminifera has been continued with the diagnosis of the individual species, biometrical analyses, and photography, assisted by the scanning electron microscope (Arne Dinesen). Ostracods from the Upper Eocene and Oligocene have been investigated with a view to a stratigraphic subdivision (Kirsten Lieberkind). Work on the Miocene foraminifera from the North Sea boreholes continues, whilst treatment of the less deep boreholes near Gram has been completed (Finn Nyhuus Kristoffersen). Work on the Miocene mollusc faunas from the Lille Tønde and other borings continues (Leif Banke Rasmussen). Electron microscopic studies have been made of Younger Tertiary *Azolla* species (Finn Bertelsen).

Studies on the Quaternary foraminifera have been continued, using material both from deep boreholes and from surface localities; work on the material from Holmstrup is in print (Arne Buch).

Microscopy of the evaporites has been continued, and a few eruptives have been examined (Fritz Lyngsie Jacobsen).

Extensive studies of the Fennoscandian Border Zone have been commenced, starting with comparisons of the published geological data (Ole Bruun Christensen) and analyses of seismic profiles combined with mapping of selected seismic horizons (Johannes Carl Baartman and Lars Madsen).

Mapping of the Prequaternary surface relief and of the individual formations has been carried out on East Fyn (Inger Bang), in the Ålborg area and in Copenhagen (Erik Stenestad). Development of computing techniques and theoretical studies relating to cartographic work has been continued (Ole Bruun Christensen).

The institute's photographic laboratory and scanning electron microscope both belong under this department.

Hydrogeological Department

This department has the following areas of work:

1) Storage and retrieval of well records in accordance with the Water Supplies Act (Well Record Archive).
2) Archive of the permissions for extraction of ground water (LVK Archives).
3) Replies to enquiries and other consultative work.
4) Commissioned investigations, including, for example, hydrogeological mapping, test pumping investigations, and geoelectrical surveys.
5) The carrying out of ground water survey activities under the International Hydrological Decade programme.
6) Research and teaching on hydrogeological subjects.

The following geologists and civil engineers are employed in this department:

Chief geologist Lars Jørgen Andersen, Niels Viggo Jessen, Bent Bagge, Niels Kelstrup, Zvonimir Haman, Kurt Ambo Nielsen, Knud Højgaard, and Villy Krogh.

The drilling archives, which are attached to the department, contain information from a total of ca. 125,000 boreholes. Borehole profiles record information on borehole depth, strata penetrated, ground water level, technical details, etc., together with descriptions of the samples taken. The position of the boreholes is recorded on maps of scale 1:20,000 or 1:25,000.

The systematic measuring of the ground water level has been continued by the DGU's network of measuring stations. At present 78 stations are in operation, covering a total of 90 observation points. 21 measuring stations covering 27 observation points are included in the observation network of the International Hydrological Decade. Measurements of the level of the ground water are also carried out in connection with borehole localisation work.

The information in the department's archives is used to a great extent in the advisory work of the department, which deals with problems of water supplies, disposal of sewage wastes, pollution problems, etc.

The work of the department in connection with commissioned investigations can be summed up as follows:

Mapping of basic hydrogeological data has been carried out in numerous areas. The "Søhund" report (covering the area around lake Arresø and Hundested) was produced early in the year, and mapping of basic data in the Viborg Amt area was initiated in connection with a water planning programme there. Basic data maps have been produced in connection with other commissioned investigations, to serve as a foundation for the evaluation of the geological and hydrogeological conditions in the areas in question (the Tolne area, the Lake Esrum area, the Langeskov area, and the Ringsted-Haslev area).

Test pumping investigations have been made in connection with a number of water supply projects, in order to determine the water extraction possibilities and the effects resulting from pumping. Corresponding investigations have been carried out in connection with plans to excavate chalk to great depths at two sites in the Aalborg-Nørresundby area. Investigations have also been made to evaluate the danger of seepage of polluted ground water from an upper to a lower ground water reservoir (Rørvig), to establish safety precautions for above-ground oil storage tanks (Hedehusene), and to evaluate the pollution hazards associated with septic tank systems.

17 geoelectric surveys have been made in the course of the year – 16 in water supply investigations and 1 with the object of localising occurrences of gravel.

In addition to work with the archives, which forms more than a third of the work of the department, a considerable proportion of the staff has been engaged on work associated with municipal and country water planning. According to the new Water Supplies Act, the overall planning for water supplies becomes the responsibility of the county councils, and as a result there have been requests from numerous county councils for assistance with this planning in one form or another. Since a clear picture is needed of the extent to which DGU's assistance will be required in the planning problems for which the Environmental Directorate is the controlling body, a working group was set up in 1973 to evaluate the Environmental Directorate's need for the assistance of the institute. The working group, composed of representatives from the Ministry of the Environment, the Environmental Directorate and the Geological Survey of Denmark, produced a report at the end of the year, which called for a considerable expansion of the department in order to deal with the following tasks:

1) Data-processing of the material in the Drilling Archives.
2) Basic data mapping of the entire country.
3) Establishment of the ability to take part in concrete projects aiming at development of methods and establishment of guidelines for the carrying out of hydrogeological projects.
4) Establishment of an environment section having hydrological expertise in the problems of water supplies, waste water and sewage disposal, disposal of solid wastes, placing of oil storage centres, etc.

Research and methodological activities have gone on primarily in connection with the test pumping investigations, and as part of the Danish decade programme within the International Hydrological Decade. Considerable work has also been done on the rationalisation of data-processing, by utilizing computing techniques in the production of the hydrogeological basic data maps (cyclogram maps).

Finally, programmes have been produced for the processing of water-level observations, soil humidity measurements and geoelectrical measurements.

The hydrogeological department has prepared the Danish section of map-sheet C 4, Hydrogeological Map of Europe, 1:1,5 mill., covering the southern part of Denmark.

The department houses the secretariate of the Danish Committee for the International Hydrological Decade. This has co-operated in joint Scandinavian publications of hydrological basic data, descriptions of the representative areas, and of Scandinavian Hydrological Terminology.

Geochemical Department

The task of the geochemical department is to carry out geochemical investigations and the necessary analyses, including chemical analyses for other departments, and, to a certain extent, to carry out geochemical investigations and analyses commissioned from elsewhere.

The following geologists are employed in the department:

Chief geologist Werner Christensen, Henning Kristiansen, and Arne Villumsen.

The great majority of investigations are related to practical problems, first and foremost concerning the exploitation of raw materials, environmental investigations, etc.

The chief task of the department continues to be the investigation of both surface and ground water.

Chemical analyses of a number of concretions and a considerable number of determinations of calcium carbonate have been made under the leadership of Henning Kristiansen for the Department of Quaternary Geology. In co-operation with the Palaeobotanical Department, analyses have been made of lake sediments (core series) from Gravlev and the Faeroes, and determinations have been made of heavy metals in sphagnum, etc. A number of analyses have been carried out in connection with Arne Villumsen's investigations of Randers Fjord, which now have been completed.

Preparations for the printing of the I.H.D. water analyses for 1967–72 are largely complete and ready for data-processing.

The department has continued its investigations of postglacial sediments and their geochemical development. (Arne Villumsen has in this connection completed the mapping of the extensive postglacial occurrences of chalk and iron sediments etc. on the Aastrup estate near Tølløse, and has taken a series of samples there). Investigations and samplings have been made to study the geochemical developments around the lignite deposits at Nørrekær (near Ikast), where the Dutch geology student, Dieke Postma, is making investigations of iron and manganese sediments under the supervision of the department.

A number of supplementary investigations have been made of the fluorine content of the ground water in relation to the geological deposits.

Faeroe Department

The following geologists are employed in the department:

Chief geologist Jóannes Rasmussen and Jóhannes Jóhansen (see Palaeobotanical Department).

The sea-bed investigations have been continued, and the Lagting's research and auxiliary ship "J. C. Svabo" was again used. The work in 1973 has consisted exclusively of collecting loose boulders from the sea-bed. On the 17th and 18th of April 266 boulders were taken from the north and south sides of the Shetland Channel, whilst 225 boulders were collected from the area between Sandoy and the Faeroe Bank in the period May 28th–31st.

Treatment of the material from the sea-bed investigations has been commenced under Jóannes Rasmussen's leadership. Echo sounder records and position lists have been processed and then handed over to the Sea Chart Archives in Copenhagen. The collected boulders are being investigated by R. Waagstein. Macroscopic descriptions have been completed, and microscopic analysis has been commenced.

The Quaternary geological investigations have been continued with the measurement of profiles through moraine deposits, registration of striations, and determinations of ice-sheds.

Jóhannes Jóhansen has continued the pollen analytical investigations. Samples have been taken from the Saksun material for pollen analysis, diatom analysis, chemical analysis, and for C–14 determination.

Advisory work for public institutions, private firms, and others has been continued in the same extent as in previous years. Additional work has included participation in planning work in connection with the granting of permission to make preliminary surveys, etc., for possible occurrences of oil or natural gas.

Publications issued 1972–1973

II. Række – II. Series

85. *Viggo Münther:* Dominerende forkastningszoner på Bornholm baseret på anomalierne af den vertikale magnetiske intensitet. English summary: The main fault zones of Bornholm based upon anomalies of the vertical magnetic intensity. 1973. 161 s. 25 tvl.
99. *Finn Bertelsen:* A Lower Carboniferous microflora from the Ørslev No. 1 borehole, island of Falster, Denmark. Dansk sammendrag: En nedre karbon mikroflora fra boringen Ørslev nr. 1, Falster, Danmark. 1972. 78 s. 24 tvl.
100. *Arne Villumsen:* Geochemical and sedimentological investigations of the Rosenholm depression. Dansk sammendrag: Geokemisk-sedimentologisk undersøgelse af Rosenholm lavningen. 1973. 66 s. 2 tvl.

III. Række – III. Series

40. *Leif Banke Rasmussen, J. C. Baartman, Svend E. Henriksen, Finn Nyhuus Kristoffersen, Arne Dinesen, Inger Bang, Erik Stenestad, Arne Buch, Ole Bruun Christensen, Olaf Michelsen, Torben Juul Hansen* og *Fritz Lyngsie Jacobsen:* Dybdeboringen Nøvling nr. 1 i Midtjylland. Resultaterne af de geologiske undersøgelser. Red. af *Leif Banke Rasmussen.* English summaries: The deep test well Nøvling No. 1 in Central Jutland, Denmark. The results of the geological investigations. 1973. 164 s. 8 tvl., 1 bilag.
41. *Lars Jørgen Andersen:* Cyclogram technique for geological mapping of borehole data. Cirkeldiagram-teknik for geologisk kortlægning af boredata. 1973. 25 s. 1 kort.

V. Række – V. Series

7–A. Geology of Denmark I. (In preparation).
7–B. Geology of Denmark II. (In preparation).
7–C. Geology of Denmark III. *Johs. Iversen:* The development of Denmark's nature since the Last Glacial. Translation from Danmarks Natur, vol. 1, pp. 345–445, 1967, by *Michael Robson.* Editor: *Svend Th. Andersen.* 1973. 126 s.

Årbog – Yearbook

1972. Redaktion: *Leif Banke Rasmussen* og *Olaf Michelsen.* 1973. 89 s. 10 tvl.
Contents: *Andersen, Svend Th.*: On the occurrence of pollen similar to Bruckenthalia spiculifolia (Salisb.) Reichenb. in Danish Quaternary deposits, pp. 5–6. – *Bahnson, Henner:* Spor af muldflugt i keltisk jernalder påvist i højmoseprofiler, pp. 7–12. – *Christensen, Ole Bruun:* Aktuelle geologiske dokumentationsproble-

mer, pp. 13–18. – *Haman, Zvonimir:* Plot of s versus t/r^2 on semilogarithmic paper by using a simple stencil, pp. 19–24. – *Kristoffersen, Finn Nyhuus:* Studies on some Elphidiidae (foraminifera) from the Miocene of Denmark, pp. 25–36. – *Krog, Harald:* The early Post-glacial development of the Store Belt as reflected in a former fresh water basin, pp. 37–47. – *Michelsen, Olaf:* On Liassic holothurian and ostracod assemblages from the Danish Embayment, pp. 49–68. – *Petersen, Kaj Strand:* Some features in Clay with Tuff beds from Lower Eocene on Røsnæs, Danmark, pp. 69–78. – *Petersen, Kaj Strand, Ella Hoch* and *Niels Bonde:* A new species of mytilid bivalve, and vertebrate remains from Lower Eocene marine deposits on Røsnæs, Danmark, pp. 79–86. – *Stockmarr, Jens:* Determination of spore concentration with an electronic particle counter, pp. 87–89.

Rapporter – Reports

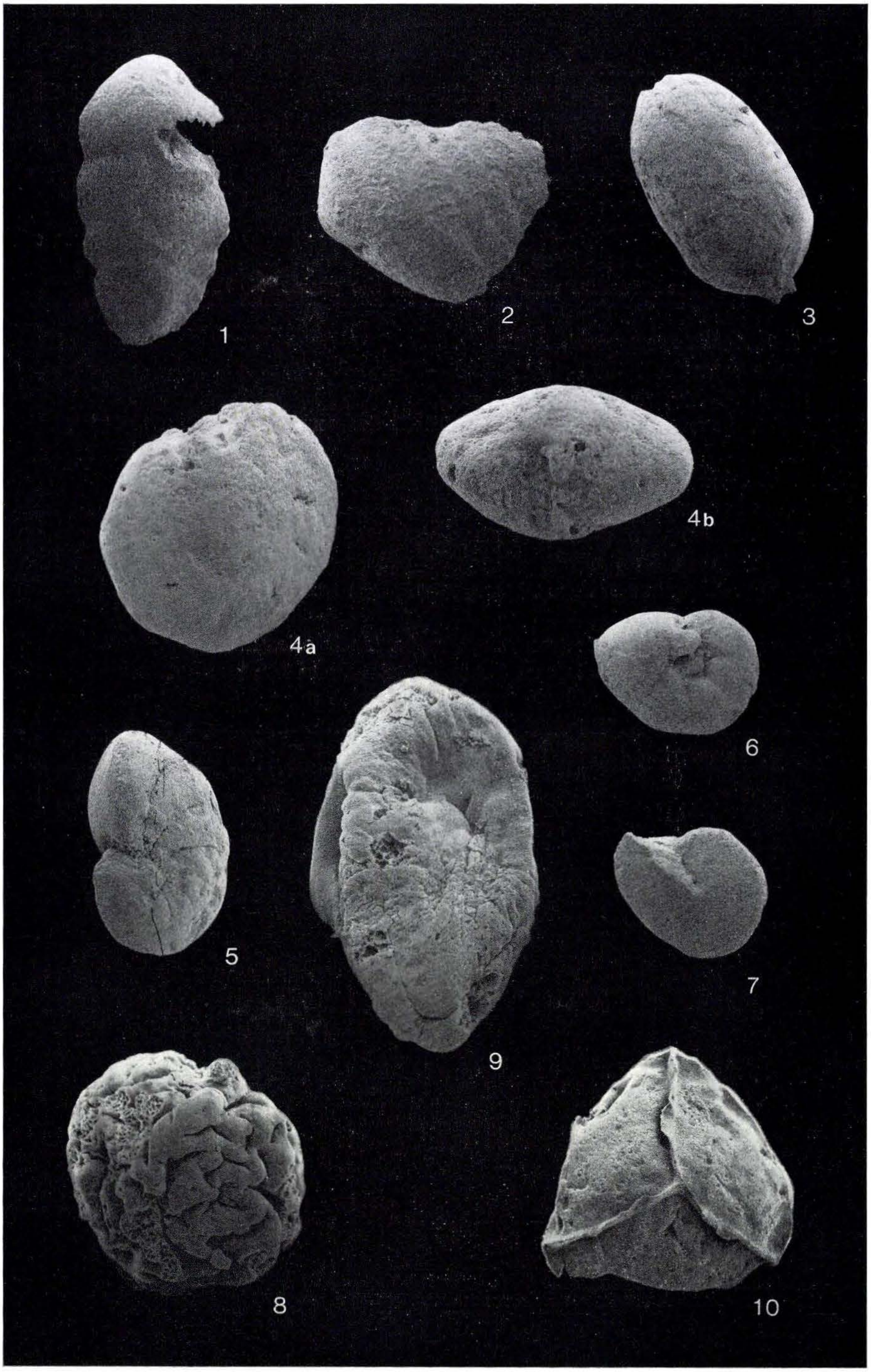
8. *Ellen Louise Mertz:* Kalundborg og omegns jordbundsforhold. En ingeniør-geologisk beskrivelse. (By-geologi nr. 5). 1972. 41 s. 2 tvl.

Plates

Plate 1

	D.G.U. Catalogue No.
Fig. 1. *Textularia gramen* d'Orbigny	
Depth 106.0–106.5 m. SH–17,8–FNK, × 25	1974–FNK–01
Fig. 2. *Textularia sagittula* Defrance	
Depth 106.0–106.5 m. SH–17,7–FNK, × 65	1974–FNK–02
Fig. 3. *Glandulina laevigata* (d'Orbigny)	
Depth 106.0–106.5 m. SH–17,3–FNK, × 65	1974–FNK–03
Fig. 4a–b. »*Elphidium*« *sp.*	
Depth 104.5–105.0 m. SH–17,9–FNK, × 100	1974–FNK–04
Fig. 5. *Florilus boueanus* (d'Orbigny)	
Depth 106.0–106.5 m. SH–17,1–FNK, × 65	1974–FNK–05
Fig. 6. *Valvulineria complanata* (d'Orbigny)	
Depth 106.0–106.5 m. SH–17,4–FNK, × 65	1974–FNK–06
Fig. 7. *Melonis affine* (Reuss)	
Depth 106.0–106.5 m. SH–17,6–FNK, × 100	1974–FNK–07
Fig. 8. *Salvinia cerebrata* Nikitin ex Dorofeev	
Depth 96.0–96.5 m. SH–38–FB–6, × 100	1974–FB–09
Fig. 9. *Salvinia intermedia* Nikitin ex Dorofeev	
Depth 99.5–100.0 m. SH–32–FB–1, × 100	1974–FB–10
Fig. 10. Megaspore sp. indet.	
Depth 96.0–96.5 m. SH–38–FB–7, × 100	1974–FB–11

All figures are scanning electron micrographs taken on a Jeol JSM–S1 scanning electron microscope at the Geological Survey of Denmark.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Catalogue No.

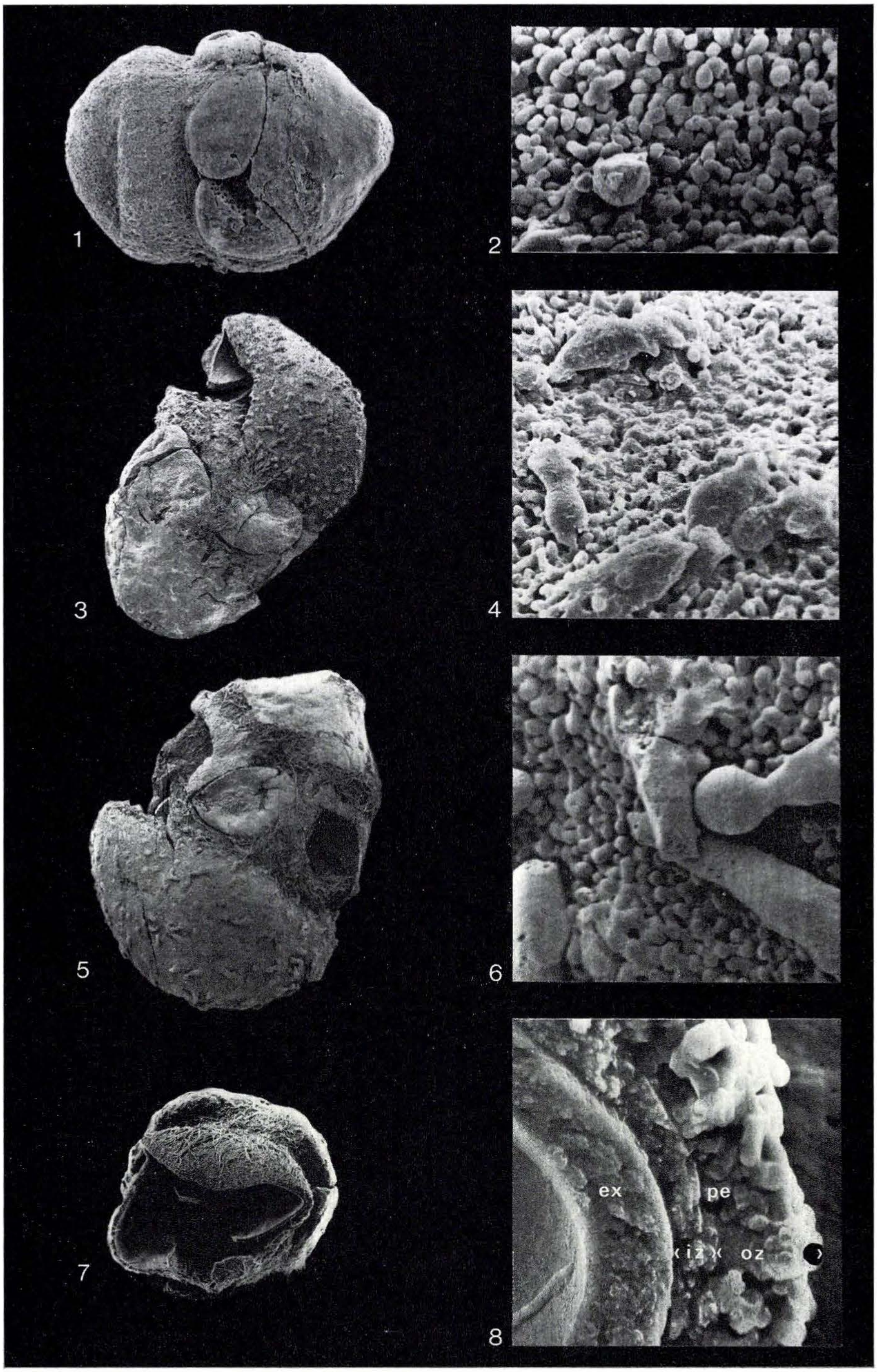
Figs. 1–2. *Azolla roemoeensis* n. sp.
Rømø borehole, 104.0 – 104.5 m, SH–28–FB–4 .... 1974–FB–01
Fig. 1. Megaspore apparatus × 100.
Fig. 2. Surface structure of the perine × 1500.

Figs. 3–4. *Azolla roemoeensis* n. sp., holetype
Rømø borehole, 102.0 – 102.5 m, SH–36–FB–4 .... 1974–FB–02
Fig. 3. Megaspore apparatus × 100.
Fig. 4. Surface structure and sculpture of the perine × 1500.

Figs. 5–6. *Azolla roemoeensis* n sp.
Rømø borehole, 106.0 – 106.5 m, SH–30–FB–3 .... 1974–FB–03
Fig. 5. Megaspore apparatus × 100.
Fig. 6. Surface structure and sculpture of the perine × 1500.

Figs. 7–8. *Azolla roemoeensis* n. sp.
Rømø borehole, 107.0 – 107.5 m, SH–27–FB–a 1974–FB–04
Fig. 7. Distal view of a broken megaspore apparatus × 100.
Fig. 8. Composition of the megaspore wall. *ex* = exine, *pe* = perine; *iz* and *oz* = inner and outer zone of the perine. Magnification × 2500.

All figures are scanning electron micrographs. Their orientation is dependent on the original direction of the electron beam in relation to the specimens. The electron source may be imagined to have been placed above the specimens. The micrographs have been taken on a Jeol JSM-S1 scanning electron microscope at the Geological Survey of Denmark.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	D.G.U. Catalogue No.
Figs. 1–2. *Azolla tomentosa* Nikitin	
Rømø borehole, 106.0 – 106.5 m, SH–30–FB–3	1974–FB–05
Fig. 1. Megaspore apparatus × 100.	
Fig. 2. Surface structure of the perine × 1500.	
Figs. 3–4. *Azolla tomentosa* Nikitin	
"Vereinigte Ville" quarry near Köln, B.R.D., Lower Miocene. SH–39–FB	1974–FB–06
Fig. 3. Megaspore apparatus × 100.	
Fig. 4. Surface structure of the perine × 1500.	
Figs. 5–6. *Azolla sp. A*	
Rømø borehole, 96.0 – 96.5 m, SH–38–FB–4	1974–FB–07
Fig. 5. Megaspore apparatus × 100.	
Fig. 6. Surface structure of the perine × 1500.	
Figs. 7–8. *Azolla sp. B*	
Rømø borehole, 103.5 – 104.0 m, SH–31–FB–2	1974–FB–08
Fig. 7. Megaspore apparatus × 100.	
Fig. 8. Surface structure and sculpture of the perine × 1500.	

All figures are scanning electron micrographs. Cf. the note to pl. 2.

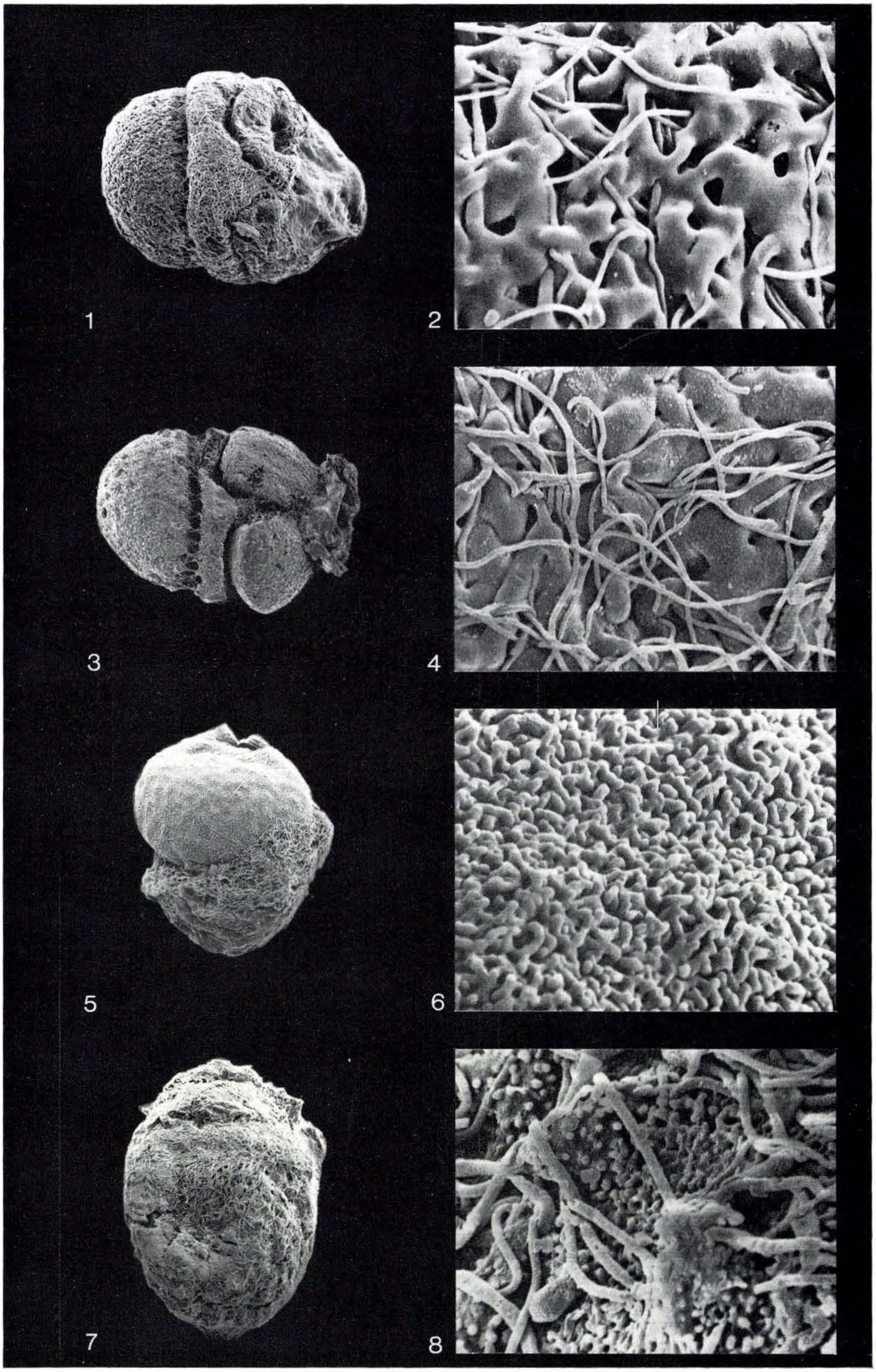
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Plate 4

Fig. 1. *Portlandia arctica* (Gray): fragment of a right valve.
(sample No. 165) × 6.3.

Fig. 2. *Lyonsia arenosa?* (Møller) fragments.
(sample No. 140) × 6.5.

Fig. 3. *Portlandia sp. juv.* with boring by a predatory gastropod.
(sample No. 197) × 5.7.

Fig. 4. *Portlandia lenticula* (Møller) in position in the clay.
(sample No. 196) × 5.7.

Fig. 5. *Dreissena polymorpha* (Pallas): fragment of the beak.
(sample No. 190) × 4.8.

Fig. 6. *Leda minuta* (O. F. Müller): right valve.
(sample No. 219) × 6.9.

Fig. 7. *Cardium ciliatum* Fabricius, young specimen, fragment of left valve.
(sample No. 207) × 6.7.

Fig. 8. *Leda minuta* (O. F. Müller): right valve; notice the weak inner carina.
(sample No. 219) × 6.9.

Fig. 9. *Abra nitida* (O. F. Müller): fractures in a right valve in position in the clay
(sample No. 233) × 6.6.

Fig. 10 and 11. *Corbula gibba* (Olivi): young specimens.
(sample No. 240) × 6.5.

The Skærumhede II Collection DGU.

Phot. O. Neergaard Rasmussen.

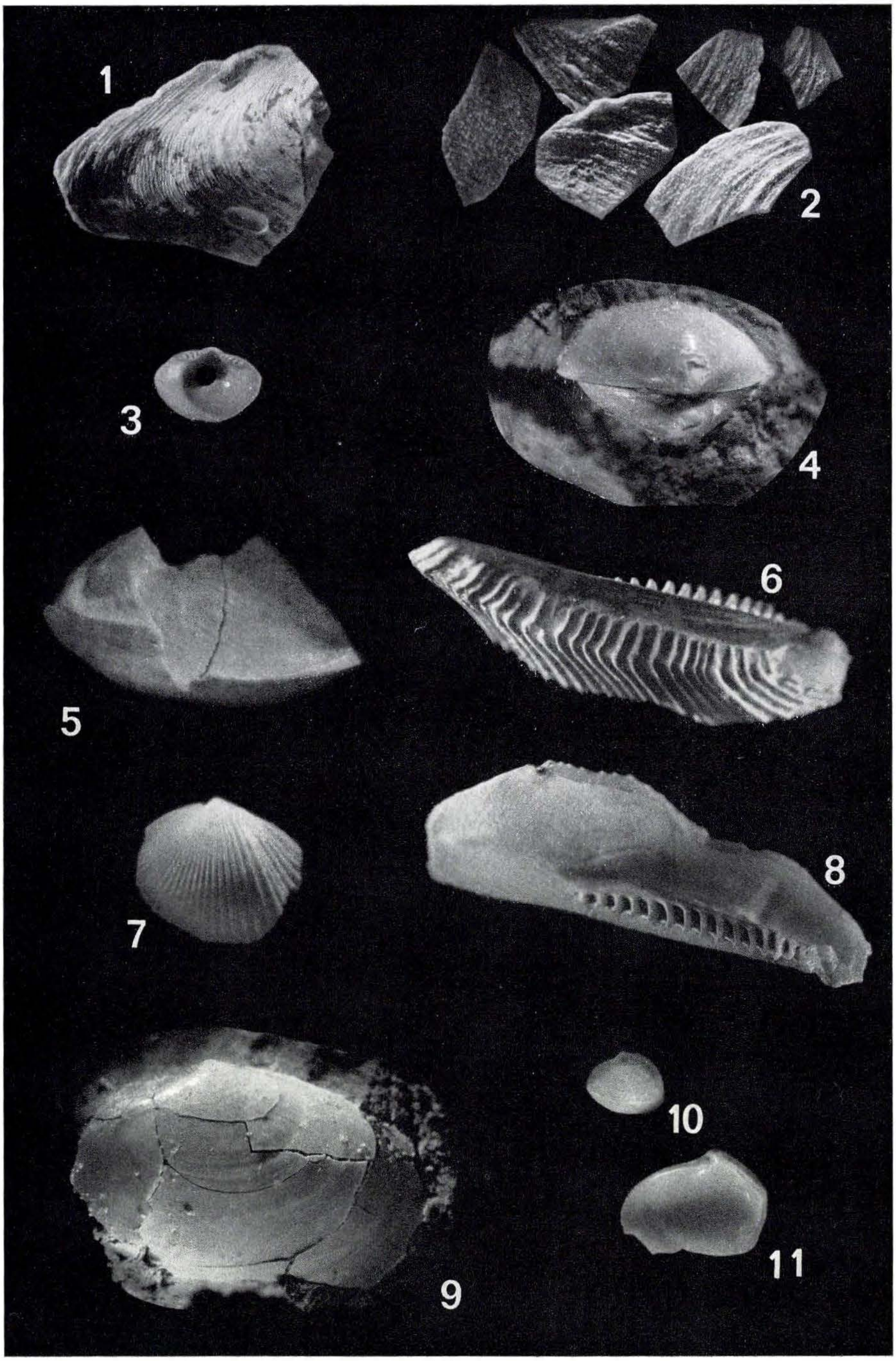
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Plate 5

Fig. 1. *Turritella erosa* Couthouy: 2 fragments.
(sample No. 189) × 4.1.

Fig. 2. *Mangelia brachystoma* Philippi.
(sample No. 240) × 12.3.

Fig. 3. *Turritella communis* Risso.
(sample No. 233) × 4.2.

Fig. 4. *Bela incisula* Verrill.
(sample No. 215) × 5.9.

Fig. 5. *Bela incisula* Verrill.
(sample No. 215) × 11.3.

Fig. 6. *Lora trevelliana* (Turton).
(sample No. 219) × 6.5.

Fig. 7. *Lora trevelliana* (Turton).
(sample No. 219) × 6.5.

Fig. 8. *Alvania cruenta* Odhner 1915.
(sample No. 202) × 12.4.

The Skærumhede II Collection DGU.

Phot. O. Neergaard Rasmussen.

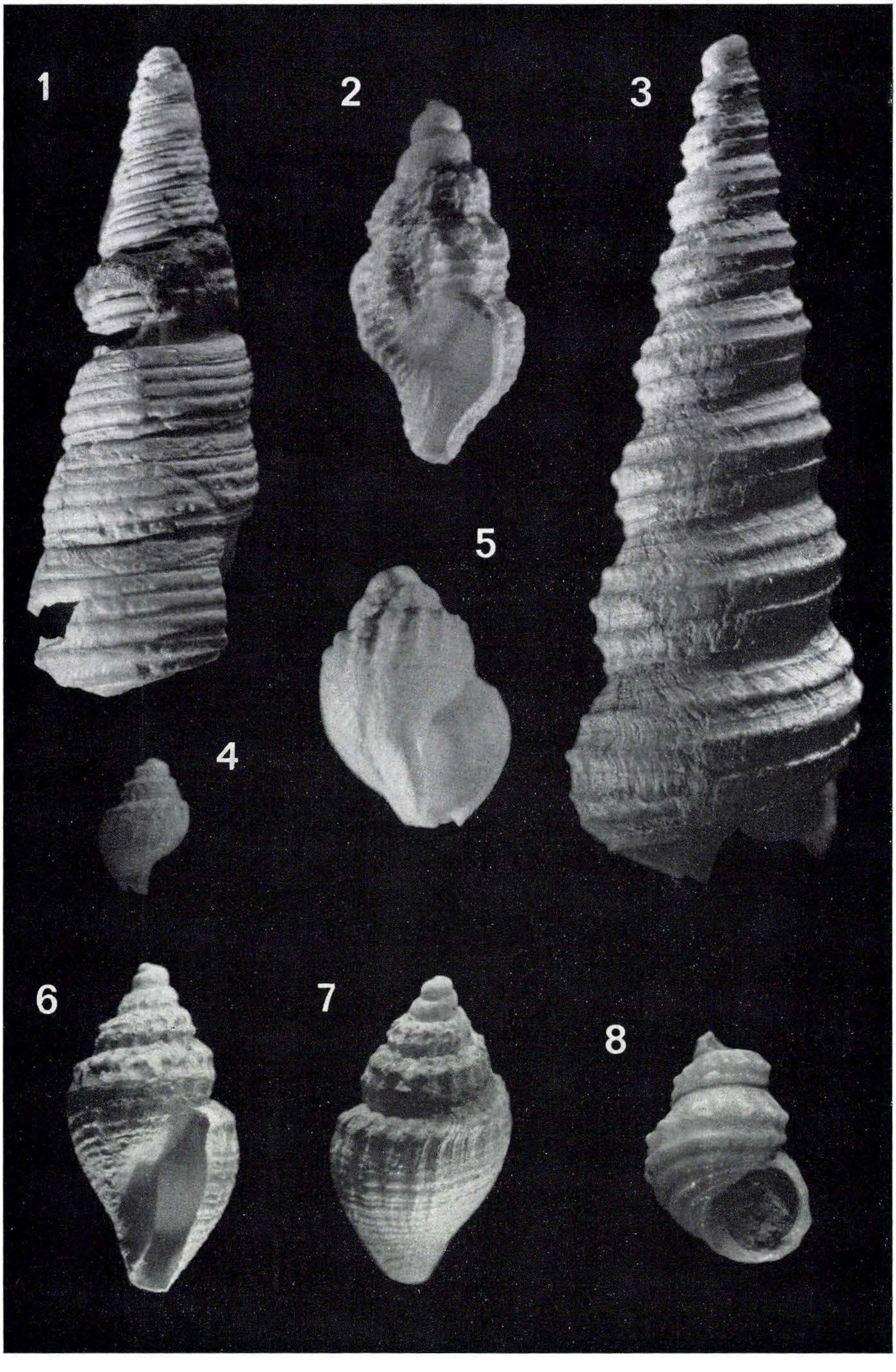
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Fig. 2. Material > 0.5 mm in sample No. 199. Notice the striation on the stone to the left.

Fig. 1. Material > 0.5 mm in sample No. 241 (The lowermost sample of Skærumhede II boring). Fragments of *Echinocardium* and skeletal elements of *Ophiura* are found in abundance. A partly broken *Turritella communis* is seen to the left and *Leda minuta* in the lower right corner of the picture.


0 10mm
fig 2

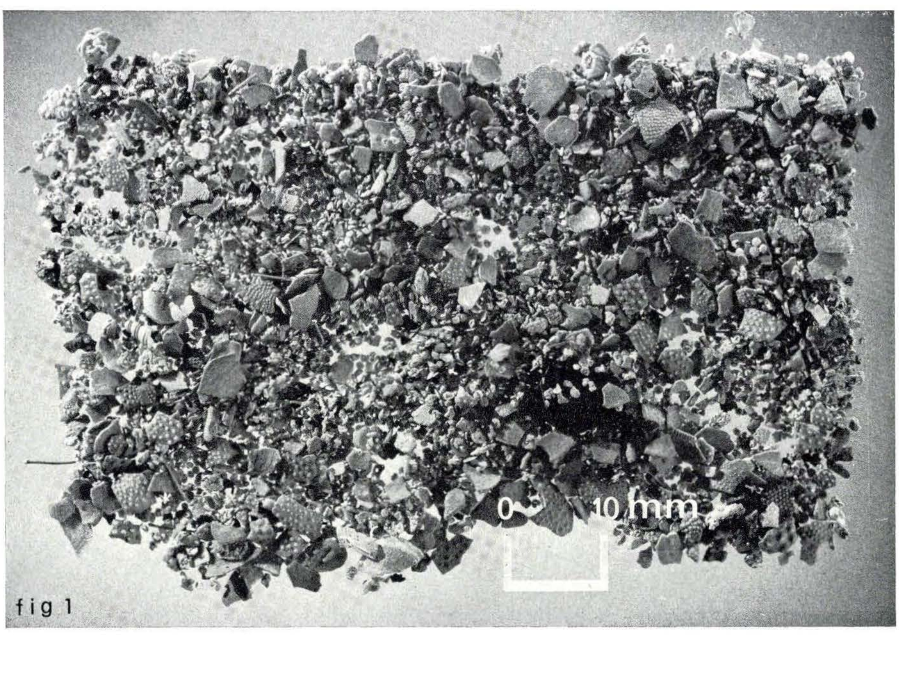
0 10 mm
fig 1

Plate 7

Fig. 2. Rhythmic bedding seen in sample No. 61, 31.5–32.0 m.b.s.

Fig. 1. Residue > 0.5 mm from the *Macoma calcarea* Zone in sample No. 113.

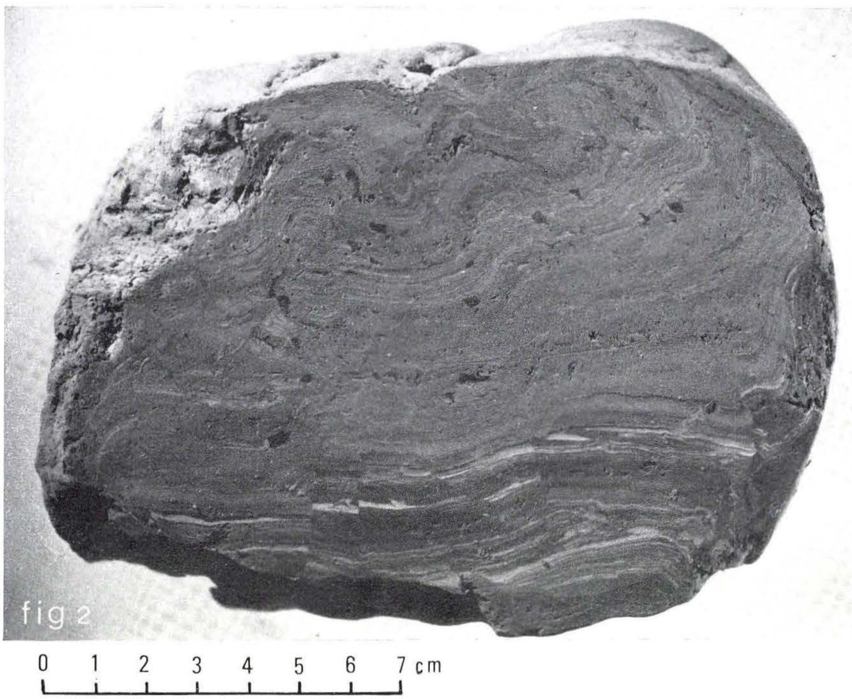

fig 2

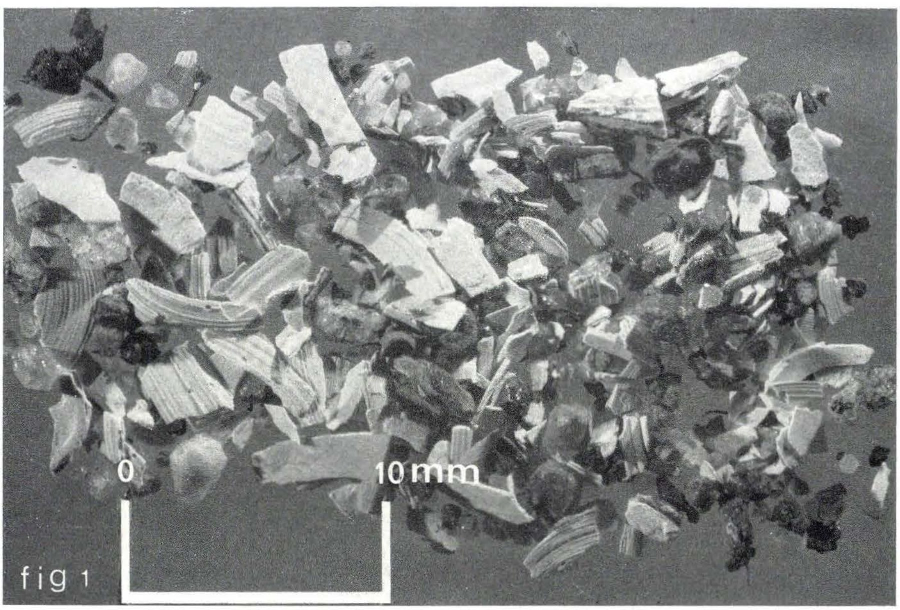

fig 1

Plate 8

Oligostegina sp. – sample 8–4–68–XI, pp. 74, 84.

	D.G.U. Catalogue No.
Fig. 1. *Oligostegina sp. 3.* × 260, max. diameter: 70 μ.	1974–AB–303
Fig. 2. Same specimen × 830.	
Fig. 3. Same specimen. Detail of the aperture and the surrounding surface. × 3000.	
Fig. 4. *Oligostegina sp. 2.* Detail of the surface showing the delicate papillary pattern. × 3000.	1974–AB–302

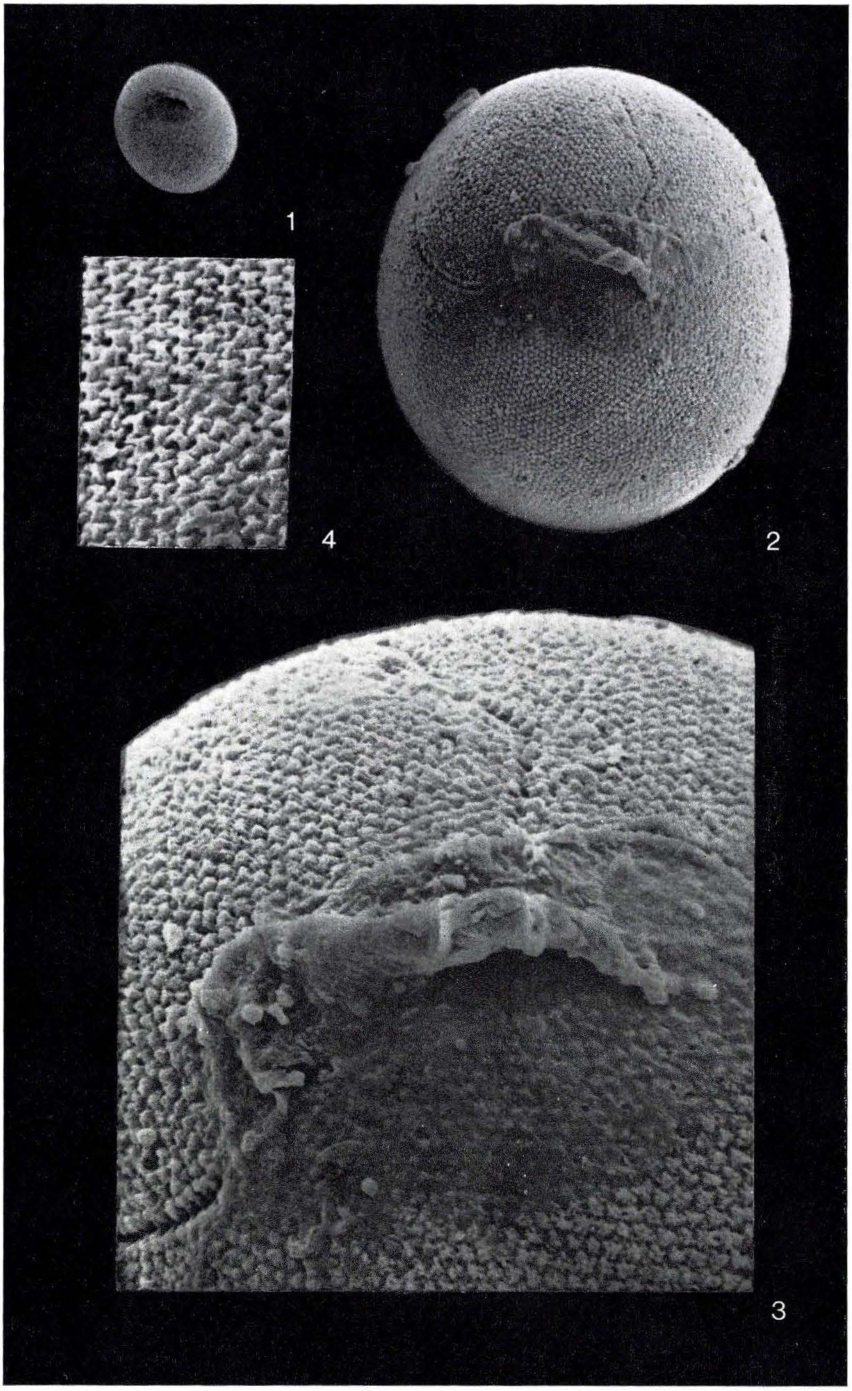
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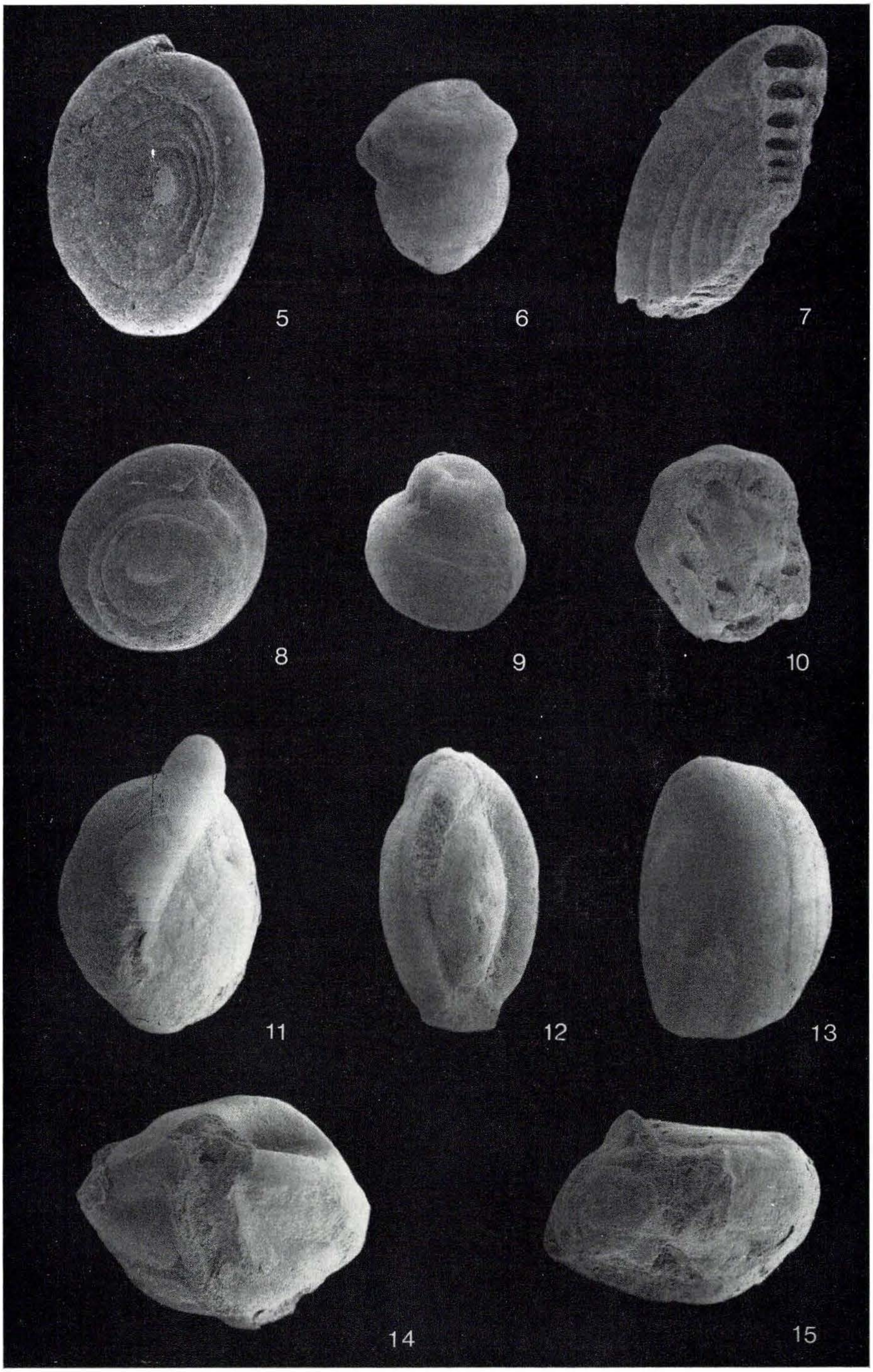
Plate 9

Foraminifera from the Tertiary clay, pp. 68–70.

	D.G.U. Catalogue No.
Fig. 5. *Involutina cretacea.*	
Sample 8–4–68–VIII, max. diameter: 300 μ.	1974–AB–201
Fig. 6. *Glomospira charoides.*	
Sample 8–4–68–VIII, max. diameter: 190 μ.	1974–AB–206
Fig. 7. *Involutina pyrotecnica.*	
Sample 8–4–68–VIII, max. diameter: 354 μ.	1974–AB–202
Fig. 8. *Glomospira charoides.*	
Sample 8–4–68–VIII, max. diameter: 240 μ.	1974–AB–204
Fig. 9. *Glomospira charoides.*	
Sample 8–4–68–I, max. diameter: 190 μ.	1974–AB–107
Fig. 10. *Glomospira charoides.*	
Sample 8–4–68–VIII, max. diameter: 210 μ.	1974–AB–209
Fig. 11. *Glomospira charoides.*	
Sample 8–4–68–I, max. diameter: 290 μ.	1974–AB–103
Fig. 12. *Glomospirella woodi.*	
Sample 8–4–68–I, max. diameter: 280 μ.	1974–AB–101
Fig. 13. *Glomospira charoides.*	
Sample 8–4–68–I, max. diameter: 275 μ.	1974–AB–106
Fig. 14. *Glomospira charoides.*	
Sample 8–4–68–I, max. diameter: 310 μ.	1974–AB–105
Fig. 15. *Glomospirella woodi.*	
Sample 8–4–68–I, max. diameter: 282 μ.	1974–AB–104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15

Plate 10

Fig. 1. Fragmentary burrow with coproliths from till a_1 sample 12–11–73–IV.

Fig. 2. *Cancellaria angulifera* with a borehole from a predatory gastropod from till a_1 sample 12–11–73–IV.

Fig. 3. *Cylichna discifera* from the till a_2 sample 12–11–73–III.

Fig. 4. *Tylocidaris abildgaardi* from the till a_1 sample 12–11–73–IV, notice the cleavage face.

Fig. 5. Specimens of *Macoma calcarea* from the marine silty clay of the main profile.

Phot. O. Neergaard Rasmussen.

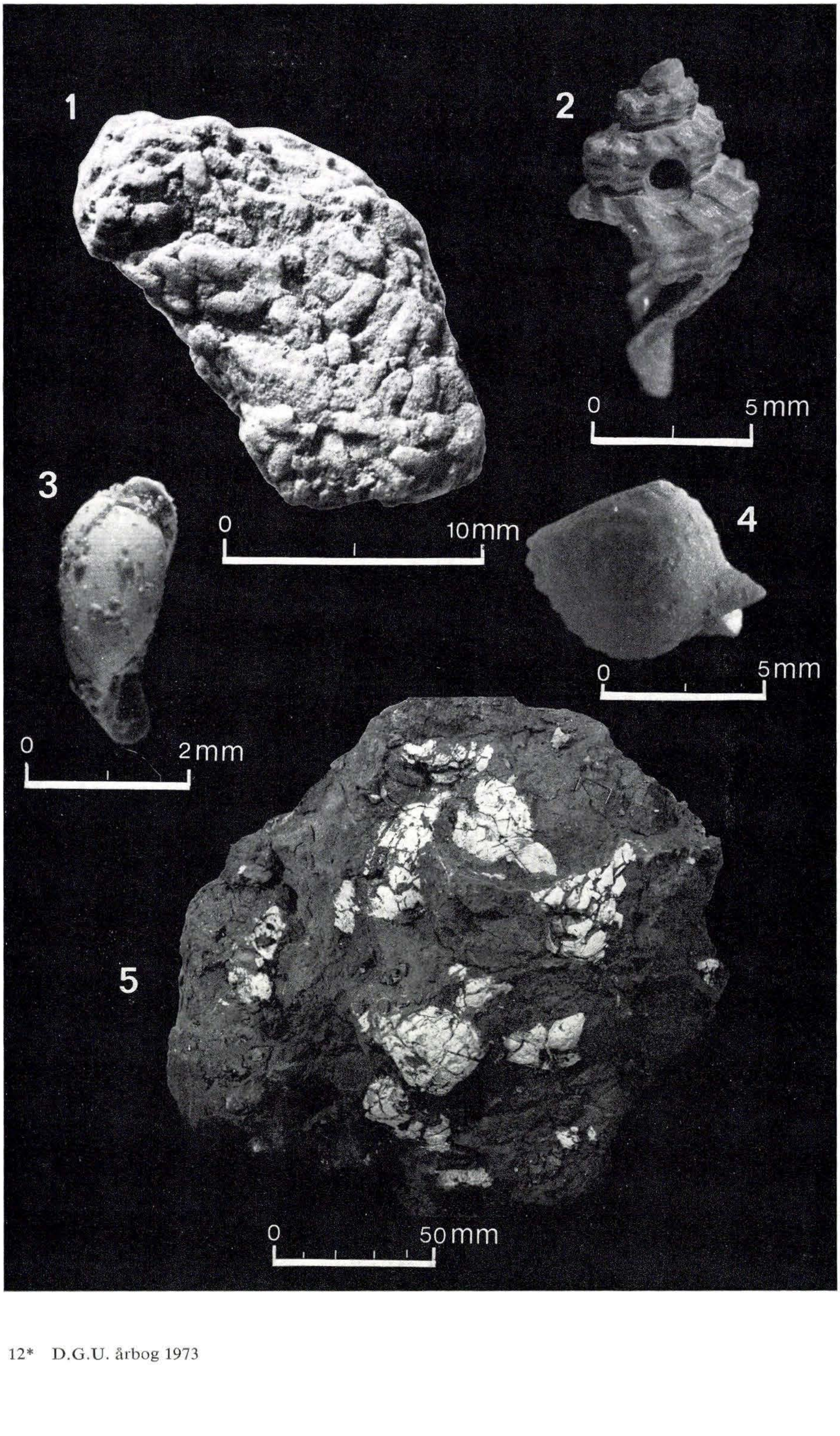

1
2
0 5 mm
3
0 10 mm
4
0 5 mm
0 2 mm
5
0 50 mm

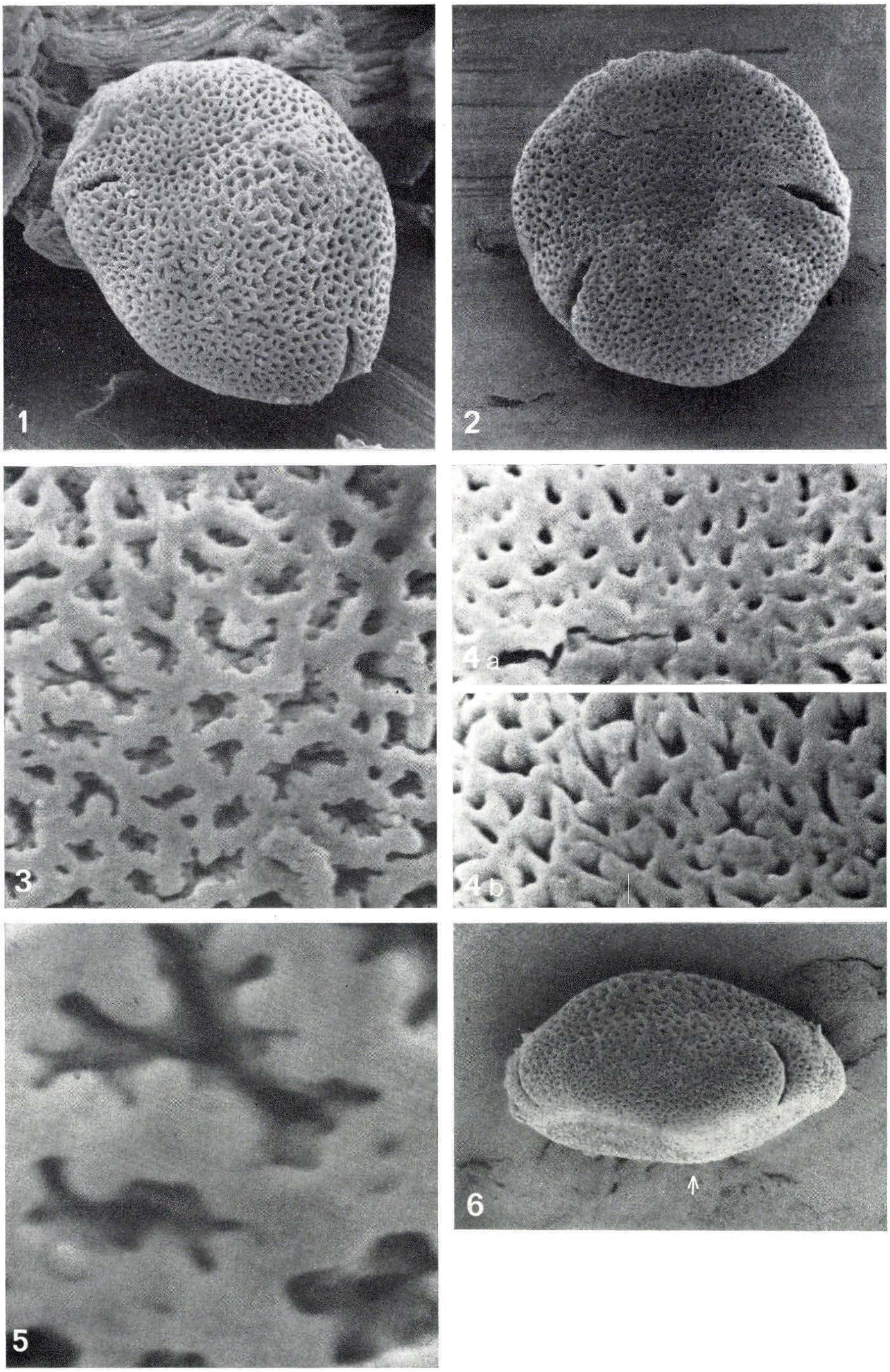
Plate 11

Tilia platyphyllos.

Nos. 1, 3, 5: distal polar view. × 1,500; × 7,500; × 22,500.

Nos. 2, 4: proximal polar view. × 1,500; × 7,500.

No. 6: equatorial view. × 1,500.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4a
4b
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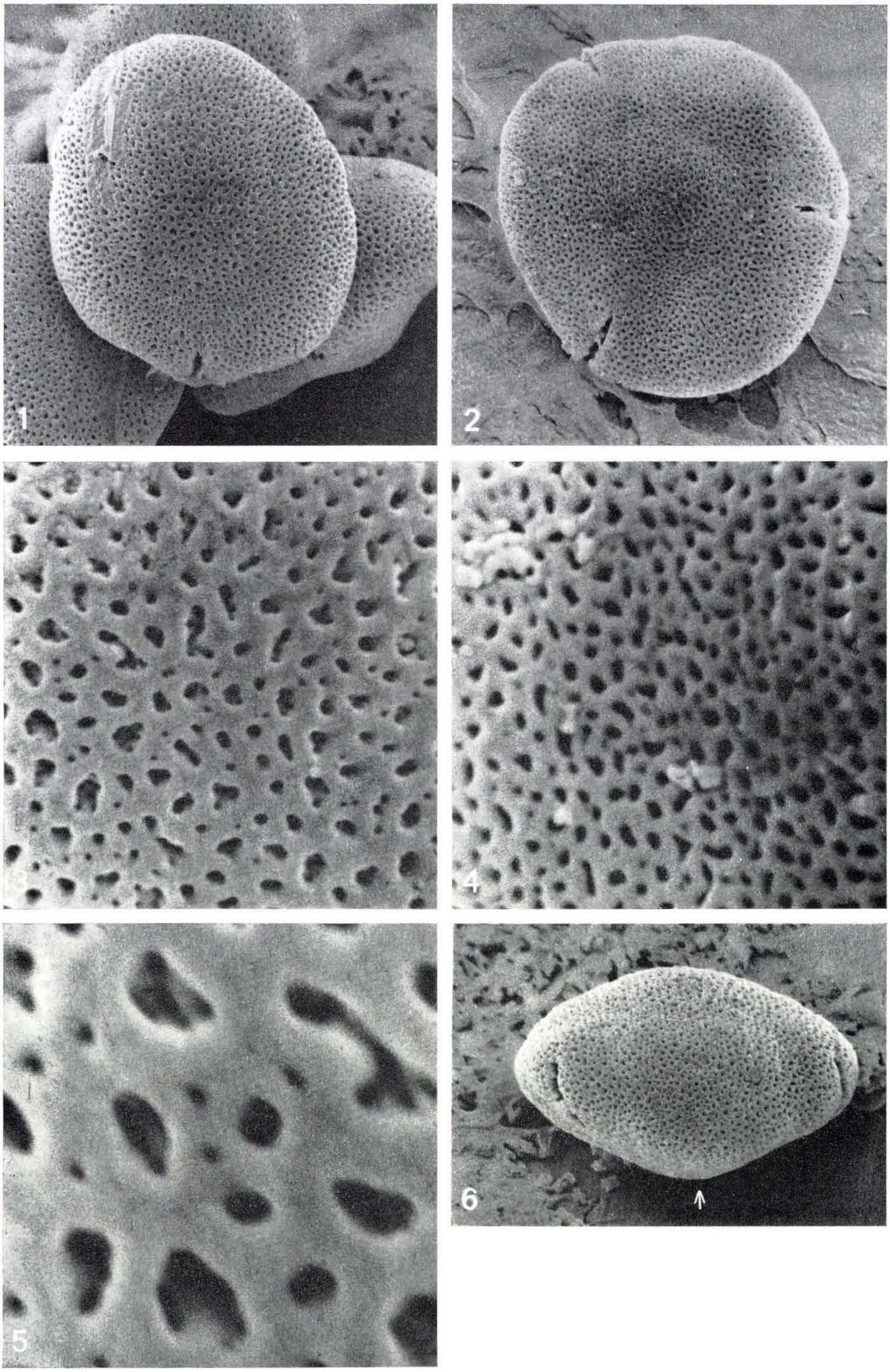
Plate 12

Tilia cordata.

Nos. 1, 3, 5: distal polar view. × 1,500; × 7,500; × 22,500.

Nos. 2, 4: proximal polar view. × 1,500; × 7,500.

No. 6: equatorial view. × 1,500.


1
2
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4
5
6

Plate 13

Tilia platyphyllos.

Nos. 1–6: fractured grains.

Nos. 1, 3, 5: from central intercolpium. × 1,500; × 22,500.

Nos. 2, 4, 6: from distal pole. × 1,500; × 7,500.

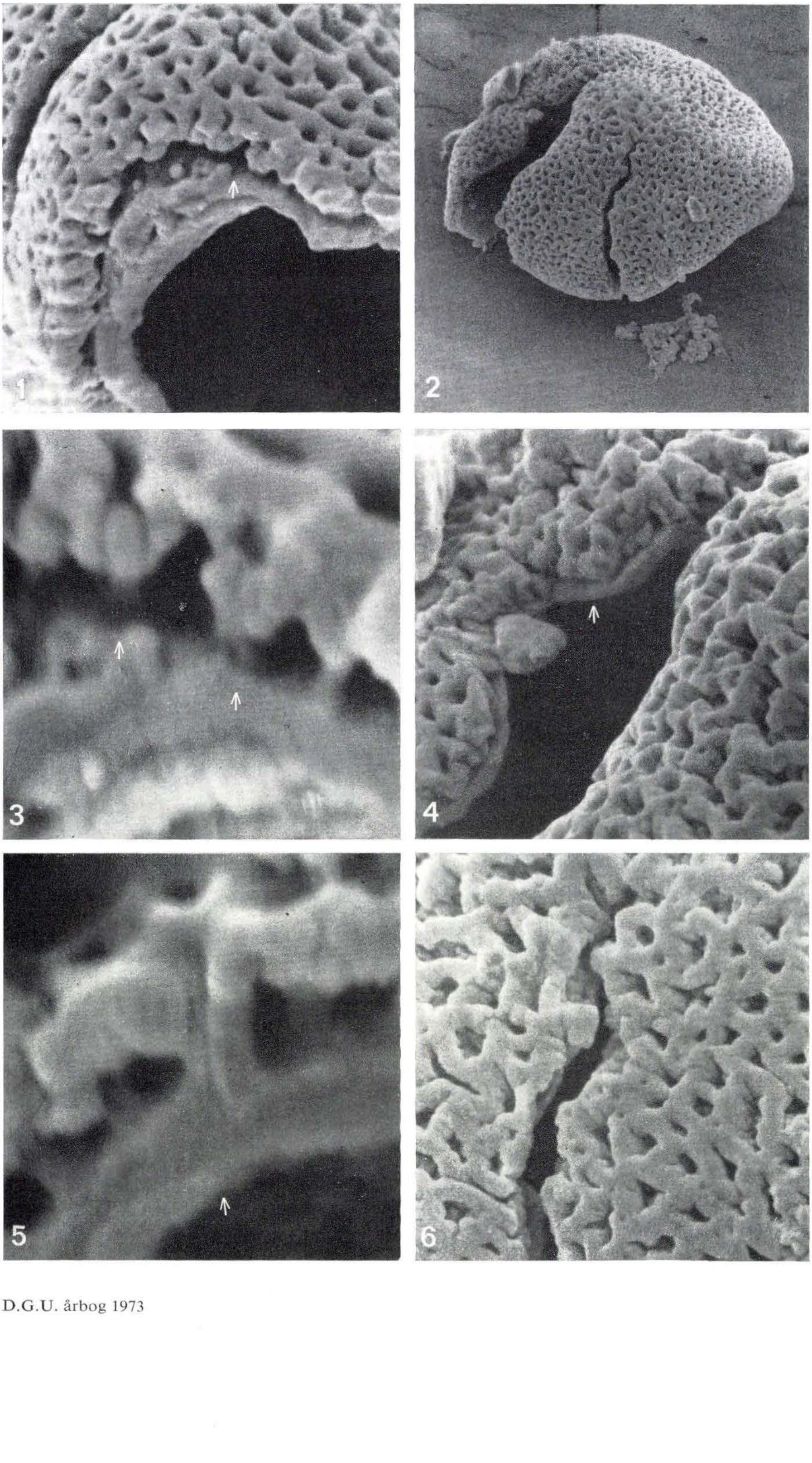
1
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Plate 14

Tilia cordata.

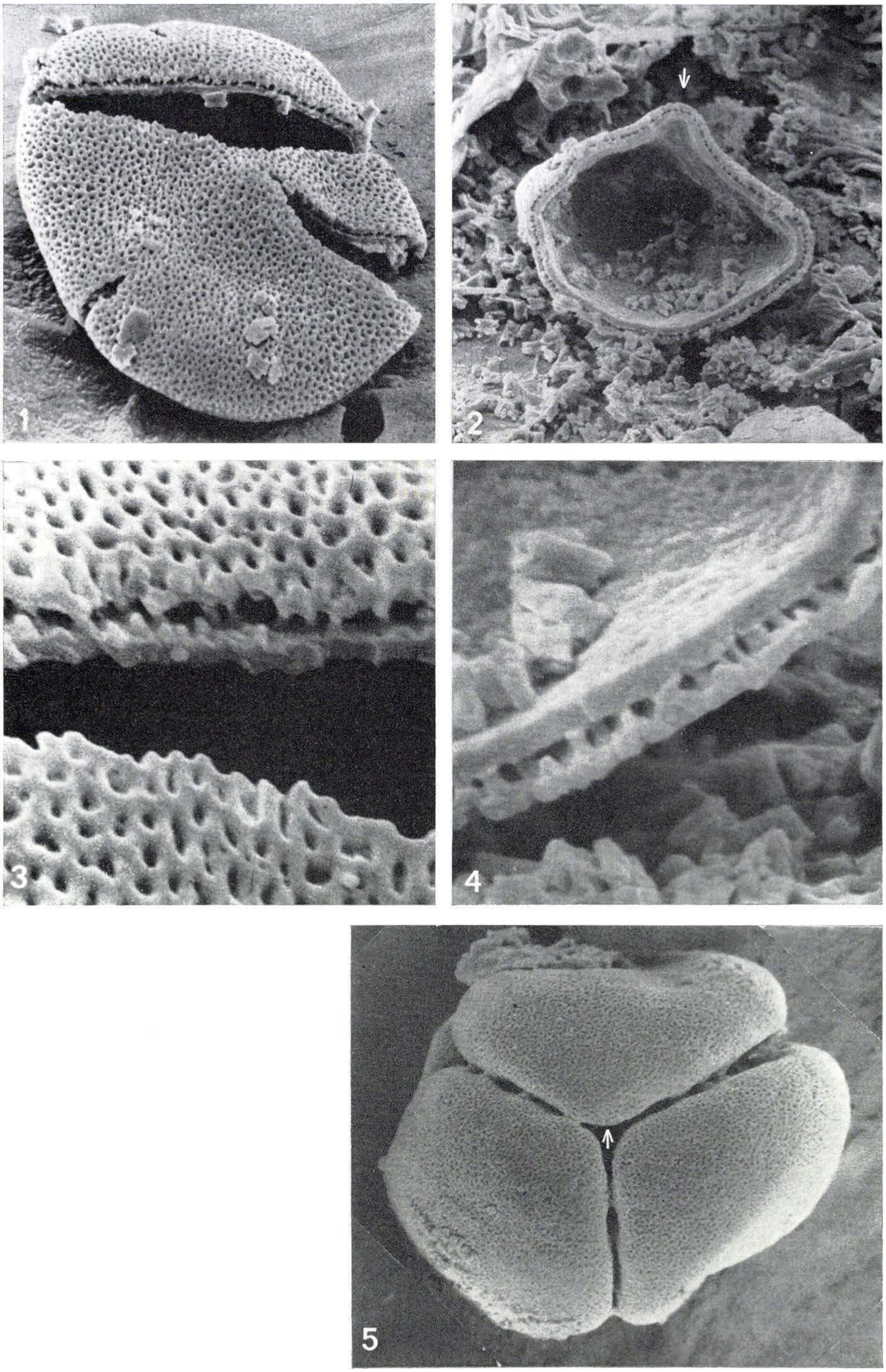
Nos. 1–4: fractured grains.

Nos. 1, 3: from proximal pole. × 1,500; × 7,500.

No. 2: meridional view. × 1,500.

No. 4: from distal pole. × 7,500.

No. 5: tetrad. × 1,500.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