SEDIMENTOLOGY AND MICROPALAEONTOLOGY OF THE MIDDLE OLIGOCENE SEQUENCE AT SOFIENLUND – DENMARK

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Some aspects of mineralogical composition and foraminiferal content of the Middle Oligocene sediments from the Sofienlund area of Middle Jutland are presented. The pyritic sediments contain a high amount of montmorillonite and minor amounts of kaolinite and illite. The montmorillonite content increases in the finer fractions. The foraminiferal fauna is dominated by benthonic calcareous species. *Turrilina alsatica, Nonion affine* and *Pullenia bulloides* compose a total minimum of 40 % of the fauna. The Viborg Formation (new formal unit) in the Sofienlund area is referred to Middle Oligocene. It is assumed that the deposition of detrital clay minerals with differential flocculation in an outer continental shelf area has been a determinative factor in the clay mineral composition of the sediments. A high run-off, reducing the salinity in the sedimentological environment, might have been responsible for a low representation of planktonic foraminifers in the sediments.

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The Danish Tertiary sedimentary sequence mainly consists of sticky marine clays and marls from Palaeocene up to and including Middle Oligocene. More sandy, micaceous and darker materials, together with limnic deposits, dominate the rest of the sedimentary sequence (Rasmussen, 1961). This difference indicates a change in natural conditions, probably of tectonic character (Sorgenfrei, 1949, 1951). The two units are often characterized as Older and Younger Tertiary in Denmark (Rasmussen, 1961). Sorgenfrei (1969) uses a lower and upper division of the Tertiary sequence. Larsen (in Larsen & Dinesen, 1959) also distinguishes between an Older and Younger Tertiary, placing the boundary between the Lower and Middle Oligocene.

Rasmussen (1961), in accordance with Krutzsch & Lotsch (1957), transferred the Søvind Marl (Andersen, 1937) from Lower Oligocene to Upper Eocene.

The Middle Oligocene sedimentation in the Danish Embayment, starts with sticky clay. In Grundfør, Eastern Jutland, the basal part of the sticky clay appears to be stongly glauconitic (Christensen, 1969). In marginal parts, at Aarhus, Odder and Vejle Fjord area, the sediments are developed as dark, glauconite-bearing, sandy clays (Harder, 1913, Eriksen, 1937, Olsen, 1955, Larsen & Dinesen, 1959). The Middle Oligocene deposits amount to a maximum thickness of 80 m in the Viborg I boring (Flagler, 1940; Sorgenfrei, 1963). The thickness decreases generally southwards to only a few dm in the Vejle fjord area (Eriksen, 1937).

The sticky clay is overlain by the more sandy and glauconitic Cilleborg Clay (Ravn, 1906), of Upper Oligocene age. The Cilleborg Clay is mainly known from the marginal parts of the sedimentary basin, in the Mariager Fjord and the Aarhus areas, where it rests discordantly on Branden Clay (Sorgenfrei, 1956) or on older deposits (Madsen, 1918). In SE-Jutland, fossil-bearing Upper Oligocene deposits are developed as glauconitic sand with a minor clay content, or as a glauconitic clay. Particularly around Middelfart in the Lillebælt area, the glauconitic materials may be strongly altered to a rusty deposit, known as the Øxenrade Sandstone (Andersen, 1944).

The marine sticky clay of Middle Oligocene age has been designated Branden Clay (Ravn, 1906). When certain lithological features are considered, the Branden occurrence shows similarities to sediments in the rest of the Danish Embayment. Because of the lack of sedimentological data of the Branden Clay in the type area, it has not been found reasonable at the present time to apply the formation name outside the Branden area.

Outside Denmark, there has been an intensive study of Oligocene deposits in NW Europe. A detailed outline of lithological and foraminiferal investigations in that area is given by Batjes (1958). Among more recent foraminiferal works may be mentioned those of Ellermann (1958, 1960), Indans (1958, 1965), Kiesel (1962), Bettenstaedt et al. (1962), Hausmann (1963/64), and Spiegler (1965).

Previous work in Sofienlund

The Sofienlund locality is an abandoned clay pit situated at the southern terrace of the Gudenå Valley, east of Ulstrup, central Jutland (figs. 1 & 2).

The pit was investigated by Ravn (1907), who mentioned a sticky, plastic clay at the base of the pit. According to the molluscan assemblage, this sticky clay was considered to be of a Middle Oligocene age. Overlying this clay was found a dark glauconitic clay, with iron concretions, above which

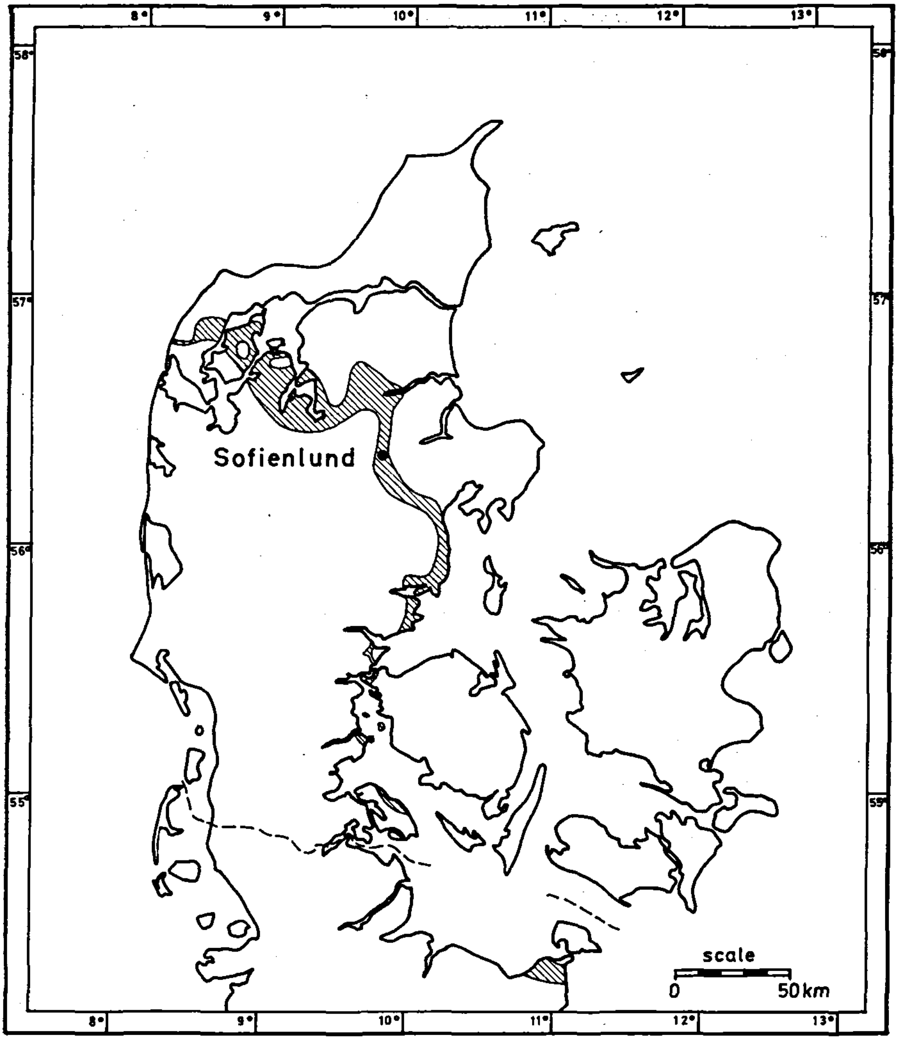

Fig. 1. Location of Sofienlund in Denmark. The shaded area shows the distribution of Oligocene rocks in the pre-Quarternary surface (after Sorgenfrei & Berthelsen, 1954).

occurred an unfossiliferous, black, sandy and micaceous clay, which graded upwards into white mica sand.

The locality was mentioned briefly by Ravn in 1914. The observations are confirmed by Sorgenfrei (1948); Rasmussen (1960); and Bahnson (1964). Bahnson (1964) briefly described the dark-brown, micaceous clay which overlies the sticky clay as having a content of glauconite and phosphorites in its basal parts. The foraminiferal fauna of the sticky clay, examined by Dinesen (see Rasmussen, 1960, p. 28), was called a typical *Dentalina* fauna,

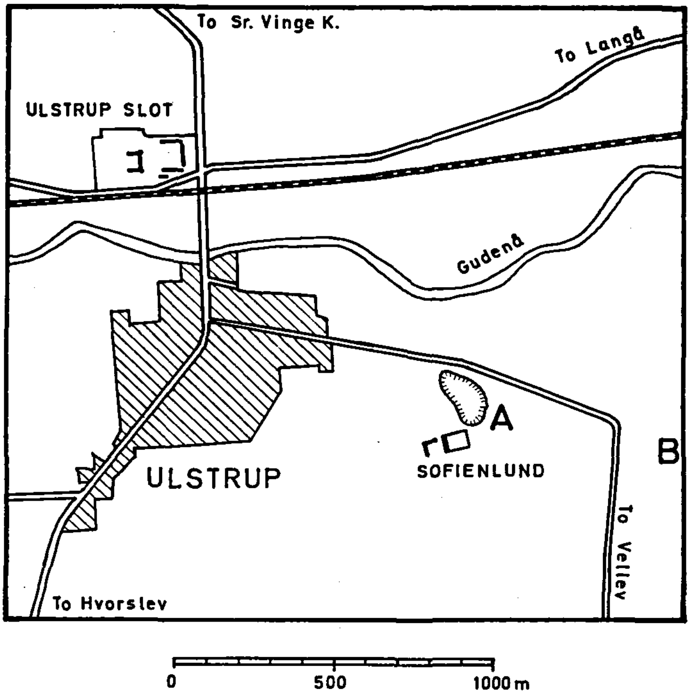

Fig. 2. Situation of the Sofienlund localities A and B in the Gudenå Valley.

as known from other Middle Oligocene localities. Tank (1963) investigated the clay minerals in four samples from the Sofienlund locality – one sample from the sticky clay and three from the dark-brown, micaceous clay – and found them to contain kaolinite, illite, and montmorillonite groups of clay minerals.

Description of locality

As the working of clay has ceased for some years, the pit is today completely overgrown by vegetation. In the western wall only a few small outcrops can be seen in three terraces created by the removal of clay (plate 1).

In the present work the sediments of Middle Oligocene (or post Middle Oligocene) age are described, and some remarks are offered on the mineral and foraminiferal content of the Middle Oligocene sticky clay. In determining the colour, the "Rock-color Chart" (Goddard et al., 1963) was used. Colour designation are given for samples having natural moisture content in the field.

The sequence in Sofienlund is divided into two new formations. The formations and members are briefly described in ascending order (plate 3).

1. Viborg Formation (designated as a new formal unit)

The formation consists of sticky clay, 5Y 2/1 – 5GY 5/2, containing pyrite, some mica, and, locally, small lenses of silt. Septarians, reported by Ravn (1907) and Bahnson (1964), are very seldom found. Fragments of molluscs as well as some pieces of wood have been observed in the clay. The Viborg Formation probably dips in the same direction as the overlying formation and has a vertical thickness of at least 27 m. The lower limit was not found because of the restricted range of the boring equipment used.

As mentioned the marine Middle Oligocene in the Danish Embayment is developed as a sticky clay facies. The Viborg Formation (new formal unit) is defined as the interval from 169.5 m to 255.3 m below ground surface in the Viborg I deep bore (D.G.U. file no. 66.318), 1.5 km WSW of Viborg Cathedral. A lithological description of this interval has been given by Christensen (1969). The formation consists in the most complete development of sticky clay (5Y 6/2 – 8/1 dry samples) in the lower part, glauconitic at the base and becoming darker upwards (10YR 4/2 – 6/2 dry samples) with alternating layers of fine grained sand. Both upper and lower boundaries are marked by breaks. Flagler (1940) has treated the Viborg I deep bore in a foraminiferal stratigraphic report. A profile published by Sorgenfrei (1963) refers the interval 175 m to 255 m to Middle Oligocene age and the interval 119 m to 175 m to Upper Oligocene age.

Preliminary investigations (Christensen unpubl.) suggest lithological similarities between the lower part of the overlying sequence in the Viborg I deep bore and the Branden Clay in the Branden type area. Though Middle Oligocene molluscs have been found in the Branden Clay in the type area (Ravn, 1906) preliminary foraminiferal investigations (Dinesen, pers. com. and Ulleberg, unpubl.) show high frequency of *Asterigerina guerichi guerichi* (Franke) which is referred to as *Asterigerina* fauna. It it known stratigraphically from the base of Upper Oligocene elsewhere in NW Europe. The *Asterigerina* fauna is observed by Flagler (1940) in the Viborg I deep bore, above the sequence of the Viborg Formation.

These preliminary results probably indicate that the Viborg Formation in the Viborg I deep bore cannot be correlated with the Branden clay sequence or part of the sequence in the Branden type area.

The close lithological similarity between the sticky clay sequence in the Sofienlund area and the upper part of the Viborg Formation in the Viborg I Deep bore suggests correlation. It seems reasonable therefore to consider the sticky clay section investigated in the Sofienlund area to be a lateral continuation of the Viborg Formation in the Viborg I deep bore and henceforth this section at Sofienlund will be referred to as Viborg Formation.

The lower limit of the Viborg Formation at Sofienlund is probably observed in the uppermost part of a clay pit 700 m to the east at locality B (fig. 2). Here, the Viborg Formation overlies a slightly lighter sticky clay which contains an Eocene foraminiferal fauna with *Pseudohastigerina wilcoxensis* (Cushman and Ponton). Dinesen (pers. com.) suggests that the clay represents the Eocene Lillebælt Clay (Harder, 1922) or the transition beds from the Lillebælt Clay to the Søvind Marl. Unfortunately, a heavy vegetation cover presented further observations.

2. Sofienlund Formation (designated as a new formal unit)

The formation has a total thickness of more than 11 m and is represented by predominantly dark clays, glauconitic at the base and clayey silt and light crossbedded sand at the top.

The Sofienlund Formation crops out in Sofienlund. Both lower and upper boundary of the Sofienlund Formation are marked by breaks.

The Sofienlund Formation is subdivided into four members. The age of the two lowermost members is referred to Chattian (*Uvigerina gracilis* zone). The two uppermost members are referred to Chattian or post Chattian.

2 a. Ulstrup Clay (designated as a new formal unit)

A greenish, glauconitic clay, separated from the Viborg Formation by a well defined boundary. The clay contains two layers of iron stone concretions and some fragments of molluscs. The thickness of the Ulstrup Clay range from a few cm up to 60 cm. The clay is visible in some places in the central part of the outcrops as a distinct layer, striking about 50° and dipping 25° northwestwards (plate 1). It crosses the northern part of the lowest terrace, where it probably wedges out. The clay layer cannot be located in the southern part of the wall. It cannot be ruled out that the locality might have a complicated glacial tectonic history, since Ravn (1907) mentions that the sticky clay dips southwards. The Ulstrup Clay has been traced to Hvorslev 4 km west of Ulstrup.

2 b. Sofienlund Clay (designated as a new formal unit)

The member is a yellowish brown sticky clay with a high pyritic content. Locally the clay contains some shell-fragments and a poorly preserved foraminiferal fauna. The thickness of the clay is 5–10 cm and has so far only been found at the Sofienlund locality.

2 c. Sofienlund Silt (designated as a new formal unit)

This consists of a dark brown clayey silt with a high content of lignitic material. The lower part contains small lenses and fine layers of lightcoloured sand, amounting to a maximum thickness of a few cm, whereas in the upper part the sand appears as distinct layers amounting to 20–30 cm. The bedding is parallel to the upper boundary of the Ulstrup Clay. No fossils have been observed.

The thickness varies from 6 to 8 m. The member bas been traced to several localities in the northern part of the Gudenå Valley around Ulstrup.

2 d. Sofienlund Sand (designated as a new formal unit)

The member consists of fine-medium grained, white micaceous sands, with intercalations of silt and clay in the upper part. Cross-bedding is frequently developed. No fossils have been observed.

The Sofienlund Sand has been traced laterally to Langå in the east of the Gudenå Valley. The facies changes from a more coarse grained to an often cross-bedded finer grained sand. The thickness is more than 3 m in Sofienlund increasing to more than 10 m in the eastern area.

Materials and Methods

Materials

The samples investigated in this paper were collected from two borings, B 1 and B 2, and from an excavated profile (plate 1 B).

The boring equipment used was of skrew-auger type which provides only discontinuous core. Samples were taken at approximately 1 m intervals. The vertical interval of each sample was 30–35 cm. Profile samples were taken after digging a one meter deep trench in order to diminish weathering factors. Here the vertical interval of sample was about 10 cm.

B 1 is 23.0 m deep and consists of 24 samples from the Viborg Formation. The excavated profile forms an extension of B 1 upwards, consisting of 4 samples from the Viborg Formation. This gives a sequence of 28 samples compiled in a standard profile (plate 3), starting immediately below the Ulstrup Clay and ending approximately 27 m deeper. B 2 (10.2 m deep) penetrates the Ulstrup Clay at a depth of 1.1 m. From the 9.1 m interval from the Viborg Formation, 9 samples have been examined. B 2 is inserted in the upper part of the examined profile (plate 3). The examined section of Viborg Formation is lithologically very homogeneous, though the colour darkens and the silt content increases upwards.

Methods

Only intact parts of samples, obtained after careful cleaning, were used for examinations. Cleaned samples were split into two parts; one part was used for sedimentological petrographic investigations, and the other part was used for foraminiferal investigations.

Sedimentological investigations comprized grain-size measurements by wet sieving of sandsize fractions and the sedimentation method using the Andreasen pipette for the silt and clay fraction. Microscopic investigations of the sand fraction and X-ray investigations of clay fraction were carried out. Oriented slides for X-ray diffraction analyses were prepared from the $<$ 2 microns (equivalent settling diameter) fraction. Samples were first dispersed in distilled water and the $<$ 2 microns fraction was obtained by centrifuging and the clays pipetted on to glass slides and air dried. X-ray analyses of samples were performed by a Philips diffractometer (PW 1050/25) equipped with a proportional counter and discriminator, using Ni-filtered Cu-radiation at 34 kv and 22 mA. The scanning interval was 2–60° 2 θ with varying scanning speeds. The thin clay film was glycolated for at least 48 hours at room temperature. Subsequent heat treatment to 600° C and the K-saturation procedures of Weaver (1958 a, b) were used with X-ray diffraction in order to further characterize the clay minerals.

Interpretation of the X-ray diffractometer diagrams of the clay fraction is based mainly on the monographs on clay minerals edited by Brindly (1951), and a later revised edition (Brown, 1961). All X-ray data used are obtained from these two monographs and they will not be referenced further.

Comparative semi-quantitative estimates of the clay mineral compounds in all samples has been carried out.

For the micropalaeontological investigation, 100 g of dried material from each sample was used. Standard laboratory treatment (Hiltermann, 1958, and Feyling-Hanssen, 1958, 1964) was applied except for the separation of wash residues in heavy liquid. Because of the large pyrite content of the clay, a mixture of bromoform and alcohol (S. G. 1.85) was used instead of carbon tetrachloride (S. G. 1.63). The total number of foraminifers larger than 0.1 mm in the heavy and light fractions were examined in each sample.

Sediments

Texture of sediments

The sedimentary materials investigated are very homogeneous throughout (fig. 3 and plate 3) consisting predominantly of mud and clay mud (less than 1/16 mm in size). Sand and gravel amount to only a few percent whereas silt and clay each amount to nearly 50 %. At certain stratigraphic levels the clay fraction exceeds more than 60 % of total material (fig. 4). In order mainly to study the fine grained materials, it was found conveniant to divide the silt-clay end member series into classes of 80 %, 55 % and 33 % clay as suggested by Marlowe (1965).

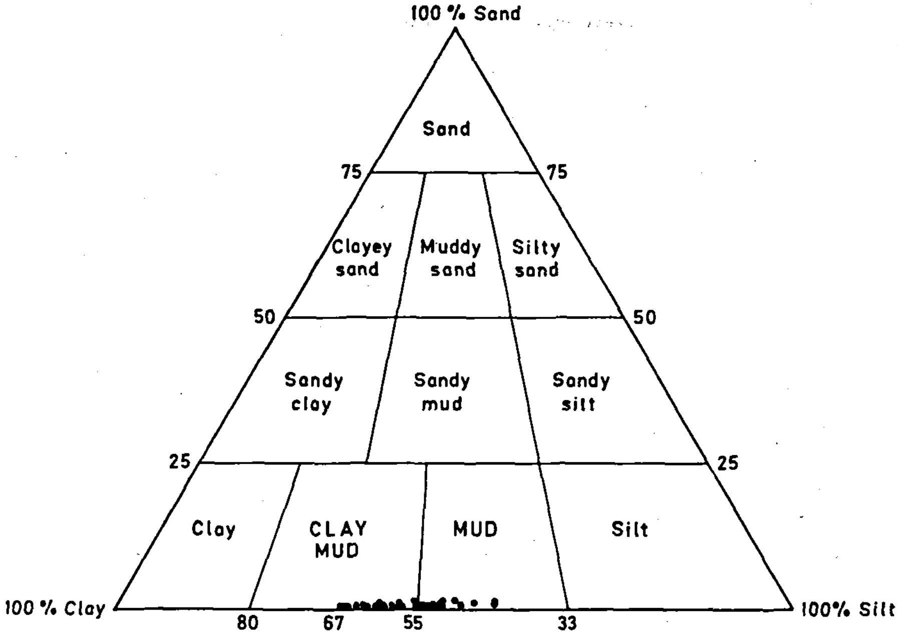

Fig. 3. Textural classification used in the study of sediments of the Viborg Formation at Sofienlund.

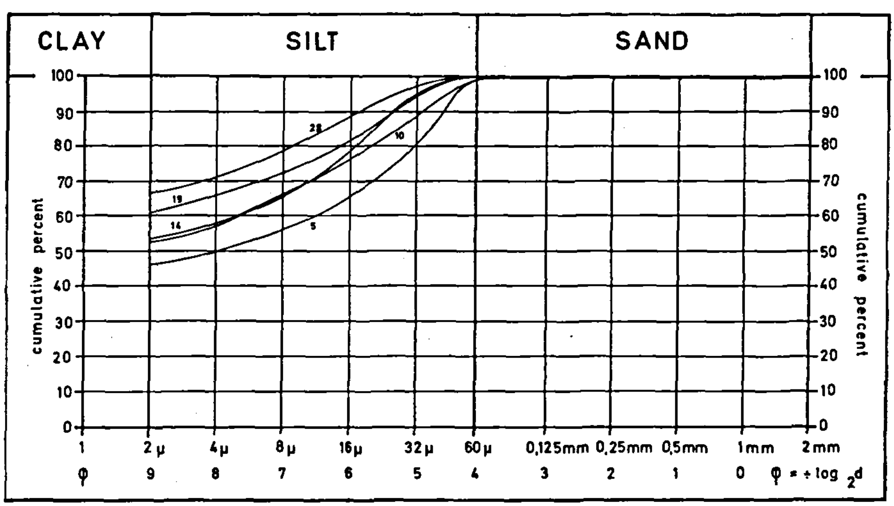

Fig. 4. Cumulative frequency curves of selected samples from the Viborg Formation. Increasing figure corresponds to increasing depth in standard profile (plate 3).

Mineralogy of sediments

Sand fraction. This ranges from less than 1 % to about 3 % (weight percent). The most common minerals are pyrite and micas, pyrite occuring in all sand fractions and making upp all of the monomineralic coarsest sand fractions. The amount of mica increases in the finer sand fractions, together with microfossils. A few grains of quartz are normally found in medium-sized sand fractions. Pyrite occurs as separate unoxidized grains or in certain cases as fillings of foraminiferal tests. Grains show different forms – for example they may be stem-like or have an irregular bullet-shape. Casts of foraminiferal tests occur in some samples. Typical pyrite grains are shown in (plate 2 A).

The finer sand and silt fractions are composed mainly of mica flakes. These flakes are often bent along their margins.

Clay fraction. The clay fraction (< 2 μ) makes up between about 40 and 60 % of the total material (fig. 4 and plate 3).

The mineralogical composition of the clay fraction is similar in all of the samples, consisting of montmorillonite, illite and kaolinite groups of clay minerals (fig. 5). Some X-ray diffraction patterns of these are illustrated

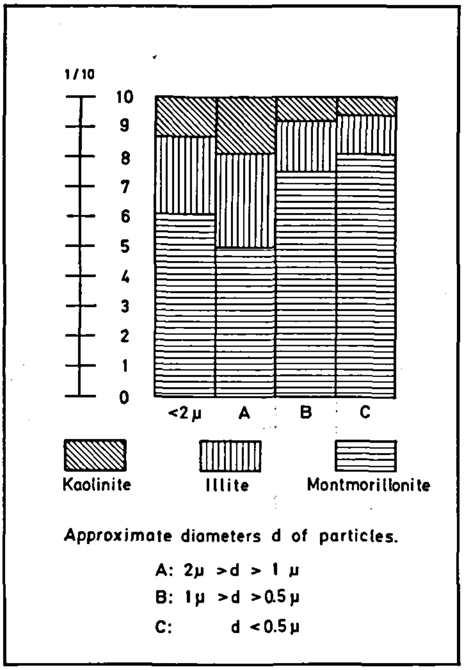

Fig. 5. Clay mineral composition of fractions split by centrifuging.

(fig. 6). A broad reflection at 14.7 Å in untreated samples expands on glycolation to 16.7 Å and become less diffuse and more intense, indicating

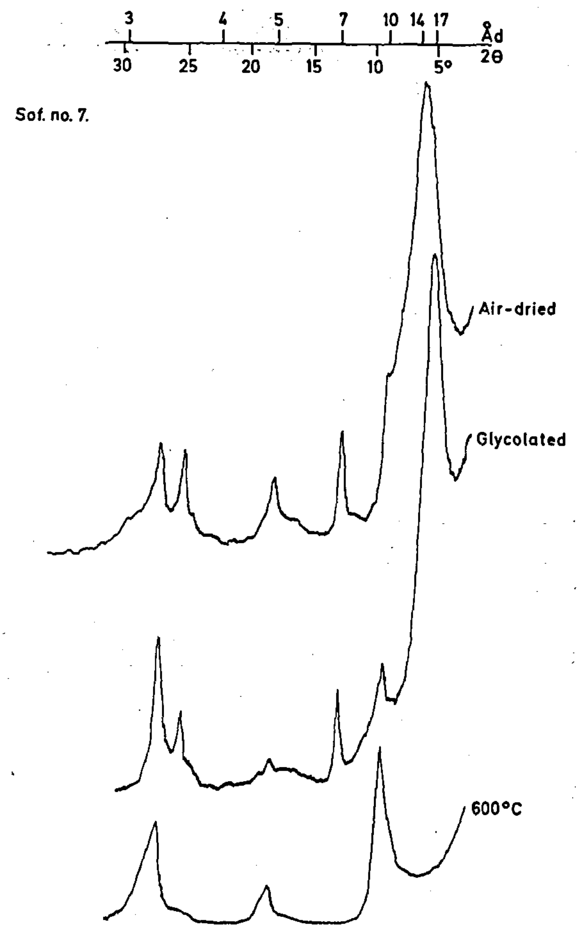

Fig. 6. X-ray diffraction patterns of an oriented specimen from the Viborg Formation at Sofienlund.

the presence of montmorillonite. The 10 Å reflection of illite is also exposed on glycolation. In the untreated sample this reflection may be recognized on the high angle side of montmorillonite. Reflections at slightly more than 7 Å are ascribed to kaolinite. Heating to 600° C destroys the kaolinite reflection at about 7 Å and the montmorillonite reflection at 16.7 Å moves to 10 Å, increasing the intensity of the 10 Å reflection.

Montmorillonite is the dominant mineral in all the clay samples and ranges from a half to two thirds of the material in the clay fraction. Illite makes up about a quarter or less whereas kaolinite amounts to only a tenth of the total clay sample.

In order to investigate the distribution of clay minerals in the clay fraction ($< 2\,\mu$) of single samples the clay fraction has been centrifuged and split in accordance with the method described by Tanner and Jackson (1947). As the method does not correspond to exact grain size boundaries, the designations A, B and C have been used for the resulting fractions. The approximate particle diameters (d) are:

A 2 microns > d > 1 microns
B 1 microns > d > 0,5 microns
C d < 0,5 microns

Results of a total sample $< 2\,\mu$ and centrifuged fractions of the same sample are shown in (fig. 5). Montmorillonite attains the highest concentrations in the C fraction and the lowest amounts in the A fraction. Illite and kaolinite are most common in the A and B fractions. This distribution is in accordance with the statement by Grim (1953), that montmorillonite occurs as very small particles whereas kaolinite and illite generally occur in coarser fractions.

Summary of mineralogical variation

The mineralogical composition of samples from the Sofienlund area is fairly uniform with only minor exceptions. Although the silt and fine sand fractions are rich in detrital material, they also contain, together with coarser sand fractions, appreciable amounts of authigenic pyrite.

X-ray diffractometer investigations of the clay fraction has revealed that the more fine grained materials are composed of a montmorillonite-illite-kaolinite clay mineral group association with montmorillonite dominant.

Mineralogic analysis of centrifuged clay fractions has shown the montmorillonite clay mineral group to occur mainly in finer fractions of the total clay sample $< 2\,\mu$.

Micropalaeontology

Foraminiferal fauna

112 different species and varieties of foraminifers were recognized in the present material. The number of specimens per sample varies from 295 to 5813. The faunal diversity (as defined by Walton, 1964) has a range of 5 to 35 (plate 3). The appearance of the foraminifers is strongly variable, ranging from glassy "recent"-looking to partly and completely pyritic and fragmented tests.

The fauna consists mainly of hyaline calcareous benthonic species. Agglutinated as well as porcellaneous tests are scarce, and very few planktonic specimens are to be found. The species *Turrilina alsatica* Andreae, *Nonion affine* (Reuss), and *Pullenia bulloides* (d'Orbigny) account for at least 40 %

of the fauna (plate 3). The majority of the remaining species belong to the superfamilies: Nodosariacea, Orbitoidacea, Cassidulinacea, and partly Robertinacea. The systematic taxa applied in the present paper are in accordance with the classification presented in Loeblich and Tappan's (1964) Treatise.

The foraminiferal fauna in the examined profiles is, in the sense of species composition, very uniform throughout. No distinct boundaries marked by appearance or disappearance of species have been registrated, but variations in relative frequency, especially among the most abundant species, do occur. Based on the stability in the composition of species, the foraminiferal fauna has been divided into the following 11 groups: Agglutinated tests, Porcellane-

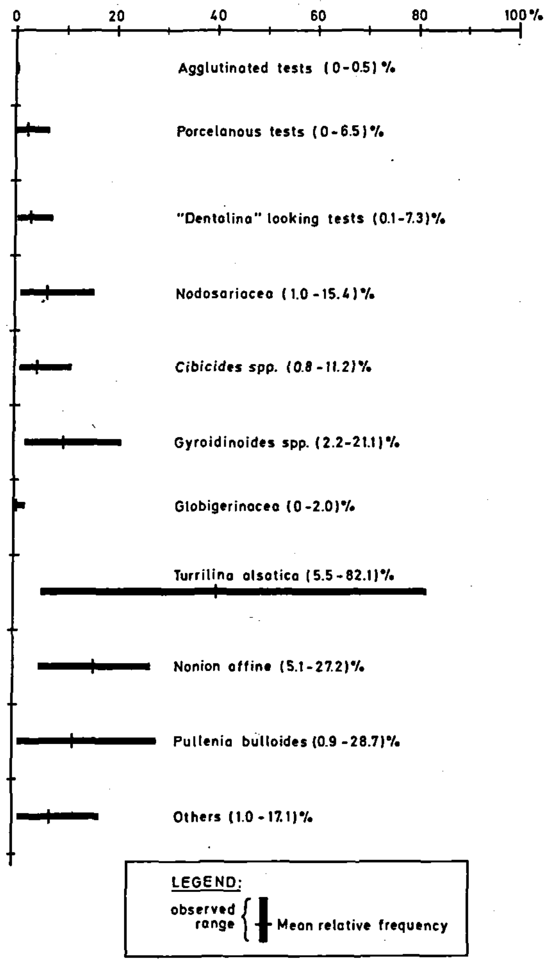

Fig. 7. The observed range and mean of the foraminiferal fauna in the Viborg Formation at Sofienlund divided into 11 foraminiferal groups.

ous tests, "*Dentalina*"-like tests, Nodosariacea, *Cibicides* spp., *Gyroidinoides* spp., Globigerinacea, *Turrilina alsatica, Nonion affine, Pullenia bulloides,* and Others. Their observed range in relative frequency, together with the mean relative frequency are shown in (fig. 7), whereas (plate 2B) illustrates a representative fauna in the examined Viborg Formation.

Descriptions of the groups are given below:

Agglutinated tests

This group is represented in only 6 samples, and then only by a few specimens. It consists of the two species: *Spiroplectammina deperdita* (d'Orbigny) and *Martinottiella muensteri* (Cushman).

Porcellaneous tests

The group decreases in frequency upwards in the profiles. This tendency might be due to secondary solution of tests in connection with pyrite formation, as these tests are often filled with pyrite in the samples from the top of the profiles. *Quinqueloculina impressa* Reuss is the most common species of the group. *Spiroloculina dorsata* Reuss and *Sigmoilina tenuis* (Czjzek) are also represented in most of the samples, but with few specimens only. The few *Quinqueloculina trianqularis* d'Orbigny and *Q. ludwigi* Reuss are very conspicuous because of their size.

"Dentalina"-like tests

To this group belong species of the genera: *Dentalina, Nodosaria,* and *Stilostomella.* The tests are strongly fragmented, so that their frequencies had to be calculated by counting the number of initial or apertural parts. *Stilostomella hirsuta* (d'Orbigny), *S. longiscata* (d'Orbigny), *S. adolphina* (d'Orbigny), *S. spinescens* (Reuss), and *Dentalina emaciata* Reuss are the most common species. Their relative frequencies never exceed 2 % of the total faunas.

Nodosariacea

This group consists of species of the families: Nodosariidae, Polymorphinidae, and Glandulinidae, except for the species belonging to the *Nodosaria* and *Dentalina,* which are grouped with the "*Dentalina*"-like tests above.

The family Nodosariidae is represented by a large number of species but a small number of specimens. Species belonging to the genera *Lagena* and *Lenticulina* are often found. *Frondicularia budensis* (Hantken) is the most common species of this family in spite of the fact that it is rarely found in the uppermost quarter of the profile. This occurrence might also be due to the secondary pyritic effect, since the specimens are usually more or less filled with pyrite.

The family *Polymorphinidae* is also represented by a large number of species and a small number of specimens. The most common species are: *Globulina inaequalis* Reuss, *Guttulina irregularis* (d'Orbigny), and *G. frankei* Cushman & Ozawa.

The family Glandulinidae does not show so many species, but some of them occur in great numbers, especielly *Glandulina aequalis* Reuss. It is the most common species of the group, and constitutes up to 4.2 % of the total fauna.

Cibicides spp.

This group is represented by attached and freeliving species. The former consists of *Cibicides aknerianus* (d'Orbigny), which is the most common of the group, and a few specimens of *C. amphisyliensis* (Andreae). The latter consists of *C. telegdi* Grossheide & Trunkó, which is also common, and some tests of *C. ungerianus* (d'Orbigny).

Gyroidinoides spp.

This group is represented by five species, of which *Gyroidinoides* cf. *angustiumbilicata* (Ten Dam), *G. soldanii* forma 1, and *G?* sp. 1 are the most frequent. *G. soldanii* forma *girardanus* (Reuss) is not so common but is conspicuous because of its size.

Globigerinacea

Planktonic tests are very rare. There is no increase in their representation in the deeper part of the section so it is unlikely that their absence is due to the secondary pyritic effect.

The low abundance of specimens, their severe fragmentation and the pyritic effect combine to make identification almost impossible. With certainty, specimens of *Globigerina ouachitaensis* Howe & Wallace and *G. praebulloides* were recognized. Some tests, belonging to the genus *Pseudohastigerina,* are probably reworked tests of the Eocene *P. wilcoxensis* (Cushman & Ponton).

Turrilina alsatica – Nonion affine – Pullenia bulloides

These groups are the most aboundant. The joint relative frequency of the three species varies from 40.5 % to 89.9 % in the faunas (plate 3). The frequency of *Turrilina alsatica* Andreae is reciprocal to the two others, that is, when it is frequent the two others are scarcely represented and vice versa.

Others

To this group belongs the rest of the registrated species and varieties. It consists of 20 species belonging to the superfamilies Buliminacea, Discorbacea, Rotaliacea, Orbitoidacea, Cassidulinacea, and Robertinacea. The four species *Ceratobulimina contraria* (Reuss), *Epistominella oveyi* (Bhatia), *Alabamina tangentialis* (Clodius), and *Eponides pygmeus* (Hantken) account for approximately ⅔ of the group.

Stratigraphy

According to the present foraminiferal investigations, the following biostratigraphical classification of the foraminiferal-bearing deposits in the Sofienlund locality is suggested (plate 3): The Viborg Formation is referred to a *Turrilina alsatica* zone because of its frequency and its representation in all examined samples. In the superimposed sediments, preliminary investigations show that only the Ulstrup Clay and the Sofienlund Clay contain a foraminiferal fauna. Both members belong biostratigraphically to the *Uvigerina gracilis* zone because the species *Uvigerina gracilis* Reuss is easily observed throughout the members, only with variations in the ornamentation of the test surface.

The foraminiferal fauna in the Viborg Formation at Sofienlund shows great affinity to the fauna in the Belgian Boom Clay (type sediment for Rupelian) and to its equivalent in Northern Germany, the Septarian Clay.

Most of the species have a wide stratigraphical range, but almost all are observable in Middle Oligocene deposits around the North Sea Basin. Only the species *Dentalina oligosphaerica* Reuss and *Cibicides telegdi* Grossheide & Trunkó, were not previously found in these deposits although they are both described from Upper Oligocene deposits in NW Germany. According to the available literature on foraminifers from the North Sea Basin, the following species in the Sofienlund material seem to be restricted to Middle Oligocene deposits in this area: *Turrilina alsatica* Andreae, *Nonionella jacksonensis* Cushman, *Frondicularia budensis* (Hantken), *Lenticulina deformis* (Reuss), *Dentalina emaciata* Reuss, *Spiroloculina dorsata* Reuss, and *Buliminina alsatica* Cushman & Parker. In Belgium, on the other hand, *Stilostomella longiscata* (d'Orbigny), *Eponides pygmeus* (Hantken), and *Robertina declivis* (Reuss) are restricted to Boom clay (Batjes, 1958). These findings strongly indicate that the examined sequence of Sofienlund is of Rupelian (i.e. Middle Oligocene) age.

Spiegler (1965), using the benthonic foraminifers, has divided the German Rupelian stratigraphically into four parts, Rupel 1, 2, 3, and 4. Rupel 1 and 3 are zones where agglutinated tests and fish fragments dominate, whereas Rupel 2 and 4 consist mainly of calcareous, benthonic foraminiferal fauna. The Sofienlund fauna shows greatest affinity to Rupel 2, as *Frondicularia budensis* (Hantken) and *Ceratobulimina contraria* (Reuss) are represented in most of the samples, and *Cibicides ungerianus* (d'Orbigny) is rare. Other "Leitformen" of Rupel 2 are not observed. Among the "Leitformen"of Rupel 4, some fragments of *Dentalina retrorsa* (Reuss) are found, and a very few specimens of *Cibicides ungerianus* (d'Orbigny).

In Niederrheinishe Bucht, Ellermann (1958, 1960) and Indans (1958, 1965) have investigated the Oligocene foraminiferal faunas. They found both a maximum of *Turrilina alsatica* Andreae in "Horizon 1" and "Horizon B" respectively (= Rupel 2, Spiegler, 1965). The species is almost completely restricted to this part of the Oligocene profile.

In the Magdeburg area, Kiesel (1962) also observed a high representation of *Turrilina alsatica* Andreae in "Horizon 2" (= Rupel 2, Spiegler, 1965), whereas its representation in the upper part of the profile (= Rupel 4, Spiegler, 1965) is very small.

The reason for setting up the group of "*Dentalina*"-like tests (fig. 7) is that Dinesen, in Rasmussen (1960), assumed that the foraminiferal fauna in the Viborg Formation of Sofienlund represents the typical German, Middle Oligocene "*Dentalina*-Fauna" (Staesche & Hiltermann, 1940). The German "*Dentalina*-Fauna" is of upper Middle Oligocene age (= Rupel 4, Spiegler, 1965). However, the present writers do not consider the fauna of Sofienlund a typical "*Dentalina*-Fauna", as envisaged by Staesche & Hiltermann (1940, pl. 22). Only the three species *Dentalina pauperata* d'Orbigny, *D. soluta* Reuss, and *D. approximata* (Reuss) are found in the Sofienlund material, and the "Dentalinas" do not at all dominate the fauna (cf. fig. 7). Furthermore, the "Dentalinas" of Sofienlund are dominated by *Stilostomella* spp., so it would be better to call it a "*Stilostomella* fauna". Regarding this, Spiegler (1965) says about Rupel 2: "Verschiedene *Stilostomella*-Arten sind oftmals in dieser Zone besonders häufig."

Spiegler (1965) considered that the deposits of the Rupel 2 sea probably show the maximum of the Oligocene transgression in Northern Germany.

Summing up, the foraminiferal fauna in the Viborg Formation at Sofienlund is of Middle Oligocene age, and compared to the Middle Oligocene in Northern Germany it might probably be of Lower Rupelian age (= Rupel 2, Spiegler, 1965). Younger Rupelian sediments have not been observed in the Sofienlund locality. The Ulstrup Clay and the Sofienlund Clay are, according to preliminary foraminiferal investigations, of Upper Oligocene age. This is also confirmed by Ravn (1907) who examined the mollusc fauna.

Summary and conclusions

Occurrence of mica flakes and muscovite-like illite may suggest a denudational area composed of rocks formed under high temperature conditions.

From heavy mineral studies, Larsen (in Larsen & Dinesen, 1959) concluded that the source rocks of the Vejle Fjord Formation were probably a Fennoscandian regional metamorphic complex.

Weaver (1958a, b) assumes the majority of clay minerals in sediments to be of detrital origin. The high montmorillonite content in the Viborg Formation may be ascribed to alterations of volcanic ash materials. If this is so, a high montmorillonite content would be expected in Middle Oligocene sediments from other localities in the Danish Embayment; However this is not the case (Tank, 1963 and Christensen, 1969).

The increase of the montmorillonite content in the finer fractions was probably caused by changes of one or more of the following factors: Currents, distance of transport, salinity and depth of water in the depositional environment. This might be connected with different settling velocity of flocculated clay minerals, different flocculation rates, and different sizes of clay aggregates resulting from flocculation. As montmorillonite in general occurs as minor particles compared to illite and kaolinite, the settling velocity of montmorillonite also will be lower, keeping montmorillonite minerals in suspension for a longer time than would be the case with illite and kaolinite. Montmorillonite, therefore, may be transported to more distant areas. This process may be increased by flocculation in sea water. Whitehouse (1952), Whitehouse & Jeffrey (1955) and Whitehouse et al. (1960) have shown kaolinite and illite to flocculate immediately upon arrival in waters characterized by low salinity, whereas flocculation of montmorillonite occurs mainly at higher salinities and then more slowly. Furthermore, the flocculated montmorillonite aggregates will never attain the same size as equivalent aggregates of illite and kaolinite. Tank (1963) discusses similar possibilities of interpretation for the distribution of clay minerals in zone 1 in the Danish Tertiary sequence.

From Recent sediments in the Paria bay, Andel & Postma (1954) have shown a kaolinite – illite association in delta sediments, whereas off-shore deposits are characterized by a montmorillonite – kaolinite association. Laughman & Craig (1962), studying clay mineral composition in Recent sediments along the Australian east coast, considered differential flocculation to be factor determining clay mineral composition. Porrenga (1966 and 1967), studying Recent marine sediments from tropical areas, has shown that the sedimentary materials contain detrital kaolinite, montmorillonite and illite. Montmorillonite content increases with depth of water and distance from shore, ranging from 30 % in delta areas up to 50 % 100 km from the shore. Porrenga (1966 and 1967) assumes this mineral distribution to have been caused by differential sedimentation in moving sea water.

Regarding the use of the actuality principle on foraminifers in palaeoecological conclusions Pokorny (1963) says: "The knowledge gained on Recent

Foraminifera cannot be used for the assessment of the ecology of fossil assemblages without reservation because present-day environmental conditions differ in many respect from those prevailing in the past." Therefore, only some general similarities to Recent seas are indicated.

The fauna in the Viborg Formation at Sofienlund consists of a large number of genera and species. A total of 46 genera have been observed. The number of species in each sample is usually between 40 and 65 (plate 3). Except for the extremely low representation of planktonic tests (plate 3), these numbers roughly correspond to those of the lower part of the outer continental shelf or the upper part of the continental slope in Recent seas (Phleger, 1965). A scarce representation of planktonic tests is often explained as the result of near-shore conditions (Smith, 1955, Hay, 1960) but may be due to a decrease in salinity which the planktonic foraminifers cannot tolerate (Pokorny, 1963).

The dominance of hyaline foraminifers against agglutinated and porcelaneous tests means deeper water, that is, an environment comparable with the present-day outer continental shelf (Greiner, 1970).

The attached *Cibicides*-tests have an important ecological significance. They have probably been attached to algae, which means that they must have lived in the euphotic zone of the sea; alternatively they might have merely drifted in to the area.

In Oligocene deposits of the Isle of Wight, Bhatia (1957) found a "well" marked representation of polymorphinids in the Brockenhurst and Roydon zones which together represent a deeper marine facies of the Middle Headon beds. They are not found in the middle and upper parts of the superimposed "Venus" beds which represent a nearshore, epineritic environment.

Nonion affine (Reuss) and *Pullenia bulloides* (d'Orbigny) occur in Recent faunas, and they are both restricted to deep-sea environment. Smith (1964) observed them at depths between 1600 m and 3100 m off the west coast of Central America. Pokorny (1963) considers that *P. bulloides* (d'Orbigny) has experienced a "depth-migration" through time and finds it to be very common in shallow-water sediments of Miocene age.

In the Belgian Boom clay, Batjes (1958) observed two facies; a western sticky clay-facies, and an eastern sandy clay-facies. The latter is a shore facies of the western, open sea-facies. The sandy shore-facies differs from the other one by showing an aboundance of *Dentalina emaciata* Reuss and *Cibicides ungerianus* (d'Orbigny), whereas Chilostomellidae, i.e. *Pullenia bulloides* (d'Orbigny) and *Sphaeroidina bulloides* d'Orbigny) are rare. Among the common species of the sticky Boom clay are: *Nonion affine* (Reuss), *Pullenia bulloides* (d'Orbigny), and *Gyroidina soldanii* d'Orbigny var. *girardana* (Reuss). The fauna in the Viborg Formation at Sofienlund indicates conditions intermediate the two facies of the Boom clay but with strongest affinity to the one which represents the open sea environment.

The high pyrite content of the clay materials in the Viborg Formation may indicate anaerobic conditions during sedimentation, but the rich benthonic foraminiferal fauna contradicts this. The pyrite, therefore, probably originated below the water-sediment interface. This is also pointed out by Batjes (1958) concerning the pyrite content of the Boom clay.

The central position of the Sofienlund area in the Danish Oligocene basin, the fine grained textural composition of the materials in the Viborg Formation, the clay mineral association and the ecological factors discussed, lead the authors to assume that the materials constituting the Viborg Formation at Sofienlund was probably deposited in an environment like that of a present-day outer continental shelf area. The extremely low representation of planktonic specimens may indicate a high run-off which would provide lower salinity than that of open sea-water in the central North Sea basin. However, the low planktonic representation may also be due to the existence of some kind of barrier in the outer part of the Danish Oligocene basin, for instance an island barrier as illustrated by Smith (1955) in the Recent Mississippi area.

Marine conditions prevailed during the deposition of the Ulstrup Clay and the Sofienlund Clay. The lignitic material in the Sofienlund Silt suggests a low oxygen content in the depositional area and probably slight water movements. The environment was a near shore marginal basin. The cross bedding in the Sofienlund Sand suggests fluviatile conditions with a sand infilling of the area.

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Dansk sammendrag

Der gives en beskrivelse af sedimenter og foraminiferfauna i den tertiære lagserie i Sofienlund teglværks nedlagte lergrav ved Ulstrup i Midtjylland. Lagserien består nederst af fossilholdige, marine lersedimenter og øverst af siltholdige ler- og sandsedimenter. Lagserien opdeles i to formationer, som opstilles som nye formelle enheder. Den nedre formation, Viborg Formationen, er undersøgt mere indgående, mineralogisk og mikropalæontologisk. De fede lermaterialer i denne formation indeholder et lermineralselskab domineret af montmorillonit og mindre mængder af kaolin og illit. Montmorillonitindholdet er stigende i de finere fraktioner. Foraminiferfaunaen er domineret af benthoniske kalkskaller. *Turrilina alsatica*, *Nonion affine* og *Pullenia bul-*

loides udgør tilsammen minimum 40 % af foraminiferfaunaen. Viborg Formationen i Sofienlund er placeret i mellem oligocæn. Det antages, at aflejring af lermineralerne i forbindelse med differentieret flokkulation, i et kystfjernt marint miljø har været en bestemmende faktor for lermineralsammensætningen. Udstrømning af ferskvand fra floder kan have reduceret saltholdigheden i aflejringsmiljøet og sandsynligvis forklare den ringe repræsentation af planktoniske foraminiferer i Viborg Formationen.

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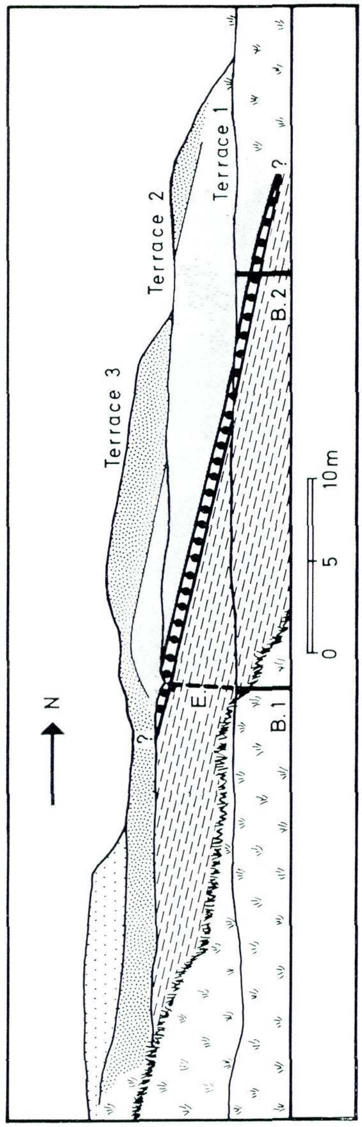
Plate 1

A. Sofienlund locality, western wall.

B. Explanation of the same, showing lithostratigraphical distribution and location of borings and excavation profile.

A



B

Legend to profile 1B.

VIBORG FORMATION

Sticky clay

SOFIENLUND FORMATION

Light, micaceous sand

Dark, clayey silt

Glauconitic clay, and yellowish-brown clay

Vegetation cover

Glaciofluval sand

B1 = Boring no.1

E = Excavation profile

Plate 2

A. Pyrite grains in the Viborg Formation. Grain size fraction 0.25–0.50 mm.

B. A representative foraminiferal fauna in the Viborg Formation from Sofienlund.

A. *Turrilina alsatica* Andreae
B. *Nonion affine* (Reuss)
C. *Pullenia bulloides* (d'Orbigny)
D. *Stilostomella hirsuta* (d'Orbigny)
E. *S. longiscata* (d'Orbigny)
F. *S. adolphina* (d'Orbigny)
G. *Frondicularia budensis* (Hantken)
H. *Dentalina emaciata* Reuss
I. *Guttulina irregularis* (d'Orbigny)
J. *G. frankei* Cushman & Ozawa
K. *Glandulina aequalis* Reuss
L. *Gyroidinoides* cf. *angustiumbilicata* (Ten Dam)
M. *G?* sp. 1.
N. *Pararotalia fallax* (Steuer)
O. *Cibicides aknerianus* (d'Orbigny)
P. *Ceratobulimina contraria* (Reuss)
Q. *Robertina declivis* (Reuss)
R. *Spiroloculina dorsata* Reuss
S. *Quinqueloculina ludwigi* Reuss

A

B

Plate 3

The Tertiary sequence of the Sofienlund area.