A sedimentological mineralogical investigation of the Tertiary sediments from the borehole M–2X in Central Trough, North Sea

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Nielsen, O. B.: A sedimentological mineralogical investigation of the Tertiary sediments from the borehole M–2X in the Central Trough, North Sea. *Danm. geol. Unders. Årbog 1979:* 41–50, København, 1. december 1980.

Grain size and mineralogical analyses have been carried out on samples (cuttings) of Paleocene to Upper Miocene age from the M–2X borehole in the Central Trough of the North Sea.

The Paleocene sequence and the Lower Eocene ash series are dominated by smectite, while kaolinite has not been detected. However kaolinite occurs in large amounts in the younger Eocene sediments. At the transition from the Paleogene to the Neogene the grain size increases abruptly, the amount of smectite decreases and that of kaolinite and illite increases. Kaolinite indicates a subsequent supply of terrigenous weathering products presumably from the Baltic area and/or from the land areas of Scotland. The large amounts of smectite in the Paleocene and Lower Eocene is thought to be a result of a halmyrolytic transformation of the volcanic material. The distinct change in the type of sediments in the Upper Oligocene is thus believed to have been a response to the uplift of the surrounding landmasses and/or a lowering of the sea level.

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The purpose of this study is to elucidate the possibilities of a lithological correlation between the sediments from the M–2X borehole (fig. 1) and those of the surrounding boreholes as well as from the on-shore localities. Furthermore, the possible origins and the modes of dispersal of the sedimentary material will be discussed.

The investigation includes a lithologic description of the material derived from the cuttings, an analysis of the grain size distribution, and a qualitative and semi-quantitative analysis of the mineralogical composition which was performed partly on the crushed bulk samples and partly on the oriented samples of the clay fraction ($< 2\ \mu m$).

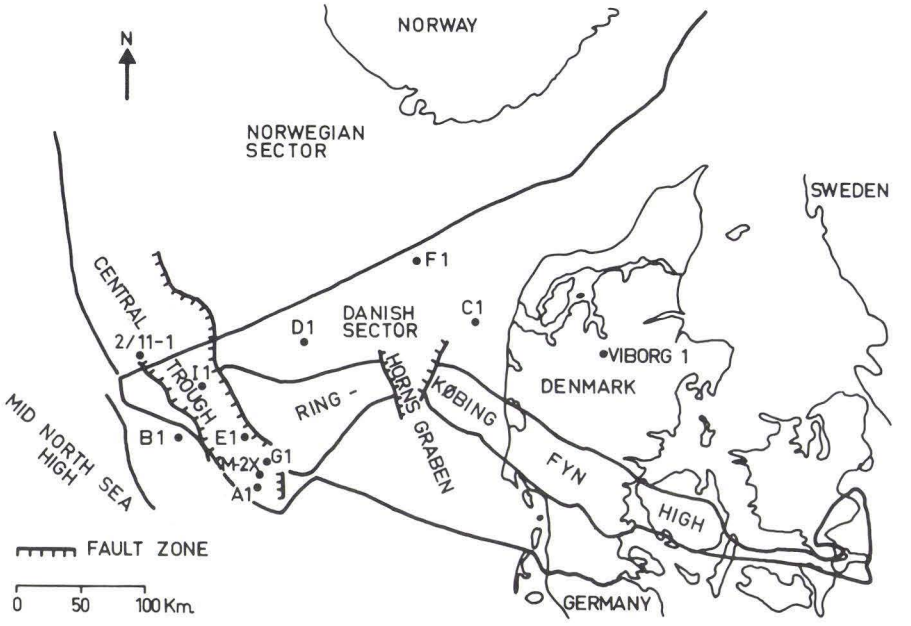

Fig. 1. Location map (Based on O. Michelsen 1978).

Methods

The analysis of the grain size was carried out using the Andreasen-pipette method while the mineralogical composition was determined by means of the X-ray diffractometry.

In order to calculate the content of the minerals in the bulk samples peak heights were used according to the method described by Schultz (1964). Clay mineral peak heights at the maximum intensity plus the intensity at ½° 2θ at each side of the position for the maximum intensity were used as peak intensities according to the method described by Tank (1963). Peaks from glycollated samples at 17 Å were ascribed to smectite, at 10 Å to illite and at 7 Å to kaolinite. No chlorite was identified. The peak intensity at 10 Å was multiplied by a factor 4 and the 7 A peak intensity was multiplied by a factor 2 before comparing with the uncorrected 17 Å peak intensity. (Biscaye 1965).

Results (Conf. fig. 2 and fig. 3)

The samples from the interval between ca. 5100' and ca. 6100' consist of silty clays with the fraction < 2 μm constituing more than 60 %. Besides the clay minerals the samples contain quartz and pyrite. In many samples calcite, gypsum and feldspar were also identified.

The average grainsize (the median) is smaller than 1 μm. Unoriented powder diffractograms show reflections from kaolinite and illite, but in contrast to the superposing interval also very distinct smectite reflections (001) occur.

The clay fraction is characterized by high amounts of smectite, especially in the lowermost part of the interval, where kaolinite was absent. The basal spacing of smectite within this interval is located in 12,75–13,25 Å range. Upwards the kaolinite content increases and reaches a peak at about 5700'. The illite content within this interval is very uniform, but shows a faint tendency to increase upwards. Besides the clay minerals, the clay fractions in this interval contain minor quantities of quartz and jarosite.

The samples from the interval between ca. 3700' and ca. 5100' differ in many aspects from the samples of the underlying interval. The material is coarse grained clayey silt with a median ranging from 4 to 8 μm and increasing upwards. The amounts of quartz and feldspar increase while those of pyrite and clay minerals decrease. The clay content varies from 30–40 %. Calcite occurs in minor amounts in the lower part of the interval while gypsum is absent.

In contrast to the interval below the clay fraction is characterized by the absence of quartz and jarosite and by a very distinct decrease upwards of smectite. At the same time the illite and kaolinite content increases. The basal spacing of smectite within this interval is located in 13.75–14.25 Å range.

Discussion

No biostratigraphical analyses of the material from the borehole M-2X have been published so far, but a comparison of the different logs of this boring with those of the surrounding boreholes especially A-1, A-2, G-1 (Rasmussen 1974 and 1978) indicate that the boundary between the Danian limestone and the Paleocene clay is situated at about 6106' (fig. 4), the upper boundary of the ash-series at about 5990', the Eocene/Oligocene boundary at about 55-5600', the Middle/Upper Oligocene boundary at about 5200' and the Middle/Upper Miocene boundary at about 4100'.

The upper boundary of the ash-series and the boundary between the Middle and the Upper Miocene is marked by very characteristic gamma-ray log peaks and is therefore believed to be relatively closely determined.

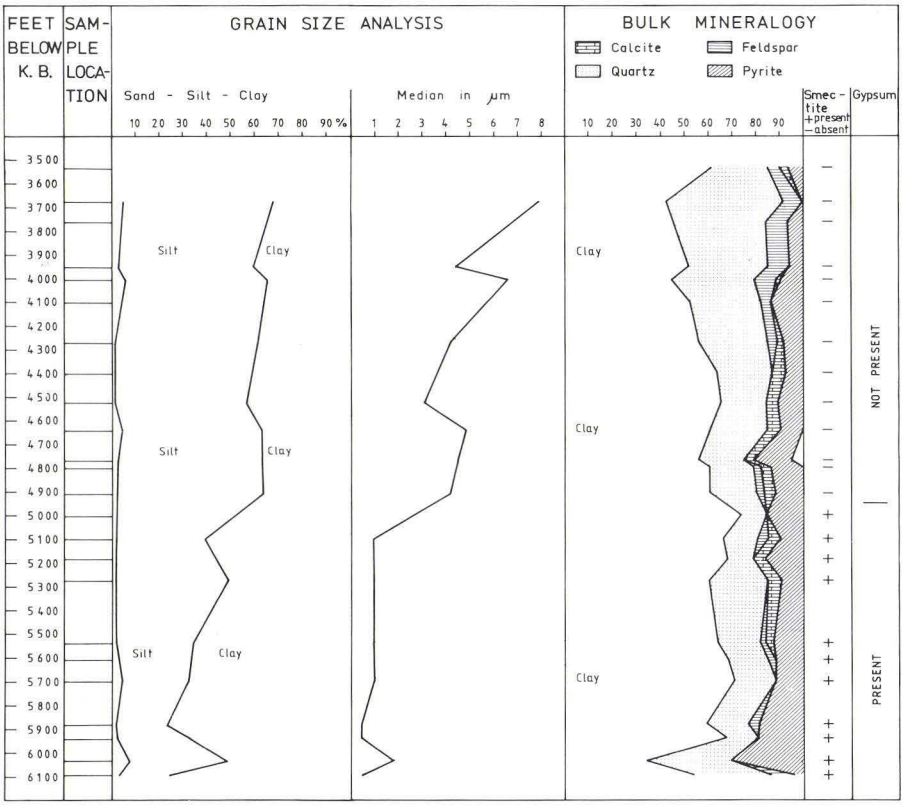

Fig. 2. Grain size and bulk mineralogy.

The grain size.

Compared with the borehole 2/11–1, located about 130 km to the northwest of M-2X (Karlsson et al. 1979), it is obvious that, generally, the material from M-2X is somewhat more fine-grained in the Eocene and Oligocene sections, but somewhat more coarse-grained in the Miocene section. In the Paleocene and the lowermost Eocene the sediments in both boreholes are more coarse-grained than higher up in the sections. This is presumably caused partly by the presence of the volcanic ash particles of sand and silt grain sizes. This same phenomenon was described previosuly from the boreholes in the North Sea Basin as well as from the on-shore localities. A distinct change in grain size between the Middle and the Upper Oligocene is not obvious in the 2/11-1 borehole. Karlsson et al. (1979) suggested, in agreement with Parker (1975), that 2/11-1 during the Paleocene was located in a distal part of a submarine fan with a source to the northwest. The boundary of the substratum, i.e. the Maastrichtian or Danian limestone, is

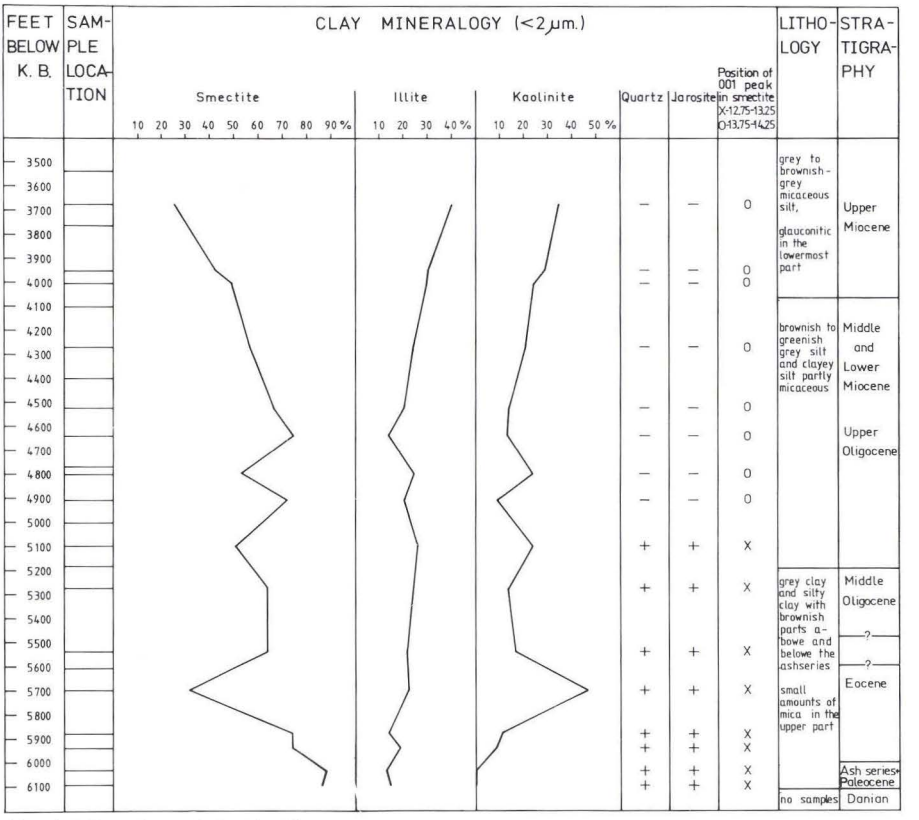

Fig. 3. Mineralogy of clay fraction.

situated about 2400' lower in 2/11–1 than in M-2X and the thickness of the sediments up to about the Upper Miocene boundary is more than two times greater in 2/11-1 than in M-2X. This indicates that the sources of the materials to the northwest were of a decisive importance during this period.

The thicknesses of the Eocene and Oligocene sequences are of the same magnitude as those of the on-shore localities while the Paleocene clay deposits are remarkably thinner (Dinesen et al. 1977).

The abrupt change in the grain size in the Upper Oligocene could mean that there was another source delivering more coarsely grained material to the southeastern part of the Central Trough. On-shore localities in Denmark are also often characterized by an abrupt change to more coarsely grained clay, silt and sand in the Upper Oligocene (Christensen and Ulleberg 1973). This change in the grain size is often related to an erosional unconformity. Vail et al. (1977: 85) have described a large scale global fall in the sea level in the early Upper Oligocene. This event might be responsible

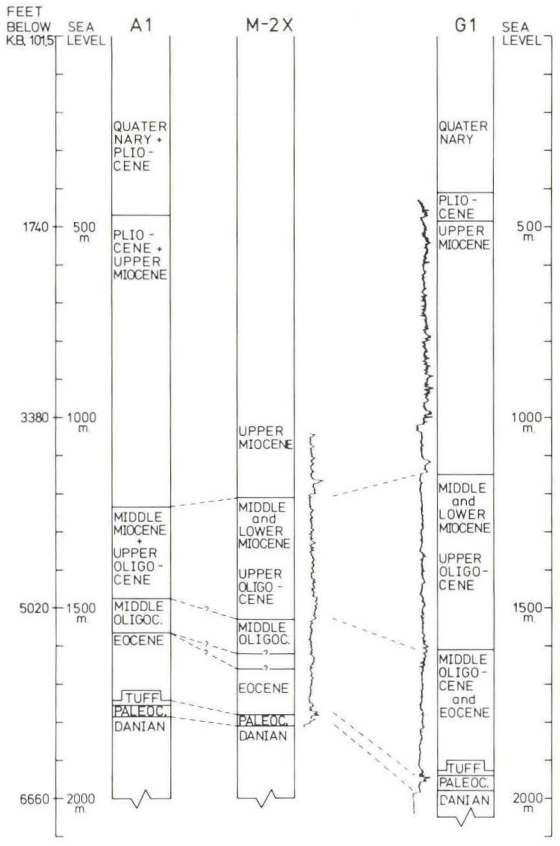

Fig. 4. Correlation between M-2X and A-1, G-1.
The logs are gamma-ray logs.
(A-1 and G-1 from Rasmussen, 1974 and 1978 respectively).

for this unconformity on localities closer to the shore. The increase in the grain size in the M-2X could also be explained in this way.

The mineralogy.

The gypsum in the bulk-samples and the jarosite content in the clay fraction of the Paleogene sediments is believed to originate from a post-drilling weathering of the pyrite. The widespread marl formations from the Paleogene of Denmark, i.e. Kerteminde Marl of Paleocene age and Røsnæs Clay and Søvind Marl of Lower and Upper Eocene age, respectively, are not found in the M-2X borehole. According to the descriptions of the other

North Sea boreholes (Rasmussen 1974 and 1978), these sediments are not characteristic of the Danish part of the North Sea either, although there is no general hiatus in the intervals mentioned. This absence, or scarcity, of carbonates apparently indicates different depositional environment.

An abundance of quartz in the clay fractions in the Paleogene is also reported by Karlsson et al. (1979). It was proposed that this quartz originated as a result of a halmyrolytic transformation of glass into smectite, silica and zeolites (Müller 1967).

Quartz, feldspar, calcite and pyrite in the bulk samples are known to be of silt and sand grain sizes. None of these minerals – except for some quartz – occurs in the clay fraction. The increase in the amount of quartz and feldspar in the Neogene sediments corresponds to an increase of the grain sizes, especially of the silt fraction.

The clay minerals.

The clay mineral composition and its variation is generally in agreement with the observations made on the samples from the borehole 2/11-1 and on those from the on-shore localities. Smectite is dominant in the Paleocene sediments and in the ash-series. This possibly indicates that a halmyrolytic transformation of the volcanic material has taken place (as proposed by Nielsen (1974) and Karlsson et al. (1979)). The supply of the terrigenous material was very limited. Tank (1963) suggests that smectite in the Paleocene may originate from the reworking of the Cretaceous and Danian bentonite intervals, as described by Christensen et al. 1973, Unmack 1949 and Valeton 1959, 1960. According to Hansen and Andersen (1969) an earlier Paleocene volcanism might have been responsible for the presence of clinoptilolite replaced foraminifera. Heulandite has also been identified in the Paleocene of the Viborg 1 borehole in Central Jutland (fig. 1) and in the local tuffs of Paleocene age in the North Sea (Harrison et al. 1979 and Knox 1979).

It is here believed that the names heulandite and clinoptilolite are apparently used interchangeably for the same mineral, as the distinction, based on the X-ray diffractograms, is not sharp (Brown et al. 1969).

The characteristic occurrence of kaolinite above the ash-series is in good agreement with the observations made on the samples from the borehole 2/11-1 and also from the Danish on-shore localities. Is is remarkable that the amount of kaolinite is so high, as it seems that it decreases westwards in Danish localities. This as previously mentioned, might be the result of a supply from another and closer source area to the northwest.

The upwards decrease in smectite and increase in illite and kaolinite probably reflect a diminishing role of volcanism as a source of the sedimentary material while, at the same time, the supply of terrigenous material was be-

coming more important. In contrast to 2/11-1 chlorite has not been identified in the Upper Miocene. This might be because either the material of the entire Miocene section was not investigated as yet or the source of chloritic material was from the northwest and thus did not reach as far southeast in the Central Trough as M-2X. Further analysis of the Upper Miocene and younger sediments in M-2X, as well as other boreholes, will presumably show whether the occurrence of chlorite in the Neogene sediments is a general feature for the North Sea Basin.

The observed change of basal peak position for the smectite at the transition from the Paleogene to the Neogene could be explained by the differences in exchangeable cations, or due to variation in amount and composition of interstratified components.

Conclusions

This investigation has shown that the mineralogy and the texture of the Tertiary deposits from the borehole M-2X are subject to very characteristic changes, which are generally in agreement with the results obtained from other North Sea boreholes and outcrops in Denmark. In a few cases the differences may indicate a variable influence of supply of the terrigenous material from different sources, presumably the Baltic area and Scotland.

Compared with the on-shore localities, there are no proper marl horizons, the carbonate never exceeding about 10 %.

In the Paleogene sediments smectite is the main mineral, quartz is present in the clay fraction and kaolinite is absent in the lowermost part of the section, which is probably due to a halmyrolytic transformation of the volcanic material and to a very minor supply of the terrigenous material. Higher up the amount of smectite decreases and kaolinite appears. This is believed to be caused by a supply of the weathering products from the surrounding land masses. Pyrite and quartz make up most of the silt- and sandfraction.

At the transition to the Neogene the grain size increases abruptly and continues to increase upwards. Similar conditions are described for the on-shore localities. This is believed to be a result of the uplift of the surrounding land masses and/or of a decrease in sea level.

Upwards in the Neogene smectite decreases and kaolinite and illite increase concurrently with the increase in grain size. These conditions may arise from a decrease in the supply of smectite, as the volcanic activity ceased, or because the sedimentation was taking place under more energy-rich conditions, possibly closer to the coast and generally under a regressive phase. Such events might have resulted in a decrease of smectite which nor-

mally is believed to be the most fine-grained of the identified minerals, and therefore would be kept in suspension and deposited under more quiet conditions.

Acknowledgements. The samples studied were kindly placed at my disposal by Dansk Boreselskab A/S. Financial support was provided by the Danish Natural Science Research Council.

Dansk Sammendrag

Prøver fra boringen M-2X i Central Trough, Nordsøen dækkende intervallet fra overfladen af Danienkalken til op i Øvre Miocæn er blevet underkastet texturelle og mineralogiske undersøgelser.

Det fremgår heraf, at overgangen fra Paleogen til Neogen markeres af et tydeligt skift i kornstørrelsesfordelingen fra finkornede siltede leraflejringer i Paleogen til lerede siltaflejringer i Neogen. Aflejringerne bliver tydeligvis grovere opadtil. De mineralogiske analyser har afsløret, at smectit dominerer i Paleogen især i Paleocæn og under aflejring af askeserien, og at kaolinit ikke er tilstede heri, men først dukker op senere i Eocæn. Samtidig med den stigende kornstørrelse i Neogen sker der et fald i indholdet af smectit og en forøgelse i illit- og kaolinit indholdet. Chlorit er ikke registreret.

Den kraftige dominans af smectit i Paleocæn og Nedre Eocæn er sandsynligvis forårsaget af en halmyrolytisk omdannelse af vulkansk materiale. Kaolinit kan tolkes som et indicium for en senere tilførsel af terrigent forvitringsmateriale sandsynligvis fra det baltiske område eller fra landområder omkring Scotland. Det er meget tydelige skrift i sedimentets textur i Oligocæn er eventuelt forårsaget af tektonisk hævning af omkringliggende landområder eller af en sænkning af havspejlet.

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