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

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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.

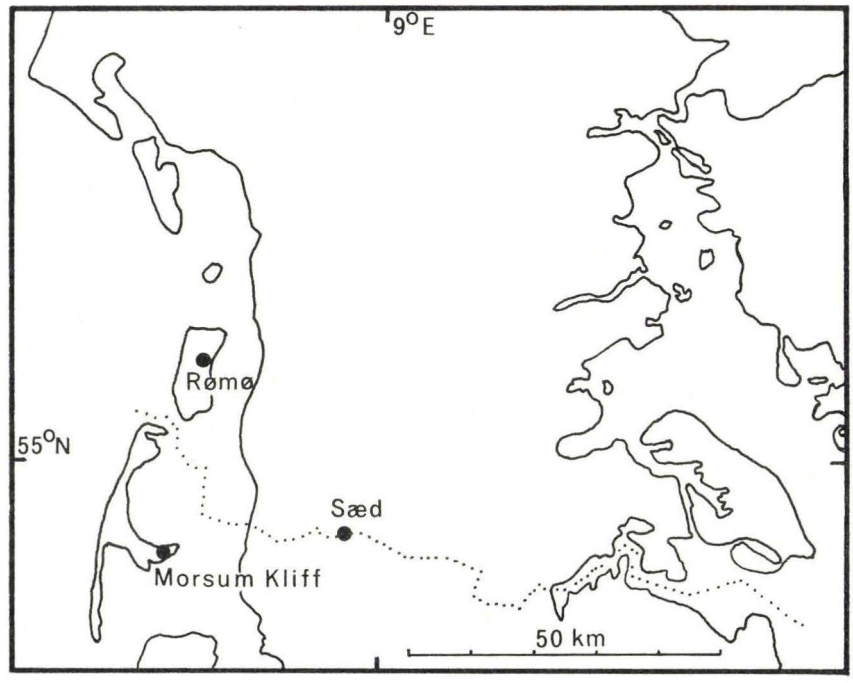
The borehole on the island of Rømø (text-fig. 1), of which the Tertiary fauna and flora are dealt with in the present paper, was drilled in the course of 1973 by the Geological Survey of Denmark. The purpose of the project was to investigate the Quaternary series, and thus the drilling was given up in 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 re-

covered *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.

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

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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