Lithostratigraphy and sedimentary petrography of the Paleocene and Eocene sediments from the Harre borehole, Denmark.

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ABSTRACT

The Paleocene and Eocene cores have been described and investigated comprising textural, mineralogical and geochemical analyses. A correlation with the detailed established lithostratigraphy has been performed.
The Paleocene section of the Harre cores represent an almost complete section and comprises the formations; Danian Limestone (not penetrated), Kerteminde Marl, "grey slightly to non-calcareous clay", Holmehus Formation, Ølst- and Fur Formations.
The Eocene section represents only fragments of the section known from other localities and comprises the following units; Røsnæs Clay Formation - Beds R1, R3 and R4 - and Lillebælt Clay Formation - Bed L5. Major hiati are located in the Eocene comprising i) Beds R5 and R6 of the Røsnæs Clay Formation and L1, L2, L3 and L4 of the Lillebælt Clay Formation and ii) Bed L6 of the Lillebælt Clay Formation and the Søvind Marl. Minor hiati are present at the transition Danian Limestone/Kerteminde Clay, Holmehus/Ølst Formation and Ølst/Røsnæs Clay Formation. Movements of salt in the salt structures surrounding the site, is believed to be the major cause of the differing degrees of completeness of the Paleocene and Eocene sections. Reworked sediment is especially found immediately above these hiati.
The Paleocene and Eocene interval is characterized by very finegrained marine deposits. Sand-sized and most coarse silt-sized particles are either of biogenic origin (coccoliths, foraminifers and faecal pellets or of authigenic origin (pyrite, glauconite and zeolites). In the Ølst- and Fur Formations eolian transported sand-sized ashparticles of volcanic origin are frequent in distinct layers, often with graded bedding. Lateral facies-variations are very small within the onshore Danish area. Coarser grained nearshore sediments are not found, but occasionally slightly decreased contents of clay-sized particles and smectite, and corresponding increases in siltgrades, kaolinite and illite, might indicate dispersal patterns of detrital supplied material.
Oxic bottomwater conditions dominated during deposition of the Røsnæs Clay Formation, while anoxic conditions prevailed during deposition of the lower Ølst- and Fur Formations. In the other formations less favourable conditions dominated with intercalations of true anoxic and true oxic events.
Except for porewater expulsion and related precipitation of part of the dissolved material in concretions, no diagenetic mineral transformations have been observed.

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INTRODUCTION

The Paleocene section of the Harre borehole (Fig. 1 in the introductory chapter) is well-developed and comprises three lithostratigraphic units: the Kerteminde Marl, the "grey slightly to non-calcareous clay" and the Holmehus Formation (Nielsen, *et al.*, 1994, this volume). At the transition between Paleocene and Eocene the Ølst and Fur Formations are present almost as complete as known from other Danish localities and with a very characteristic interfingering between the two different facies represented by the two different but comtemperaneous formations. The Eocene section is rather incomplete, but contains lithostratigraphic units easy to identify according to the subdivision of Heilmann-Clausen *et al.* (1985). The section comprises parts of the Røsnæs Clay Formation and parts of the Lillebælt Clay Formation, while Søvind Marl is absent. The Røsnæs Clay Formation is represented by Beds R1, R3 and possibly R4, while the Lillebælt Clay Formation is represented only by Bed L5. The Oligocene/Miocene part of the Harre cores is investigated by Friis (1994, this volume).

METHODS

Based on the detailed lithologic descriptions of the different lithostratigraphic units 47 samples were selected for further sediment petrographic analysis comprising texture, mineralogy and geochemistry. Samples of 5 grams for grain size analysis were dried at 105^{o} C for 24 hours, weighed, suspended in distilled water and sieved through a 63 μm sieve. The > 63 μm fraction (the sand range) was dried and weighed. 10 milliliters of .01 M $Na_4P_2O_7 * 10H_2O$ was added to the < 63 μm fraction and the suspension was grain size analysed in an Andreassen pipette. Approximately 5 grams of each sample was dried at 50^{o} C for 72 hours, weighed and suspended in distilled water and sieved through a 63 μm sieve. The sand fraction was dried and weighed. The fraction from 2-63 microns (the silt range) was produced by repeated decanting of the clay fraction (< 2 μm) in distilled water. The silt fraction was dried and weighed. The clay fraction was concentrated by centrifugation and oriented glass plate-preparations were X-rayed on a Philips diffractometer with Cu, K-alpha radiation.

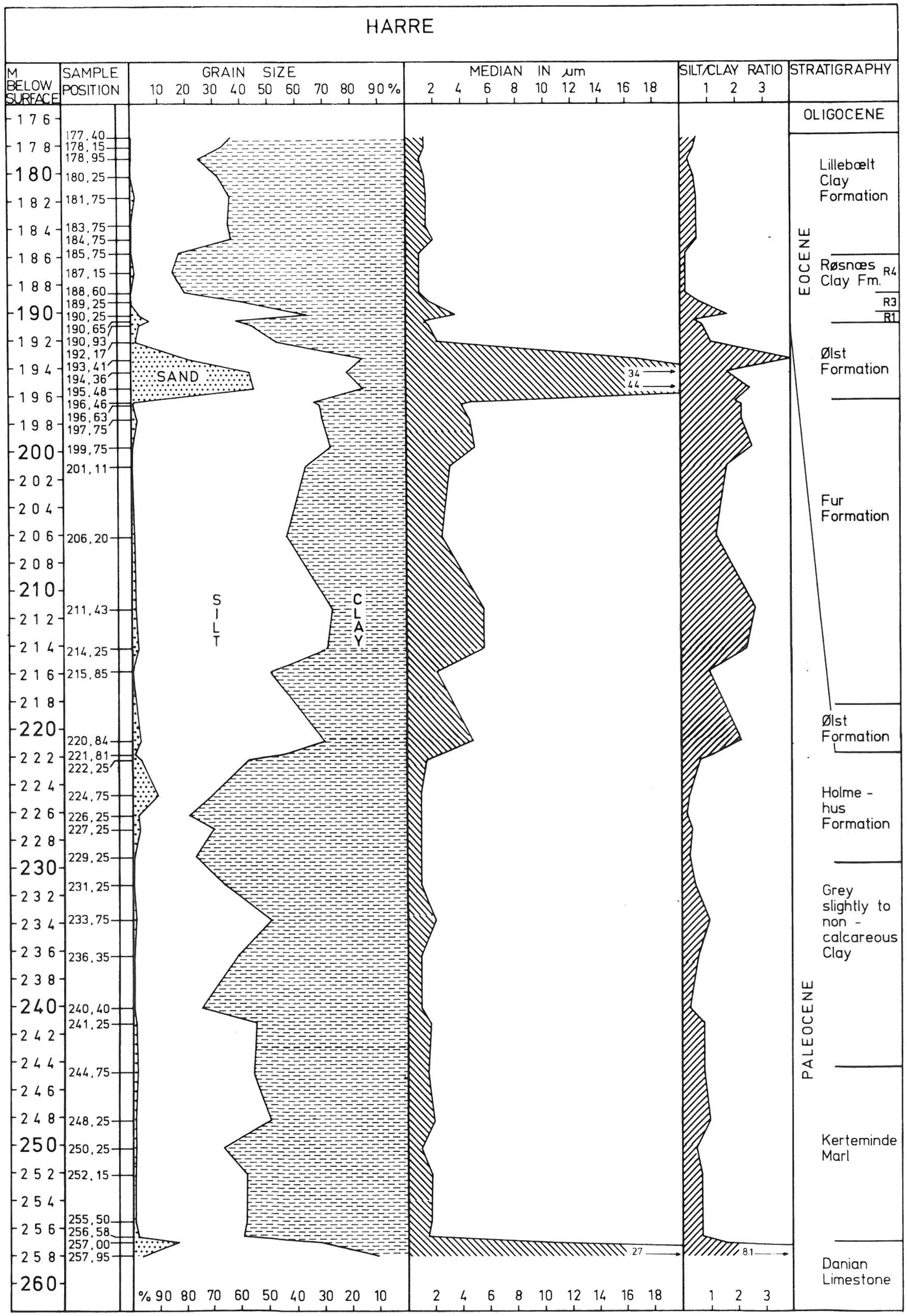

Fig. 1. Grain size distribution of the Paleocene and Eocene section in the Harre borehole.

Records were made of air-dried, of glycollated and of heated preparations respectively. Bulk mineralogical analysis was performed on subsamples dried at 105^{o} C for 24 hours, ground in a mortar and mounted in an Al-preparation without preferred orientation. The preparations were X-rayed from 2-65^{o} 2Θ in the same diffractometer and conditions as the clay fractions (see above). Clay- and bulk minerals were identified and quantified (Schultz, 1960; Brindley & Brown, 1980). The content of carbonate and Org. C was calculated using a LECO induction furnace. The chemical analysis were performed on totally dissolved samples (HF solvent) on a Perkin-Elmer atomic absorption spectrophotometer.

RESULTS

DANIAN LIMESTONE

Lithology and lithostratigraphy

The Danian Limestone (below 256.9 m.b.s.) is a light grey sandy calcisiltite with some flint bands, which, together with the section in the borehole Viborg 1, represents a younger period of the Danian than known from other localities in Denmark. (Thomsen & Heilmann-Clausen, 1985). The uppermost 0.5 m is intensely bioturbated.

Texture

The few grain size analyses carried out in this unit demonstrate that the lithology is a calcisiltite, as also interpreted from the macroscopic description (Fig. 1). Sand-size particles comprise 13%, silt-size 69% and clay-size 18% of the material.

Mineralogy and geochemistry

Calcite is the dominant mineral and smectite dominates the non-carbonate fraction. (Figs. 2 & 3). The chemical composition (Fig. 4) supports the mineralogical quantification based on X-ray diffraction (XRD).

Data for the Danian Limestone are very sparse and only available for the uppermost part. No attempt is therefore made to carry out comparisons with other localities and detailed interpretations.

KERTEMINDE MARL

Lithology and lithostratigraphy

The Kerteminde Marl is 12.4 m (244.5-256.9 m.b.s.) thick, light grey and silty, and is characterized by a smaller grain size of the authigenic and biogenic particles than the underlying Danian deposits and by a lower and an upwards decreasing carbonate content. The contact with the Danian Limestone is not very sharp because of intense bioturbation. (See also Thomsen & Heilmann-Clausen, 1985). The burrows are rich in glauconite, but a proper layer of Lellinge Greensand, present in some other localities, mostly more to the east in Denmark, is not present. In the upper part there is a level with a lower carbonate content, also found in other localities, even if some of these localities have a much greater thickness of marl. (see Skovbjerg, 1988 and Steensen-Bach *et al.*, 1988). Just above the low-carbonate level the marl becomes slightly silicified. It is not possible to tell whether the Kerteminde Marl in the Harre borehole represents the complete sequence in a very condensed version, or represents only a limited part of the whole period with marl deposition.

Texture

The lowermost sample is slightly more sandy than the remaining part of the marl (Fig. 1), probably due to a higher content of glauconite. The marl contains generally very little sand, approximately 1%, 38% silt and 61% clay with only small variations.

Mineralogy and geochemistry

Carbonate minerals, mainly calcite, are the dominant constituent, with an upwards decreasing tendency. Their origin is mainly from reworking of Maastrichtian microfossils (von Salis Perch-Nielsen, 1994, this volume). Clay minerals make up the second most frequent mineral group (Fig. 2) with smectite as the dominant component (78%) and an illite content of 22%. (Fig. 3) Kaolinite is absent. The quartz and feldspar contents increase upwards, and zeolites of the heulandite-clinoptilolite type are present throughout the interval. Cristobalite is only present in one sample in the upper part. Other localities, as f. ex. Boulstrup (see Fig. 1 in the introductory chapter) contain only cristobalite and zeolites in the upper part and it is thus possible that in the Harre cores there is a hiatus comprising the lower part of the Kerteminde Marl. The lower part of the marl at Harre belongs to NP Zone 4/5 (von Salis Perch-Nielsen, 1994, this volume)

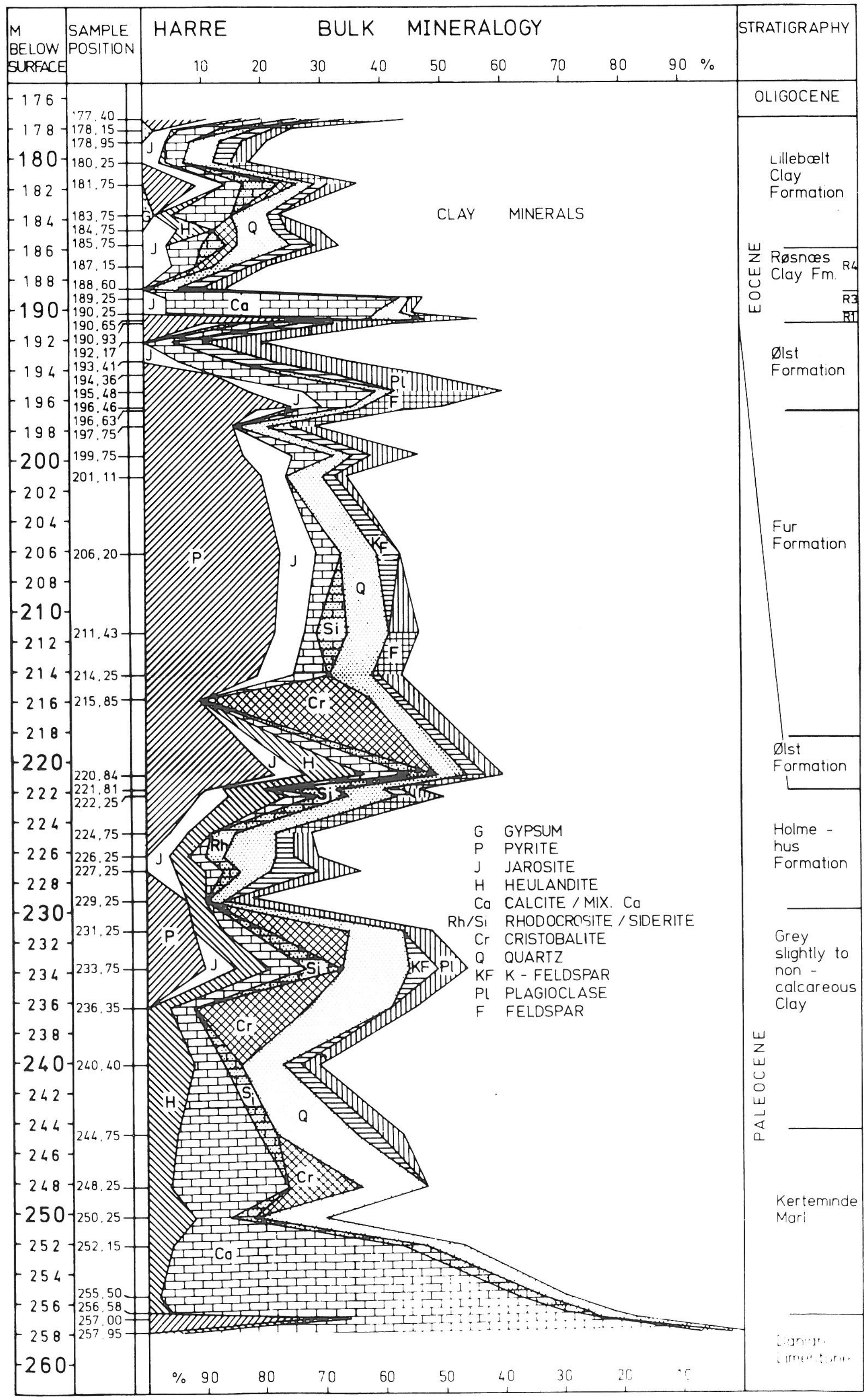

Fig. 2. Bulk mineralogical composition of the Paleocene and Eocene section in the Harre borehole.

while the underlying limestone belongs to NP Zone 3 and 4/5. The content of Org. C is generally close to 3/4% and surprisingly constant through the formation (Fig. 4). The Mn content is low and the other elements measured reflect the content of carbonates, i.e. in carbonate richer intervals the Ca content is high and the other elements are low because of the dilution effect of the carbonates. This is distinct for the Fe content and less distinct for K and Mg (Fig. 4). The content of sulphur is generally below 1/2%, supporting the fact that the pyrite content is below the detection limit on XRD.

Depositional environment, provenance and lateral variations

During the deposition of the Kerteminde Marl the environment was marine and generally oxic with a high degree of bioturbation. The transgression which followed the regression at the end of the Danian has led to a strong reworking of older sediments, mainly of Danian and Upper Cretaceous age. The reworking was especially favoured by the uplift of a narrow NW-SE trending belt in Kattegat in Upper Cretaceous and Paleogene. The thickness of the formation is greatest in eastern Denmark and there are both lateral and vertical compositional variations (Skovbjerg, 1988).

"GREY SLIGHTLY TO NON-CALCAREOUS CLAY"

Lithology and lithostratigraphy

The "grey slightly to non-calcareous clay" is silty, 14.6 m thick (229.9-244.5 m.b.s.) and is olive black or greenish to greyish black. The interval from 240.56 to 241.40 m.b.s. has a very characteristic light grey colour. The unit is bioturbated and contains varying amounts of pyrite, especially in the upper part, glauconite, especially in the lower part, and zeolites, which appear as whitish specks. Some intervals are partly silicified, especially from 234.35-234.50, 234.71-234.86, 235.12-235.20 and 236.07-236.70 m.b.s., of which the interval 236.17-.22 contains several well-preserved burrows with spreiten type of backfill. Weakly silicified horizons appear from 237.15-237.25 and from 238.25-238.45 m.b.s.. A few cm thick interval at 240.75 m.b.s. is strongly silicified, almost like chert, and the interval from 240.50-240.65 m.b.s. is "normally" silicified. No formal nannofossil zonation has been assigned to this formation.

Texture

The sand content is very low (Fig. 1), between .25 and 1.25% while the clay content is high, from 50 to 75 %. Only the Holmehus Clay and the Røsnæs Clay are more fine grained. Except for the sample at 240.40 m.b.s., which has an extraordinary high clay content of 75%, there is no significant variation in the grain size distribution.

Mineralogy and geochemistry

In the clay fraction smectite dominates (ca. 80%) and kaolinite is only sporadically present (Fig. 3). There are no systematic variations through the formation. Clay minerals also dominate the bulk mineralogical composition (Fig. 2). Quartz, heulandite, calcite and feldspars are present in all samples in amounts up to 10 %. Cristobalite, siderite/rhodocrosite, jarosite and pyrite are present in some samples. Quartz, feldspars and clay minerals are probably mostly of detrital origin, while heulandite, cristobalite, siderite/rhodocrosite and pyrite are of authigenic origin. Jarosite is probably a result of a recent to subrecent weathering of part of the original pyrite content. The content of Org. C is about 3/4% like the underlying Kerteminde Marl, but it varies a little. There is no significant variation in the analysed elements. (Fig. 4). The content of sulphur is occasionally above 1%, pyrite is identified in these samples on XRD.

Depositional environment and lateral variations

The boundary between the Kerteminde Marl and the "grey slightly to non-calcareous clay" is gradual. The composition and thickness of the unit is rather uniform (Fig. 5). The unit is a marine low energy deposit and generally the bottomwater was oxygenated, but shorter periods with oxygen deficiency existed.

HOLMEHUS FORMATION

Lithology and lithostratigraphy

The Holmehus Formation is 7.9 m in thickness (222-229.9 m.b.s.) and is a very fine-grained waxy greenish black to dark greenish grey non-calcareous clay with scattered white specks and pyrite of sand size. Especially the lower part is somewhat bioturbated and contains small amounts of carbonate minerals. A few thin zones appear finely laminated. The lower boundary is relatively sharp, while the upper one is located between 2 cores. Based on the gamma response on the wireline log, the upper boundary seems to be very sharp, as also seen in outcrops. At ca.

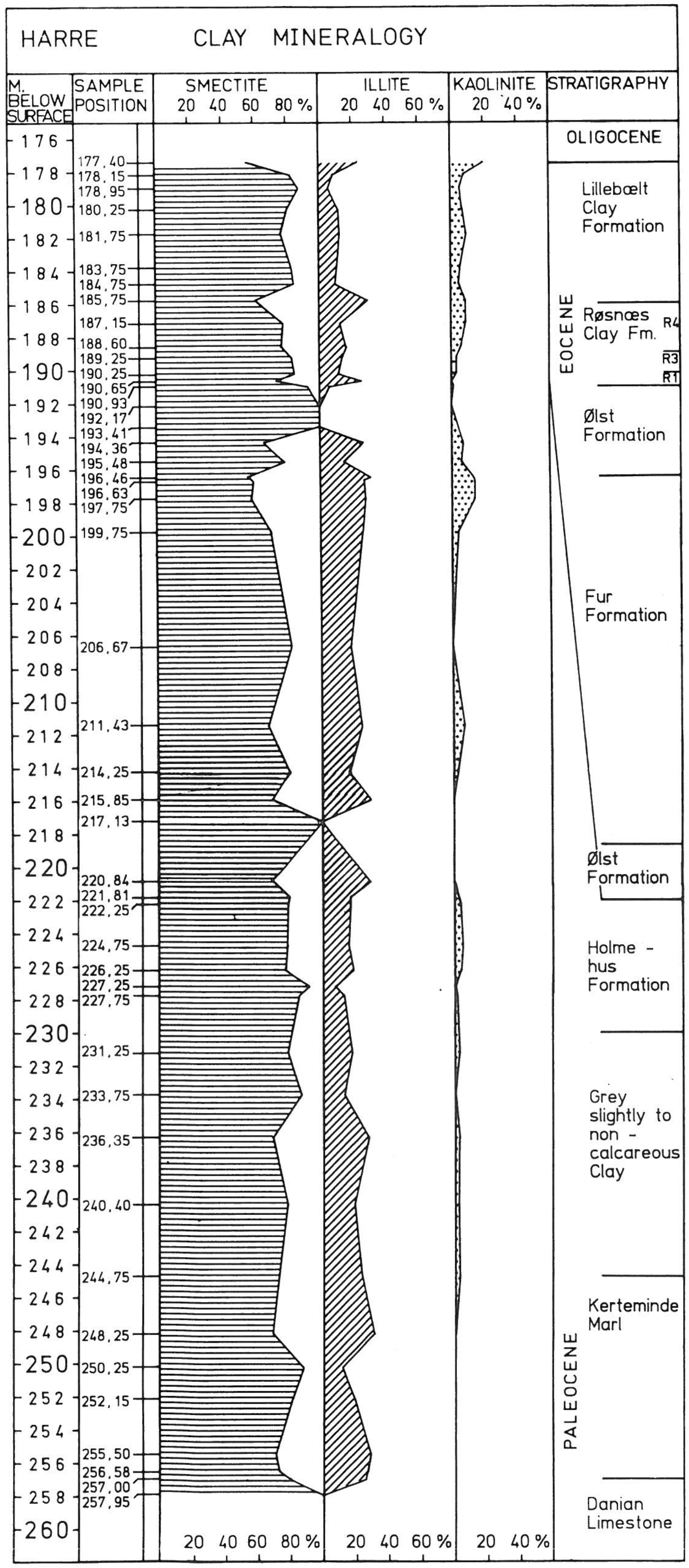

Fig. 3. Clay mineralogy of the clay fraction (< 2 μm) from the Paleocene and Eocene section at Harre.

227.5 m.b.s. a 7 cm thick, light grey bioturbated carbonate concretion is present, and at 228.5 m.b.s. a 3 cm thick light grey non-calcareous concretion is seen. No formal nannofossil zonation has been assigned to this formation.

Texture

The sand content is relatively high (up to 9%) (Fig. 1), but also the clay fraction is relatively high (up to 80%). Silt is consequently sparcely represented. The sand sized particles are most likely mainly of authigenic origin, as heulandite, carbonates and pyrite make up up to 20% of the samples, while the detrital components, as quartz and feldspars, only constitute up to 15% and often are clearly identified in the silt- and the coarser part of the clay fraction. At most localities sand-sized glauconitic grains appear in the uppermost part of the formation, leading to a small but distinct increase in the gamma-response just below the large increase at the transition to the laminated lower part of the Ølst Formation. On spectral natural gamma logs (SNG logs) it is evident that the gamma signal mainly originates from K, probably in glauconites, in the upper part of the Holmehus Formation and from U, related to the organic matter, in the lower part of the Ølst Formation. Unfortunately no SNG log has been performed in the Harre borehole. As in most carbonate-poor mud rocks there is a good correspondence between the size of the clay fraction and the amount of clay minerals defined by XRD, i.e. that the amount of non-clay minerals of the clay fraction corresponds to the amount of clay minerals greater than 2 μm . In carbonate-rich mud rocks biogenic carbonate particles may destroy this correspondence because they sometimes (see the Kerteminde Marl) contribute substantially to the clay fraction. Detailed analyses of the grain size distribution indicates that 52.7% of the particles are smaller than 1 μm and 6.4% of the particles are smaller than 0.125 μm. After settling in 320 days (corresponding to .0063 μm according to Stoke's law) no particles were found in suspension. Only sediments from the Lillebælt Clay Formation, L3 and L4 are found to be more fine-grained amongst the Danish Palaeogene clays.

Mineralogy and geochemistry

Clay minerals are the dominant mineral group (Fig. 2). Authigenic minerals, such as jarosite, pyrite, heulandite and different carbonates, and other detrital minerals, such as quartz and feldspars, make up approximately 15 % each. Quartz and feldspars are more frequent in the silt- and clay fractions, than the authigenic minerals, which consequently make up a greater percentage of the sand fraction. As in most of the Paleocene and Eocene clays in this borehole smectite is the dominant clay mineral in the clay fraction, illite comprises almost entirely the remaining part, while kaolinite consequently is only sporadic present. Other clay minerals are absent. (Fig. 3) The content of Org. C is very low (Fig. 4), while the Mn and Fe contents are high or very high. Normally these two elements show parallel distributions, as f. ex. a higher content in reddish (oxic) sediments probably due to the presence of stable oxides of these elements in their highest oxic state. The Holmehus clay here is greenish and consequently ferric and manganic oxides are absent. The high content of smectite is believed to originate from the volcanic activity present in the area at this time. In all equivalent sediments the same relatively high Fe and Mn concentrations are observed and similar results are found in other basins and at other periods where volcanic activity is demonstrated. (see f. ex. scientific reports from DSDP/ODP). The sulphur content is generally very low (below 1/2%), but in some samples the content may exceed 2%. In these samples pyrite is identified on XRD.

Depositional environment and lateral variations

The appearence, thickness and composition of the Holmehus Formation is very uniform in the entire Danish onshore area, and where cores are present and analysed from the Central Graben of the North Sea almost the same parameters are found (Fig. 6). The typical gamma log marker is not seen in all North Sea wells, but as cores are not available from these wells, it may be that Holmehus clay has a different composition and/or gamma response in some areas in the North Sea.

The thickness is not always known, as the upper and/or lower boundary might not have been identified in all boreholes because of lack of good cores or logs. The thickness is, however, always between 5 and 12 meters.

Variations in grain size are present (Fig. 6) but small, probably representing variations in the content of authigenic components such as cristobalite, pyrite and heulandite. These minerals are most frequent in the sand and coarse silt fractions. Thus, these grain size variations were probably not present at the time of deposition. At Rødbyhavn, which is situated in the North German Basin and is the easternmost locality

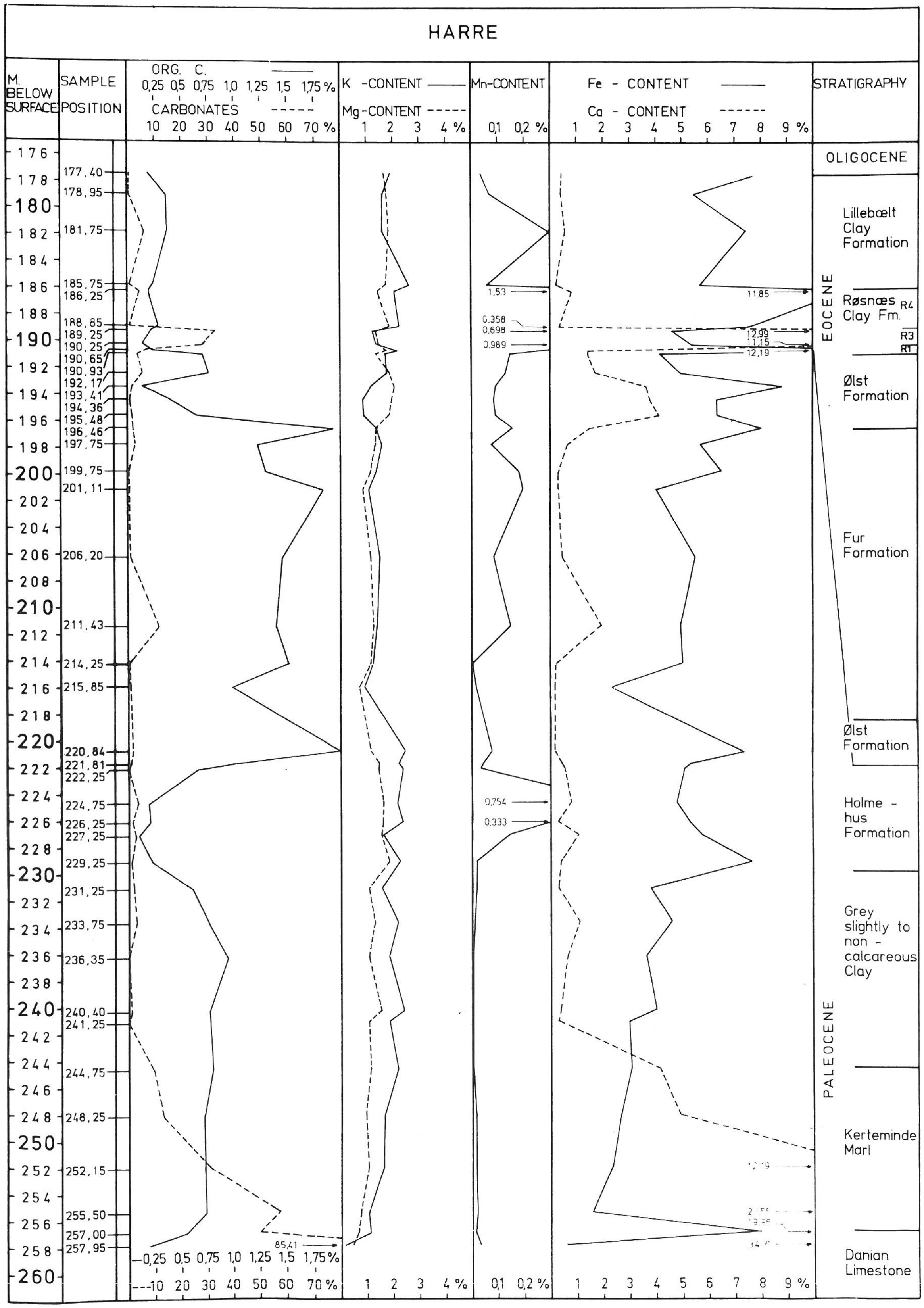

Fig. 4. Bulk geochemical composition of the Paleocene and Eocene section in the Harre borehole.

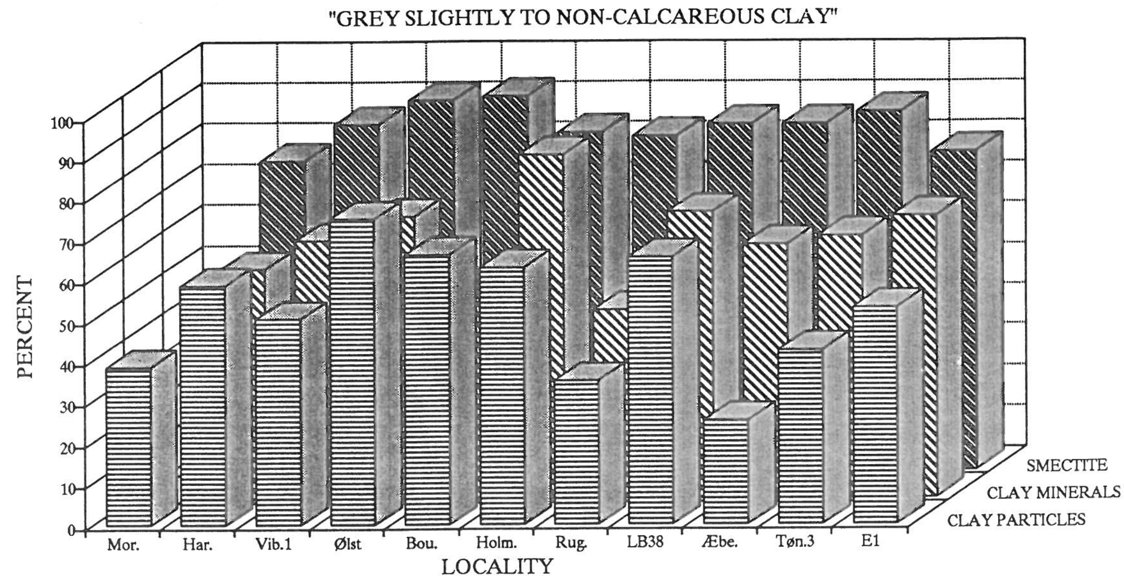

Fig. 5. The amount of clay sized particles, clay minerals and smectite of the clay fraction in the "grey slightly to non-calcareous clay" from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Sil.=Silstrup, Erte.=Ertebølle, Mor.=Mors, Har.=Harre, Vib.1=Viborg 1, Lys.=Lysnet, Bou.=Boulstrup, Holm.= Holmstrup, Rug.=Rugaard, Alb.=Albækhoved, Æbe.=Æbelø, Røj.=Røjle, Karls.=Karlskov very close to Røjle, Røs.=Røsnæs, Øste.=Østerrende, Tøn.3=Tønder 3, Rød=Rødbyhavn.

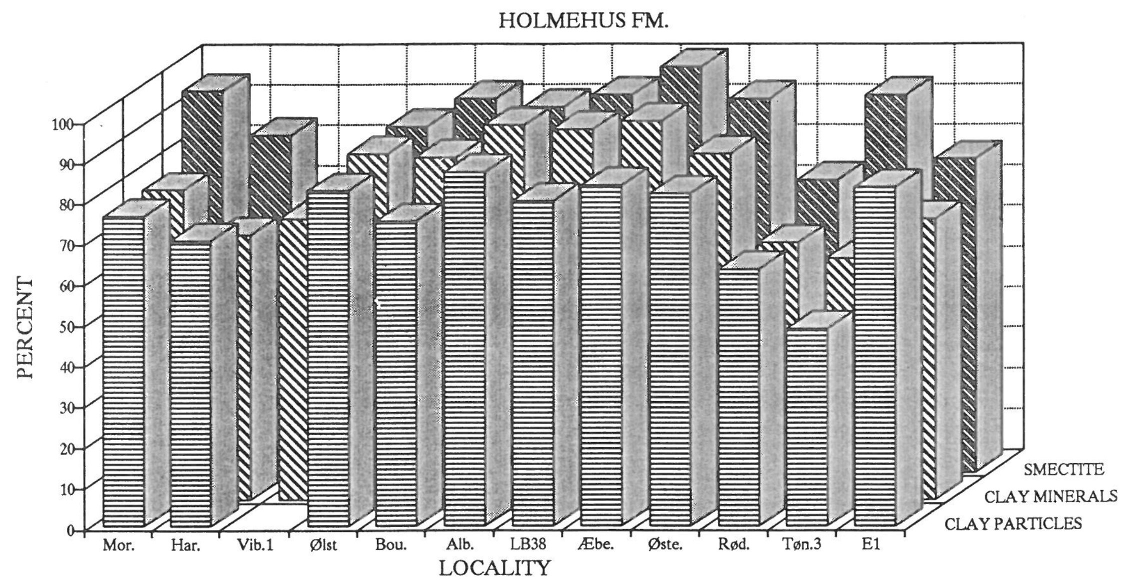

Fig. 6. The amount of clay sized particles, clay minerals and smectite of the clay fraction in the Holmehus Formation from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

with Holmehus clay, the silt content is somewhat higher and the clay content correspondingly smaller (Pedersen, 1992). The amount of clay minerals measured by XRD is also smaller than elsewhere and so is the amount of smectite of the clay fraction (Fig. 6). Illite is the only other clay mineral present while kaolinite is absent or present in small quantities. Chlorite is never identified. The reason for the difference in composition at Rødbyhavn is believed to be that the locality is situated closer to the eastern margin of the basin, and thus received denudation products of different composition and size from the inversion zone and southern Sweden.

The formation is normally characterized by the presence of both thin laminated intervals and bioturbated horizons *(Zoophycos* and *Chondrites),* containing also agglutinated benthonic foraminifers (Heilmann-Clausen *et al.*, 1985 and Nielsen & Heilmann-Clausen, 1986). The Org. C and pyrite contents are intermediary (0.09-0.66% and 0-5% respectively). In some localities red intervals are distinct, but the green colour is the most frequent. The depositional environment is thus marine and generally less well-oxygenated than f. ex. during deposition of the Røsnæs Clay Formation, but also less stagnant than during the deposition of the Ølst- and Fur Formations.

ØLST- & FUR FORMATIONS

Lithology and lithostratigraphy

The Ølst- and Fur Formations have a thickness of 31.12 m (190.88-222 m.b.s.). The Fur Formation represents the diatomite and diatom-dominated clay interlayering the volcanic ash-layers in sediments from the transition between Paleocene and Eocene and situated between the Holmehus and Røsnæs Clay Formations. The Ølst Formation represents the generally much thinner diatom-poor and non-diatomaceous clay interlayering the ash-layers, while the Fur Formation represents the diatom-rich facies. These two formations are mostly both geographically and stratigraphically separated, i.e the Fur Formation in NW-Jylland and the Ølst Formation in the remaining Danish area and only represented in NW-Jylland in the lowermost part of the interval (Heilmann-Clausen *et al.*, 1985). In this borehole, however, the two formations are more intensively interfingering and an intermediate facies with gradual transitions between the two end members is also present. From the upper boundary at 190.88 m.b.s. down to 196.5 m.b.s., equivalent to ash layer No. +4 the clay layers are non-diatomaceous and consequently referred to the Ølst Formation. Many ash layers are identified, with varying certainty, according to the system defined by Bøggild (1918), and the thicknesses of the interlayered clay layers are equivalent to the outcrop at Ølst. The Fur and lower part of Ølst Formations are generally laminated and without burrows, while in the upper part of the Ølst Formation laminations are generally absent and burrows are occasionally identified.

Below is a list of observations concerning the ash layers with a characteristic appearance (see Fig. 3 in Nielsen *et al.*, 1994, this volume):

Ash layers No. +129 and No. +130 are probably identified as the youngest ashes in the borehole although their thicknesses and the interlayer thickness differ somewhat from the expected values, but their characteristic appearances are quite similar to the appearances of these ashes at other outcrops where the upper Ølst Formation is exposed. Furthermore, these two ashes are the youngest ashes found in the Ølst Formation. Younger ashes are thus only found in the Fur Formation (Heilmann-Clausen *et al.*, 1985). Ca. 35 cm below the presumed ash layer No. +129, a very characteristic black, distinctly streaked 13 cm thick ash layer is found. At outcrops in NW-Jylland layers Nos. +114 and +118 have similar appearances. Based on its thickness and position it is most likely that the layer in the Harre borehole is No. +114. A rather thick dark grey ash layer with a brownish grey lower separate part, i.e. a so-called double layer, is found at the expected position for ash layer No. +90D. Below, relatively thick ashes are present with thicknesses and positions as expected for the ashes Nos. +79, +62 and +51. Double layers at the expected positions for ashes Nos. +18D, +16D and +14D are identified. The remaining ashes are mostly identified based on their thicknesses and positions. The lowermost ash layer of the upper part of the Ølst Formation is believed to be No. +4 based on its thickness, position and colour. Its feldspar-composition, however, might indicate that it could be ash layer No. -11 (Knox, 1994, this volume). The underlying, uppermost ash of the Fur Formation, which, in Fig. 3 (Nielsen *et al.*, 1994, this volume), is considered to be either No. -11 or -12, is assigned to No. -12 due to its feldspar composition (Knox, 1994, this volume). The following ash downwards might consequently most likely correspond to ash No. -13. Realizing that the two uppermost ashes of the Fur Formation in the Harre borehole most likely are Nos. -12 and -13 respectively, the identity, based on thickness and position, of the overlying ash might be ash No. +4 or ash No. -11. Yet, the colour of the ash in question is more in accordance with +4 than -11, and it is thus impossible so far to make a final and correct interpretation of the identity of this specific ash layer. Anyway, there seem to be missing strata close to the transition from the Fur- to the Ølst Formation, which are recognised in outcrops, but the precise location and duration of this hiatus is not possible to figure out.

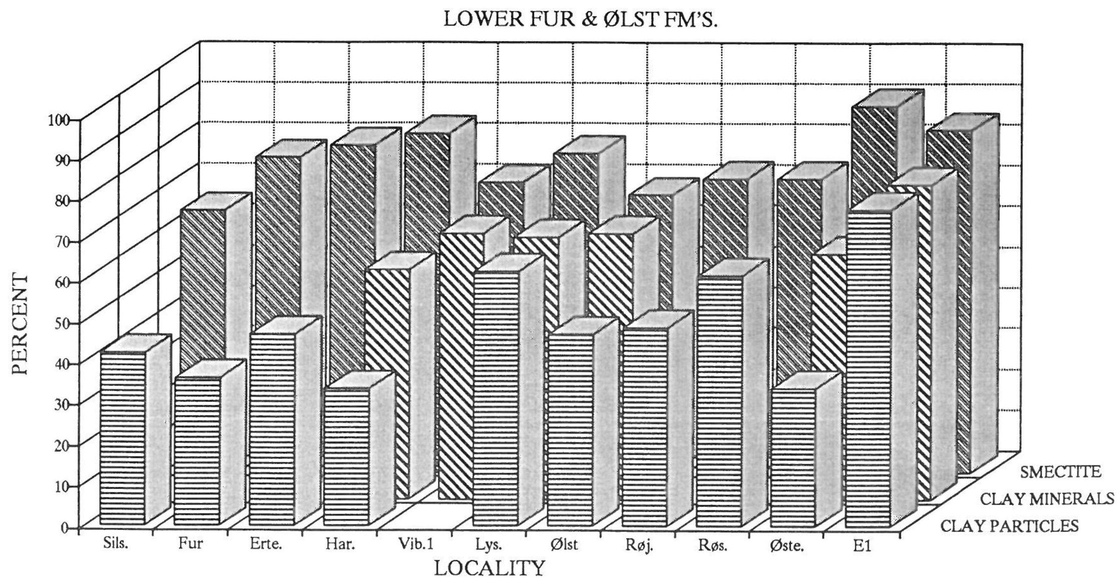

Fig. 7. The amount of clay sized particles, clay minerals and smectite in the clay fraction from clay layers in the lower part of the Ølst and Fur Formations from danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

From 196.5 down to 218.5 m.b.s. the appearance and thicknesses of the clay layers are similar to the equivalent layers on the island of Fur, and they are thus referred to the Fur Formation. The ashes are similar to the ashes from localities in NW-Jylland, and especially distinct is the occurrence of the very characteristic layer No. - 33, which also here is very light grey, almost white, and with a thickness and location as would be expected. In some levels, as for instance at 204.1 m.b.s. and 208.5-210 m.b.s., the clay layers seem to be less diatom-rich, and look similar to layers from the Ølst Formation. The lower part of the interval, from 218.5-222 m.b.s., is non-diatomaceous and almost black and is thus referred to the Ølst Formation. As in other sections of the Fur Formation silicified horizons occur in the lower part, at 214.7, 215.2, 216.5, 216.9 and 217.52-217.77 m.b.s.. They look similar to the "Skifferserien" as defined by Bøggild (1918). Poorly laminated, mostly distinctly bioturbated horizons are present at 199.5-199.73, 200.0-200.1, 201.0-201.35, 202.6-202.8, 203.73-204.75 and 206.32-206.48 m.b.s.. Besides these horizons the entire interval from 196.5-218 m.b.s. is well laminated and non-bioturbated. Partly carbonate cemented horizons occur at 200.1-200.2 and 204.1-204.28 m.b.s.. In the series with positive numbered ash layers no carbonate cemented intervals are present at ashlayer No. +77, +86 and +95, intervals, where carbonate precipitation normally is seen, but the interval known to be carbonate cemented from other outcrops at ash layer No. +30, (Bøggild, 1918, Andersen, 1937 and Nielsen, 1974) have not been recovered in this borehole.
No formal nannofossil zonation has been identified in these formations.

Texture

Clay layers

The grain size distribution in the lower Ølst- and Fur Formations is relatively uniform (Fig. 1), dominated by silt and with only small amounts of sand sized particles. There is no obvious difference between the diatom-rich Fur Formation and the diatom-poor lower Ølst Formation, although the grain size in the Fur Formation is highly influenced by biogenic silt particles. In the upper Ølst Formation, corresponding to the series containing ash layers above +19 the sand content increases abruptly and dramatically from almost 0 to ca. 40%. From Fig. 3 in Nielsen *et al.*, (this volume) it it obvious that the percentage of ash-layers increases distinctly in this series. Burrows, which occasionally are seen, and other post-depositional disturbances might have caused a mixture of the thin and frequent silt-dominated interlayers and sand-dominated ashes. At other localities, however, the grain size of the clay layers in the upper part of the Ølst Formation is also somewhat coarser than in the lower part. Yet the differences in grain size between upper and lower parts of the interval at f. ex. Ølst is not

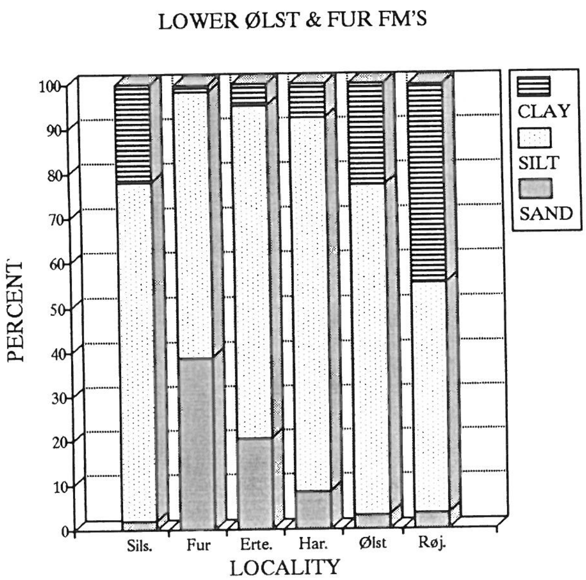

Fig . 8. The average contents of sand, silt and clay in volcanic ash layers in the lower part of the Ølst- and Fur Formations from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

large, and the magnitude of the sand fraction at these localities is considerably smaller, rarely up to 14% (Heilmann-Clausen *et al.*, 1985). It is not possible to prove the reason for these variations, as both ashes and interlayer-clays become gradually thinner and finer from the north towards the south (see Nielsen & Heilmann-Clausen, 1988). The main source for the ash is probably situated to the north of the Harre borehole, explaining the southward decrease in grain size. The provenance of the interlayer sediment and its dispersal might follow the same direction, but it is also possible that the above mentioned mixing mechanism between ashes and clays in intervals with frequent ashes, as in the upper Ølst Formation in this borehole, highly influences the grain size of the clay layers. Comparison with localities nearby does not give conclusive answers as all of these have diatom-rich interlayers, which are influenced by the "growth" size of diatoms and which all are considerably thicker than the diatom-poor interlayers at Harre, and thus much less sensitive to mixing with sand-sized ash-particles from neighbouring ash-layers.

Ash layers

Grain-size analyses of several individual ash-layers demonstrate (Figs. 8 & 10) i) that the younger and generally basaltic ashes from the upper part are coarser than the older more Si-rich ashes from the lower part, ii) that their graded bedding can be proved by multiple grain size analyses from different positions within individual layers, and iii) that they are coarser than the clay-layers above and below them. The coarseness is seen both in a higher sand-fraction, up to 85 %, but even more distinctly by a very small proportion of clay-sized particles. The coarsest locality is Fur, both in the lower and upper part. To the west, east and south the grain size decreases distinctly (Figs. 8 & 10) indicating a northerly supply. The maximal grain size for many ashes, in the western Limfjord area where they are coarsest, is ca. 400 μm; occasionally particles between 1 and 2 mm are found. As the ashes are relatively coarse grained and as the grain size decreases rapidly within a distance of only few tens of kilometers, it is believed that the source for the volcanic material is relatively close. Intense seismic investigations, however, in the Skagerrak and North Sea have so far not been able to locate the site of eruptions.

Mineralogy and geochemistry

Clay layers

Clay minerals are the dominant group of minerals although less dominant than in formations below and above (Fig. 2). Pyrite is frequent, especially in the lower Ølst- and Fur Formations. Weathering of some of this pyrite is the most likely explanation for the presence of jarosite. Diagenetically formed carbonates, some of them Fe and Mn rich, and cristobalite are present in small but distinct amounts, like the detrital minerals quartz and feldspars. The clay fraction is dominated by smectite, but there seem to be some subtle but characteristic variations (Fig. 3). In the lower Ølst Formation the smectite % is below 100 and accompanied entirely by illite. In the lower part of the Fur Formation the smectite % is close to 100. Upwards the smectite decreases to the same level as in the lower Ølst Fm. and is accompanied by illite in the lower part, while kaolinite appears with percentages up to 14 % in the upper part of the Fur Fm. and the lower part of the upper Ølst Fm., where the smectite decreases slightly. In the remaining part of the Ølst Fm. (i. e. from ash layer no. + 62 and upwards) smectite again is the only clay mineral present.

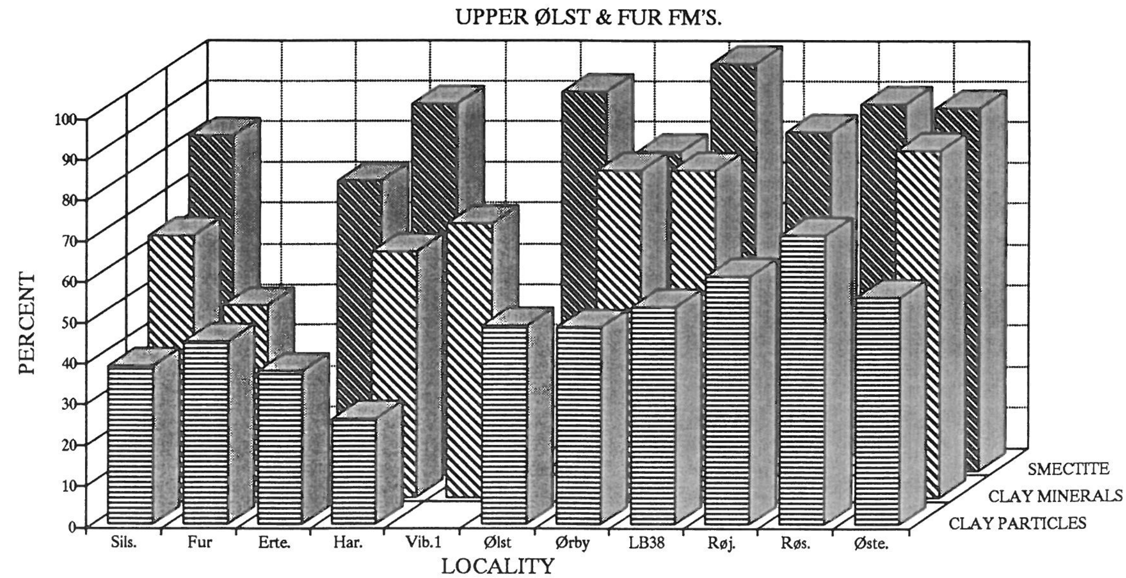

Fig. 9. The amount of clay sized particles, clay minerals and smectite in the clay fraction from clay layers in the upper part of the Ølst and Fur Formations from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

Ash layers

The ashes contain a dominance of smectite amongst the clay minerals, but often the quality of analyses is poor because the presence of non-crystalline components causes a lower signal to background ratio. High contents of diatoms play the same role in the Fur Fm. Besides smectite, plagioclase, quartz and heulandite are often found in the ashes. As the ashes often are relatively well-sorted finesand beds with a low content of fine grained particles, they often have a higher permeability than the clay layers. Therefore authigenic components such as carbonates and pyrite are first formed in ashes, sometimes acting as condensation nuclei for bigger concretions, f. ex. the well-known so-called cementstone horizons, (i. e. carbonate cemented clay- and ash-layers). The mineralogical analyses fully support this.

The content of Org. C. is high in the lower Ølst- and the Fur Formations, often between 1,5-2% (Fig. 4), while it is distinctly below 1% in the upper Ølst Fm.

The concentration of the metallic elements (Fig. 4) is clearly influenced by the dilution effect caused by the dominance of diatoms in the Fur Fm., which leads to high Si contents and correspondingly low contents of most other metallic elements.

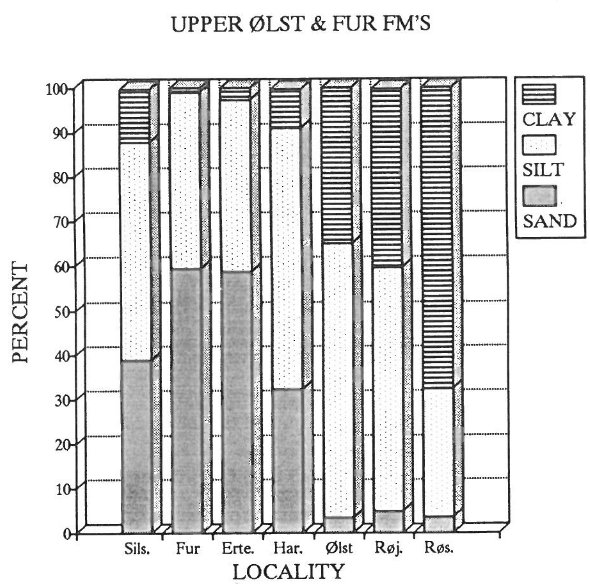

Fig. 10. The average contents of sand, silt and clay in volcanic ash layers in the upper part of the Ølst- and Fur Formations from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

Depositional environment and lateral variations

The boundary between the Holmehus Formation and the Ølst/Fur Formations is very sharp, probably representing a hiatus. The Fur Formation and the lower part of the Ølst Formation (see Fig. 3 in Nielsen *et al.*, 1994, this volume) as present in this borehole are equivalent to the Sele Formation of the North Sea (see Deegan & Scull, 1977). Its thickness is not known in all localities, but it is evident that the interval is very thin or absent in the Ringkøbing Fyn High area and in the southern part of Jylland, and that it reaches its greatest thickness, where it is almost completely developed as a diatomite, i.e. in NW Jylland.

The grain size distribution (Fig. 7) indicates that the localities to the NW in Jylland have the coarsest sediment and that it becomes succesively more fine grained towards the SE. In the Central Graben area the clay content is also very high (see E-1, Fig. 7). During the deposition of this interval the sea bottom have been inhospitable for benthic organisms or even totally anoxic as also described at other diatomite localities (Pedersen, 1981) in NW Jylland and in the North Sea (Deegan & Scull, 1977).

The upper part of the Ølst Formation (Fig. 9) is equivalent to the Balder Formation (Deegan & Scull, 1977). In localities northwest of the Harre borehole the formation is developed as a diatomite, and defined as the Fur Formation (Pedersen & Surlyk, 1983). At Harre and localities to the south/southeast diatoms are less frequent. The sediments contain less Org. C than the underlying sediment and more frequent burrows are present, indicating less inhospitable bottom waters.

RØSNÆS CLAY FORMATION

Lithology and lithostratigraphy

The Røsnæs Clay Formation is 4.88 m thick (186-190.88 m.b.s.). Only nannofossils belonging to NP 11 have been identified in the calcareous parts of the formation (von Salis Perch-Nielsen, 1994, this volume).

The lower boundary with the Ølst Formation is very sharp, and marked by a change from a grey clay of the Ølst Formation to a greenish grey clay of the Røsnæs Clay Formation. The greenish grey clay is 53 cm thick (190.88-.35 m.b.s.), non-calcareous and contains (especially in the lower part) several layers rich in sand-sized glauconitic particles alternating

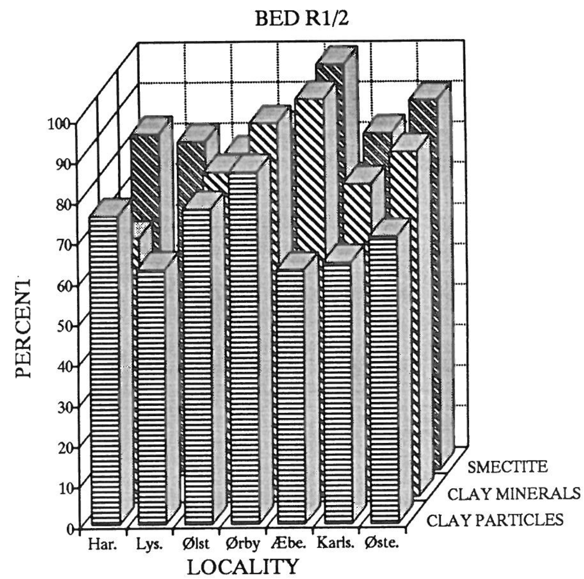

Fig. 11. The amount of clay sized particles, clay minerals and smectite of the clay fraction in the Røsnæs Clay Formation, Bed R1/2 from danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

with greyish clay layers with only few glauconitic particles. At 190.70 m.b.s. a greenish grey argillized volcanic ash layer with a sandy appearence is present. This interval is referred to Bed R1 of Heilmann-Clausen *et al.* (1985). Sediments similar to Bed R2, i.e. fine-grained brownish clay with scattered glauconitic grains, have not been observed in this well, but there is no indication of a hiatus. The absence of Bed R2 is therefore believed to indicate that its typical lithologic appearence is not developed here. Above Bed R1, a 135 cm thick (190.35-189 m.b.s.) very characteristic unit of strongly bioturbated (amongst others *Zoophycos*) and calcareous yellowish to light olive grey clay is present. Its appearance is very similar to Bed R3 of Heilmann-Clausen *et al.* (1985), and is consequently referred to this unit. Its upper boundary is not known, as the 2 overlying cores consist of entirely non-calcareous fine-grained dark yellowish to moderate brown clay. No glauconite has been found, but intervals of greenish to bluish grey clay are present at 188.93 m.b.s., 188.55-188.74 m.b.s., 187.71-187.81 m.b.s., 187.15-187.20 m.b.s. and 186.56 m.b.s.. These layers are probably argillized volcanic ash-layers (see Nielsen & Heilmann-Clausen, 1988). This interval, which has a thickness of 3 m (186.00-189.00 m.b.s.) has an appearence similar to Bed R4, but as the 2 overlying beds of the Røsnæs Clay Formation, the strongly calcareous beds R5 and R6, are absent, it is not possible by sedimentological means alone to decide whether the interval, or part of it, belongs to Bed L1 of the overlying Lillebælt Clay Formation. The biostratigraphic results (King, 1994 & von Salis Perch-Nielsen, 1994, this volume) are not conclusive either, but the most reasonable and simple interpretation seems to be that the entire interval belongs to Bed R4, and that Bed R5, R6 and L1 are missing.

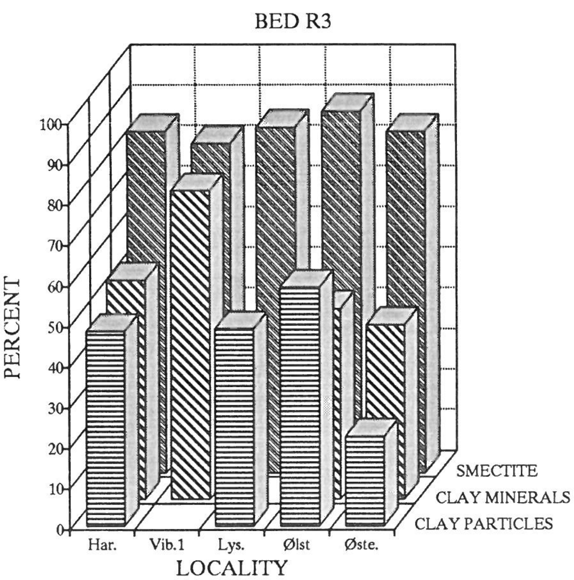

Fig. 12. The amount of clay sized particles, clay minerals and smectite in the clay fraction in the Røsnæs Clay Formation, Bed R3 from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

Texture

The sand content of Bed R1 is generally between 3 and 6 % (Fig. 1) with an upwards decreasing tendency. This is the same range as at Ølst (Heilmann-Clausen *et al.*, 1985). At both localities most sand particles consist of glauconitized pellets and/or foraminifers. Bed R2 at Ølst is distinctly more fine grained than R1. The uppermost part of Bed R1 in Harre is also more fine grained, but its appearance is quite different from that of R2. The sand content of Bed R3 in Harre is between 3.5-1 %, upwards decreasing. This is somewhat smaller than at Ølst, but at both localities the sand grains are mainly faecal pellets. Above Bed R3 the clay becomes distinctly more fine grained with sand contents of .01 to .06 %. At all other known outcrops Bed R4 is the most fine grained Bed of the Røsnæs Clay Formation, probably because of the absence of burrows (and consequently of faecal pellets), and of benthic calcareous organisms of sand and coarse silt sizes.

Mineralogy and geochemistry

The mineralogical composition of the Røsnæs Clay Formation in the Harre borehole is characterized by carbonates, up to 40 % (mainly calcite) in Bed R3 (Fig. 2). Above and below Bedc R3 clay minerals, and amongst these, smectite, dominate (Figs. 2 and 3). The Org. C content is relatively small (Fig. 4) and the Fe and Mn contents are higher in these reddish or brownish sediments than in the over- and underlying more greyish sediments. The Ca content clearly reflects the section with dominance of carbonates, i.e. Bed R3.

Depositional environment and lateral variations

At all outcrops known, there is a hiatus between the Ølst/Fur Fm. and the Røsnæs Clay Fm.. At Knuden, (Fur) this hiatus is smaller and the gap is partly filled by the Knudshoved Member (Heilmann-Clausen *et al.*, 1985) The deposition of the Røsnæs Clay Formation took place in a generally well-oxygenated marine environment with a rich benthonic fauna, including burrowers. The lateral variations are small within the onshore Danish area in the lowermost 2 beds (Fig. 11). Bed R3 is only found at a few localities, but a time equivalent sediment in another facies is probably present at other localities (Chris King, pers. comm.) Lateral variations in texture and carbonate content (mainly biogenic) are present and therefore also other parameters vary (Fig. 12). The smectite content, however, representing the detrital input, is rather similar at all localities.

The overlying three beds of the Røsnæs Clay Formation exhibit much greater variations in the detrital input. Bed R4 is much thicker and contains much more kaolinite in localities around Vejle Fjord and Lillebælt compared to all other localities (Fig. 13).

LILLEBÆLT CLAY FORMATION

Lithology and lithostratigraphy

The Lillebælt Clay Formation is 8.5 m thick (177.5-

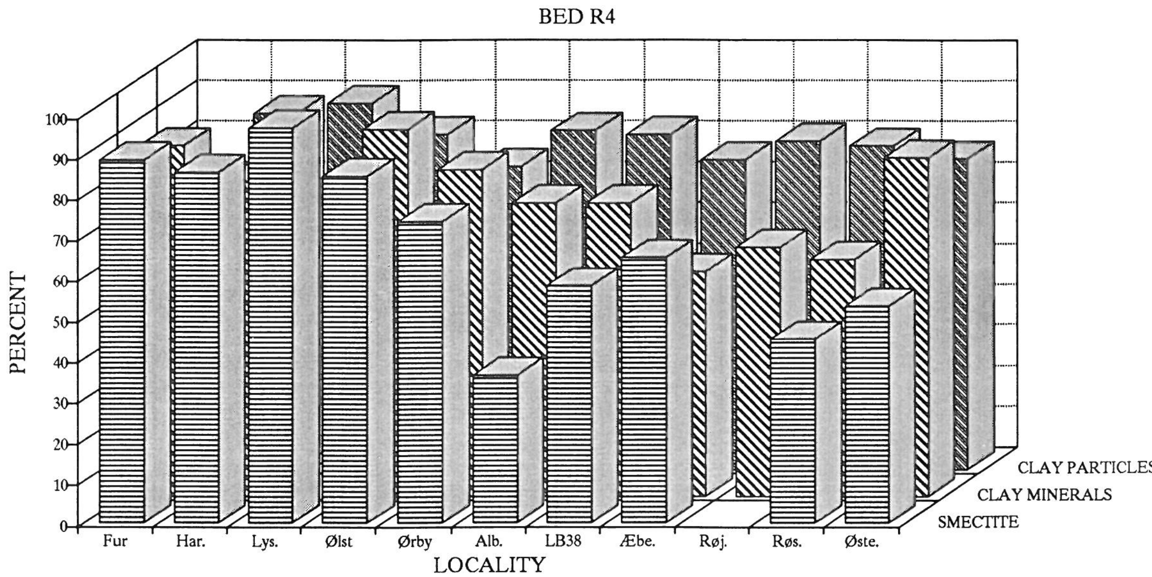

Fig. 13. The amount of clay sized particles, clay minerals and smectite in the clay fraction of the Røsnæs Clay Formation, Bed R4 from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

186 m.b.s.). The uppermost part of the formation is referred to NP 15 (von Salis Perch-Nielsen, 1994, this volume). The lower boundary is defined between two cores, and consequently the nature of the boundary between the two lithologies, which here appear sharp, is not known. The lowermost interval (178.85-186 m.b.s.) is a fine-grained dark greenish grey (5 GY 4/1) clay, varying to greenish grey (5 G 5/2) in vaguely defined intervals in the lower 1.5 m, generally non-calcareous and with scattered sand-sized foraminifers. Fissility, probably due to lamination, is present in varying degree throughout the interval. Glauconite is especially distinct at 184.65-.80 m.b.s. and in a 15 mm thick layer at 178.85 m.b.s.. The overall lithology is rather similar to Bed L2 or L5 of Heilmann-Clausen *et al.* (1985) and the thickness corresponds to the thickness of Bed L2 in the Viborg 1 borehole and to outcrops and boreholes in the Lillebælt area. It is noteworthy, however, that in Bed L2 in other localities no glauconite is present; also, in the Harre cores, pyrite has not been identified and no black layers or volcanic ash layers have been observed, as would have been expected for Bed L2. The interval from 177.5 to 178.85 m.b.s. is varying in color from moderate brown (5 YR 3/4-4/4) to dusky blue green (5 BG 3/2) and to olive grey (5 Y 4/1) and the unit might belong to the brownish grey to olive grey fine-grained non-calcareous clay of Bed L3. King (1994, this volume) refers, by means of foraminiferal zonation, the entire Lillebælt Clay Formation of the Harre borehole to Bed L4, but this interpretation seems to disagree somewhat with the lithology. The most reasonable lithostratigraphic interpretation is probably to refer the entire Lillebælt Clay Formation in this borehole to Bed L5. Consequently, the hiatus between the Røsnæs- and Lillebælt Clay Formations comprises the upper part of Bed R4, Beds R5, R6, L1, L2, L3, L4 and probably the lower part of Bed L5. At 177.5 m.b.s. the lithology changes distinctly to dark greenish grey, slightly calcareous, micaceous, silty clay with glauconite and phosphorite, characteristic of the Oligocene Viborg Formation (see Friis, this volume for further details). The upper part of Bed L5 and Bed L6 of the Lillebælt Clay Formation and the Søvind Marl Formation are absent. It is not known whether the hiatus in this borehole represents a period of non-deposition or an erosion (or a combination of these), but in this borehole (von Salis Perch-Nielsen, 1994, this volume), as in other localities, the overlying Oligocene layers contain a distinct, in lower part even an abundant, reworked Eocene microflora and microfauna, indicating that regionally, erosion of Eocene strata was a normal event, at the Eocene/Oligocene transition. In the most complete section

through this interval, i.e. in the Viborg 1 cores, the presence of a hiatus has been discussed by Mikkelsen (1975).

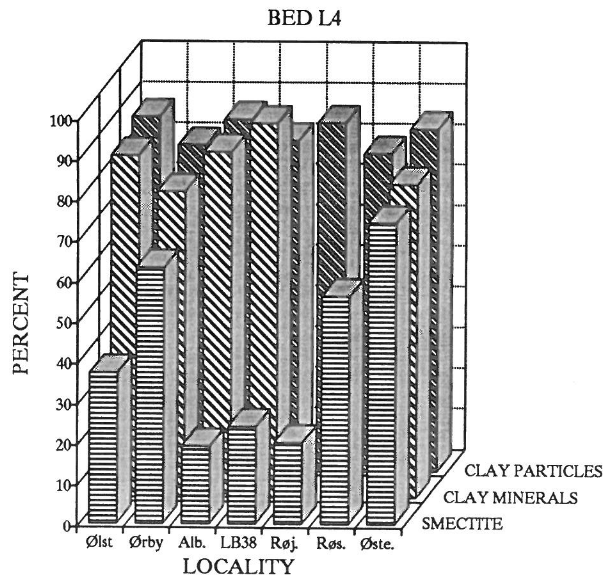

Fig. 14. The amount of clay sized particles, clay minerals and smectite in the clay fraction in the Lillebælt Clay Formation, Bed L4 from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

Texture

The grain size is rather similar in the entire interval with sporadic amounts of sand-sized particles, probably all of biogenic origin, i.e. partly glauconitized foraminifers and faecal pellets.

On average the clay fraction makes up two thirds of the sediment, i.e. twice as much as the silt fraction. This is a rather coarse grained character for the Lillebælt Clay Formation, and at other localities this grain size distribution is only seen in the upper Lillebælt Clay, Beds L5 and L6.

Mineralogy and geochemistry

Clay minerals dominate (80 %) (Fig. 2) with smectite as the most frequent one (64 %) followed by illite (10 %) and kaolinite (6 %). Quartz and different carbonates are the main non-clay minerals. A small and sporadic content of cristobalite and heulandite are present in the sequence. In the clay fraction (Fig. 3) smectite makes up 80 %, while illite and kaolinite make up 13 % and 7 % respectively. The high percentage of smectite and the presence of heulandite is normally only recognized in Bed L5. For Bed L5 there is a tendency for smectite to increase towards the north (Fig. 15). (see Heilmann-Clausen *et al.*, 1985 and Thiede *et al.*, 1980). The lithostratigraphic interpretation of the Lillebælt Clay in the Harre borehole as here suggested, would fit into this regional tendency. At Ølst the transition between Beds L4 and L5 is sharp, representing a hiatus, and might correspond to a sea level decrease, exposing older Tertiary smectite-rich and zeolite-containing sediments in the eastern margin of the basin to erosion and reworking.

The chemical analyses (Fig. 4) support the mineralogical XRD interpretation. The difference in chemical composition between the individual Beds of the Lillebælt Clay Formation are, however, too small to be used as a stratigraphic tool. The Fe content corresponds to that of other grey Beds in this formation, i.e. distinctly smaller than in red and brown units. The content of Org. C in the analysed samples is never as high as in parts of the Bed L2. Thus, the chemical data do not contradict the lithostratigraphic interpretation here suggested.

Depositional environment and lateral variations

During deposition of the Lillebælt Clay Formation the water depth of the sea was probably somewhat greater than during the Røsnæs Clay deposition. The grain size is normally smaller and the content of biogenic components is much smaller, especially of organisms with carbonate shells. There have probably been less favourable bottom conditions in certain periods during the deposition of the Lillebælt Clay. This might explain the impoverished benthic fauna, but also very few calcareous planctonic microfossils are present. There are not many carbonate concretions present, which could lead to the interpretation, that diagenetic dissolution was the major cause for the almost complete absence of calcareous fossils. It is also not very likely that the primary production of planctonic organisms was almost ceased. One explanation could be that the calcareous planctonic organisms were dissolved in the bottomwater prior to deposition. Aggressive cold seawater might have been supplied from the Atlantic through the Viking Graben. It is very difficult to find a definite proof for this. It seems, however, that the absence of carbonate is more characteristic of sediments deposited in the deepest and central part of the North Sea.

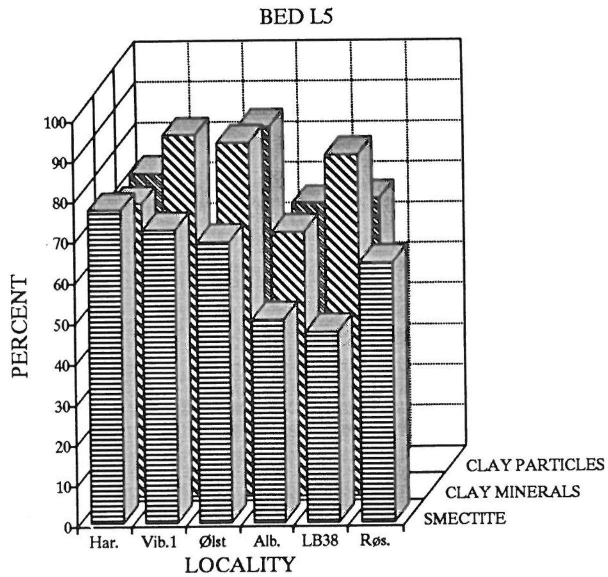

Fig. 15. The amount of clay sized particles, clay minerals and smectite in the clay fraction of the Lillebælt Clay Formation, Bed L5 from Danish localities. Their position is shown in Fig. 1 in the introductory chapter. Abbreviations see Fig. 5.

From the Ølst Formation and upwards the sediments normally become successively more rich in kaolinite and consequently poor in smectite. This tendency is most clearly seen in the Lillebælt/Vejle Fjord region (see Fig. 14). At the transition to Bed L5 (Fig. 15) the smectite content increases abruptly. The reason for this is believed to be supply of reworked older Tertiary smectite-rich sediments now exposed to erosion, caused by a drop in global sea level. Occasionally also zeolites are present in sporadic amounts in the lower part of Bed L5. Presence of zeolites is normally restricted to the Ølst/Fur Fm. or older layers. Their presence in L5 might support the interpretation of reworking of older sediments.

CONCLUSION

The Paleocene section of the Harre cores comprises the formations: Danian Limestone (not penetrated), Kerteminde Marl, "grey slightly to non-calcareous clay", Holmehus Formation, Ølst- and Fur Formations.
The Eocene section comprises; Røsnæs Clay Formation - Beds R1, R3 and R4 - and Lillebælt Clay Formation - Bed L5.
Major hiati are present in the Eocene, comprising i) Beds R5 and R6 of the Røsnæs Clay Formation and L1, L2, L3 and L4 of the Lillebælt Clay Formation and ii) Bed L6 of the Lillebælt Clay Formation and the Søvind Marl.
Minor hiati are present at the transition Danian Limestone/Kerteminde Clay, Holmehus/Ølst Formation and Ølst/Røsnæs Clay Formation.
Reworked sediments are especially found immediately above these hiati.
The Paleocene and Eocene interval is characterized by very finegrained marine deposits. The sand-sized and most of the coarse silt-sized particles are either of biogenic origin (coccoliths, foraminifers and faecal pellets) or of authigenic origin (pyrite, glauconite and zeolites). In the Ølst- and Fur Formations eolian transported sand-sized ash-particles of volcanic origin are frequent in distinct layers, often with graded bedding.
Lateral facies-variations are very small within the onshore Danish area. Coarser grained nearshore sediments are not found, but occasionally slightly decreased contents of clay-sized particles and smectite, and corresponding increases in silt grades, kaolinite and illite, might indicate dispersal patterns of detrital supplied material.
Oxic bottomwater conditions dominated during deposition of the Røsnæs Clay Formation, while anoxic conditions prevailed during deposition of the lower Ølst- and Fur Formations. In the other formations less favourable conditions dominated, with intercalations of true anoxic and true oxic events.
Except for porewater expulsion and related precipitation of part of the dissolved material as concretions, no diagenetic mineral transformations have been observed.

ACKNOWLEDGEMENT

Henrik Friis is thanked for all kinds of discussions and comments on, and Chris King for correcting the English of this text.

DANSK SAMMENDRAG

På baggrund af en ret detailleret beskrivelse af kernematerialet og et intensivt og omfattende analyseprogram, omfattende teksturelle, mineralogiske og kemiske analyser, er den Paleocæne og Eocæne lagserie blevet korreleret til den eksisterende lithostratigrafi. Boringen stoppede i Danien kalksten. Herover er der identificeret Kerteminde Mergel, "grå kalkfattig til kalkfri ler", Holmehus Formation, Ølst- og Fur Formationerne, enhederne R1, R3 og R4 fra Røsnæs Ler Formationen, samt enhed L5 fra Lillebælt Ler Formationen. Der er konstateret større hiati i Eocæn omfattende enhederne R5, R6, L1, L2, L3 og L4 samt L6 og Søvind Mergel. Der er mindre hiati på overgangen Danien kalksten/Kerteminde Mergel, Holmehus-/Ølst Formation og Ølst-/Røsnæs Ler Formation. Erosion og genindlejring af det eroderede materiale er konstateret i Kertemindemergelens kalkindhold, som primært stammer fra skrivekridt af Maastricht alder. Dette fremgår af von Salis Perch-Nielsens artikel om coccolither i dette bind. L5's høje indhold af smectit og tilstedeværelsen af zeoliter stammer formentlig også delvist fra erosion af ældre eocæne eller paleocæne sedimenter.

Bortset fra askepartikler i de vulkanske lag er de paleocæne og eocæne primære sedimentpartikler meget finkornede, med dominans af fraktionen mindre end 2 µm. En del af siltfraktionen og den væsentligste del af den beskedne sandfraktion er enten af biogen oprindelse (coccolither, foraminiferer og faecale pellets) eller authigene (pyrit, glauconit og zeoliter). Det allermest dominerende mineral er lermineralet smectit, der primært stammer fra omdannelse af vulkanogent materiale. De kemiske analyser understøtter de foretagne kvantitative mineralbestemmelser og aflejringsmiljøinterpretationer.

Gennem Paleocæn synes der kun at have været meget små laterale faciesvariationer indenfor det danske område. Ved Rødbyhavn er Holmehusleret mere siltet og mindre smectitisk end de fleste andre steder. Der ses også tydelige reduktioner af tykkelser og kornstørrelser af både aske- og lerlag i Ølst-og Fur Formationerne i sydlige retninger bort fra det vestlige Limfjordsområde. De meget sporadisk tilstedeværende eocæne aflejringer i Harre boringen giver ikke anledningen til revision af de allerede kendte, små laterale faciesvariationer.

Hele den undersøgte lagserie er marin. Partiklerne er overvejende transporterede i suspension, og der er ingen indikationer på høj-energetiske aflejringsforhold. De sandede lag i Ølst/Fur Formationerne er af vulkansk oprindelse og transporteret æolisk. Aflejringsforholdene for Røsnæs Ler Formationen har været gennemiltede, medens der herskede anoxiske betingelser ved havbunden under aflejring af Fur- og den nedre del af Ølst Formationerne. De øvrige formationer er præget af generelt mindre favorable oxidationsforhold med lejlighedsvise mindre indslag af både egentlige anoxiske og veliltede forhold.

Der ses ingen tegn på omfattende diagenetiske mineralforandringer af sedimenterne.

REFERENCES

Andersen, S.A., 1937: De vulkanske Askelag i Vejgennemskæringen ved Ølst og deres Udbredelse i Danmark *Danm. geol. Unders.*, 2, 59, 50 pp.

Brindley, G.W. & Brown, G., 1980: Crystal structures of clay minerals and their X-ray identification. *Mineralogical Society.* Monograph No. 5, 495 pp.

Bøggild, O.B., 1918: Den vulkanske Aske i Moleret samt en Oversigt over Danmarks ældre Tertiærbjærgarter. *Danm. geol. Unders.*, 2, 33, 159 pp.

Deegan, C.E. and Scull, B.J., 1977: A porposed standard lithostratigraphic nomenclature for the Central and Northern North Sea. *Rep. Inst. Geol. Sci.*, Vol. 77/25, 36 pp.

Friis, H., 1994, this volume: Lithostratigraphy and sediment petrography of the Oligocene sediments from the Harre borehole, Denmark. *Aarhus Geoscience,* Vol. 1, pp. 35-44.

Heilmann-Clausen, C., Nielsen, O.B. and Gersner, F.L., 1985: Lithostratigraphy and depositional environments in the Upper Paleocene and Eocene of Denmark. *Bull. geol. Soc. Denmark,* 33, pp. 287-323.

King, C., 1994, this volume: Eocene microfaunas of the Harre borehole, Denmark. *Aarhus Geoscience,* Vol. 1, pp. 73-80.

Knox, R.W.O'B., 1994, this volume: Feldspar compositions of Early tuff layers from the Harre borehole, Denmark. *Aarhus Geoscience,* Vol. 1, pp. 93-97.

Mikkelsen, N., 1975: Marine Lower Oligocene sediments in Denmark as indicated by coccoliths in the Viborg Formation. *Bull. geol. Soc. Denmark,* 24, pp. 83-86.

Nielsen, O.B., 1974: Sedimentation and Diagenesis of Lower Eocene Sediments at Ølst, Denmark. *Sedimentary Geology,* 12, pp. 25-44.

Nielsen, O.B., 1980: A sedimentological mineralogical investigation of the Tertiary sediments from the borehole M-2X in Central Trough, North Sea. *Danm. geol. Unders.,* Årbog 1979, pp. 41-50.

Nielsen, O.B., 1988: The clay mineralogy in the eastern and southeastern part of the Tertiary North Sea Basin. *In:* Vinken, R., *(ed.).* The Northwest European Tertiary Basin. *Geologisches Jahrbuch,* A 100, pp. 141-143 + 5p. Figures.

Nielsen, O.B. & Heilmann-Clausen, C., 1986: Lithology and stratigraphy of the Tertiary section. *In:* Nielsen, O.B., Bauman, J., Zhang, D., Heilmann-Clausen, C. and Larsen, G. Tertiary Deposits in Store Bælt. *In:* Møller, J.T. *(ed.)* Twentyfive Years of Geology in Aarhus. *Geoskrifter* No. 24, pp. 235-253.

Nielsen, O.B. & Heilmann-Clausen, C., 1988: Palaeogene volcanism: the sedimentary record in Denmark. *In:* Morton, A.C. & Parson, L.M., *(eds.).* Early Tertiary Volcanism. Geological Society of London, Special Publication No. 39, pp. 395-405.

Nielsen, O.B., Friis, H. & Korsbech, U., 1994, this volume: Lithology and lithostratigraphy of the Harre borehole, Denmark. *Aarhus Geoscience,* Vol. 1, pp. 5-14.

Pedersen, A.D., 1992: Bentonitprojekt Lolland. Fase 3. *Storstrøms Amt, Miljøkontoret,* 28 pp.

Pedersen, G.K., 1981: Anoxic events during sedimentation of a Paleogene diatomite in Denmark. *Sedimentology,* 28, pp. 487-504.

Pedersen, G.K. and Surlyk, F., 1983: The Fur Formation, a late Paleocene ash-bearing diatomite from northern Denmark. *Bull. geol. Soc. Denmark,* 32, pp. 43-65.

Perch-Nielsen, K., 1971a: Elektronenmikroskopische Untersuchungen an Coccolithen und verwandten Formen aus dem Eozän von Dänemark. *Kgl. Dan. Vidensk. Selsk. Biol. Skr.,* 18, pp. 1-76.

Perch-Nielsen, K., 1971b: Neue Coccolithen aus dem Paleozän von Dänemark, der Bucht von Biskaya und dem Eozän der Labrador See. *Bull. geol. Soc. Denmark,* 21, pp. 51-66.

von Salis Perch-Nielsen, K., 1994, this volume: Neogene and Paleogene calcareous nannofossils from the Harre borehole, Denmark. *Aarhus Geoscience,* Vol. 1, pp. 45-51.

Schultz, L.G., 1960: Quantitative Interpretation of Mineralogical Composition from X-ray and Chemical Data for the Pierre Shale. *U.S. Geol. Surv. Prof. Paper* 391-C, 31 pp.

Skovbjerg, H., 1988: En sedimentologisk og geokemisk undersøgelse af øvre paleocæne formationer i Danmark. Aarhus University. 206 p. (unpublished thesis)

Steensen-Bach, J.O., Foged, N., Larsen, G. and Baumann, J., 1988: Geological and Geotechnical Properties of Kerteminde Marl. *Proc. X. Nordiske Geoteknikermøde* Oslo, 13-15 May, 1988, pp. 99-103.

Thiede, J., Bjørslev Nielsen, O. & Perch-Nielsen, K., 1980: Lithofacies, Mineralogy and Biostratigraphy of Eocene Sediments in Northern Denmark (Deep Test Viborg 1). *N. Jb. Geol. Paläont. Abh.* 160 (2), pp. 149-171.

Thomsen, E. and Heilmann-Clausen, C., 1985: The Danian-Selandian boundary at Svejstrup with remarks on the biostratigraphy of the boundary in western Denmark. *Bull. geol. Soc. Denmark.* 33, pp. 341-362.