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PALAEOENVIRONMENT IN THE 'NORTH SEA' AS INDICATED BY THE FISH BEARING MO-CLAY DEPOSIT (PALEOCENE/EOCENE), DENMARK

by

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A previously suggested environmental model of the 'North Sea' at the Paleocene-Eocene boundary is summarized and expanded with few oceanographic details. Some criticism of the implied very high sedimentation rate of the Mo-clay is answered. The precise biostratigraphic age of the Mo-clay and its ash series is indicated as latest Paleocene (perhaps extending into the very earliest Eocene). The most common 'Mo-clay fishes' have been found by drilling just below the ash series in the Viking Trough of the North Sea. Similarities between the Mo-clay fish fauna and the contemporaneous one in Turkmenistan are mentioned.

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Contents:

SAMENVATTING

Een eerder voorgesteld model van het milieu van de 'Noordzee' ten tijde van de overgang Palaeoceen - Eoceen wordt in dit artikel samengevat en uitgebreid met enkele oceanografische bijzonderheden. Er wordt ingegaan op enige kritiek ten aanzien van de veronderstelde zeer hoge sedimentatiesnelheid van de 'Mo-clay'. De exacte biostratigrafische ouderdom van de 'Mo-clay' en de vulkanische aslagen daarin wordt aangegeven als het jongste Palaeoceen (misschien nog het alleroudste Eoceen). De meest algemene 'Mo-clay' vissen zijn gevonden in boringen juist onder de vulkanische aslagen in de Viking Trog van de Noordzee. Overeenkomsten tussen de visfauna van de 'Mo-clay' en de huidige visfauna van Turkmenistan worden genoemd.

INTRODUCTION

This paper is abstracted from a lecture given in Leiden in October 1978 at a meeting for fish-specialists under I.G.C.P. project 124 and has been extended with some remarks on correlation.

Mo-clay is a marine diatomaceous clay or rather a diatomite found so far only in a limited area in northern Jutland, Denmark (locality map in Gry, 1940 and in the semipopular serial 'VARV', edited by Geological Museum, Copenhagen, part 2, 1972). It contains an abundancy of well preserved macrofossils, especially fish skeletons (Bonde, 1966) and insects (Larsson, 1975) and further it includes a series of about 200 volcanic ash layers (Bøggild, 1918).[1]

To explain this very localized and fairly unusual occurrence of fossils and sediments an environmental model for the whole North Sea area was constructed (Bonde, 1973 with a few additions 1974) and some tests were suggested.

Since then a few more oceanographic details of the model have been sketched (to be illustrated below) and some comments on the validity of the model have occurred in the literature. Some observations on the occurrence of the 'Mo-clay fish fauna' in the North Sea will be added. Most references given in Bonde (1973,1974) will not be repeated here.

CORRELATION WITH OTHER DEPOSITS IN THE NORTH SEA BASIN

Very important for a detailed reconstruction of the palaeo-environment is the exact correlation of the sediments and fossils compared (although some methods can apparently do with less stringent demands, e.g. Larsen & Jørgensen, 1977).

Concerning the Mo-clay the ash layers are of utmost importance because the same series of identifiable ash layers can be easily recognized in southern and eastern parts of Denmark (Bøggild, 1918; Andersen, 1937a, b; Sorgenfrei, 1957; Madirazza & Fregerslev, 1969; Petersen, 1973; Pedersen et al., 1975; Rasmussen, 1977; Dinesen et al., 1977), in northern Germany (Unter Eozän 1: Andersen, 1938; Bettenstaedt, 1949; Illies, 1949; Gripp, 1964; Hinsch, 1958, 1974), and NW-Holland (Pannekoek, 1956: 57) and perhaps in SE-England (Elliott, 1971). The same ash series apparently is found

[1]Gunver Pedersen in her thesis (1978, unpublished) has very appropriately created the new formal name 'Fur Formation' to replace 'Mo-clay Formation' for the diatomaceous sediments with the ash series in the 'Mo-clay area' (western Limfjorden), one type section being the cliff 'Knuden' on the Isle of Fur.

in the North Sea in the Danish drillings (Rasmussen, 1974; Childs & Reed, 1975), in the English part (Forties Field, Thomas et al., 1975; Walmsley, 1975), and in the Norwegian area (see N. P. D. Papers nos. 1 - 16, 1976 - 1978, from Norwegian Petroleum Directorate, e.g. Rise, 1978). In the North Sea the ash layers are included in the so-called Balder Formation and are recorded at least as far north as the Frigg Field. It is worth noting, however, that Jacqué & Thouvenin (1975) indicate more than one episode of tuff formation in some parts of the North Sea and imply that the ash beds near the base of the London clay at Harwich are slightly younger than the main episode which corresponds to the 'Mo-clay Formation'.

PALAEOGEOGRAPHY IN 'MO-CLAY TIME'

The synchrony of the mentioned ash beds is of importance for estimating the position of the coast lines of the basin. Even with the possible non-significance of the Harwich ash, the Mo-clay probably corresponds to the basal part of the London Clay with its abundant diatoms like in Unter Eozän 1. If so, the 'Channel' was closed as indicated by Davis & Elliott (1957) for the first London Clay transgression, and by Jacqué & Thouvenin (1975) on the first Artois sill, so the palaeogeographic model I used (1973, 1974, figs) may still hold good, although some possible adjustments should be mentioned.

Gjessing (1978) holds that Norway and most of Sweden was continent during the entire Tertiary with continuous uplifting and the higher areas near the westcoast. The northeastern coast of the basin quite likely was in the general area of the Fenno-Scandian border zone and was continued up north not far from the present Norwegian coast. The validity, as a very exact time measure, of the so-called 'Mo-Clay flora of diatoms' in the Kristianstad area (Cleve-Euler & Hessland, 1948; Miller, 1966) perhaps is a little dubious (cf. Bergstrøm & Sundquist 1978: 66; but see Benda, 1972 on characteristic 'Lower Eocene' diatoms, suggesting some correlation possibilities). Still, part of Scania probably was submerged; note that Cleve-Euler (1941) described 'Mo-clay diatoms' from Quaternary boulders high up in Sweden - perhaps this indicates that much more of Scandinavia was submerged during part of the Early Tertiary. The Southern coast was in North Germany (Krutzsch & Lotsch, 1958), but whether north-western Poland was marine too exactly contemporaneous with the Mo-clay deposition seems rather uncertain (see Wozny, 1968, and the schemes for I.G.C.P. 124 compiled by Ciuk, 1977). On the extension towards the east of the whole 'bay' there seems mostly to be negative evidence, lack of suitable rocks. Still, the uppermost Paleocene fish fauna of Turkmenistan (Danilchenko, 1968), which is very similar to the Mo-clay fauna (Bonde, 1966, remarks 1974, 1975 and below), suggests a fairly direct water connection. An interesting palaeogeographic aspect is the possible closure of the whole water body towards north and northwest: The 'Thulean landbridge' almost certainly closed the connection with the Atlantic (Vogt, 1972; Strauch, 1970; Nilsen, 1978); and the Barents Sea shelf may well have been dry land (McKenna, 1975). So perhaps the 'North Sea' was a large, completely landlocked sea at this particular episode near the Paleocene/Eocene boundary, reaching from Svalbard to somewhere in the eastern Baltic. One should note that if the 'North Sea' had open connections to both the North Atlantic, as preferred by Szalay & McKenna (1971:284) and to the east towards southern S.S.S.R., as indicated in a Paleocene map by Wills (1952), then McKenna's Greenland-Svalbard-Barents shelf land bridge is isolated by sea from West Europe at this Paleocene/Eocene period.

BIOSTRATIGRAPHY

The biostratigraphic position of the Mo-clay (and the ash series and 'Unter Eozän 1') has mostly been arbitrarily defined in post-war times as earliest Eocene (cf. Sorgenfrei, 1957; Hinsch, 1958, 1974). However, the oil geologists working in the North Sea almost as arbitrarily have assigned it to the latest Paleocene, because distinct geophysical characteristics separate the ash series from the overlying soft 'plastic clay' (= Røsnæs Clay), giving a very suitable 'Paleocene-Eocene' boundary, easily recognizable over most of the North Sea. The difficulty with the ash series is that there are no calciferous microfossils preserved in this part of the section, and the siliceous ones, like diatoms (Benda, 1972), have not been safely tied up with the international foraminiferan and nannoplankton zonation. However, dinoflagellates appear to promise a solution, and Hansen (1979) has shown that based on *Wetzelliella* stratigraphy the Mo-clay Formation and the underlying gray 'non-fossiliferous' clay must be assigned to the *W. hyperacantha* zone (equivalent to NP 9 and latest Paleocene). Further the greyish clay below the Røsnæs Clay (which was assigned to NP 11 by Perch-Nielsen, 1976: 28) and a few metres above the proper Mo-clay (with ash layer no. 130) belongs to the *W. meckelfeldensis* zone, which is partly equivalent to NP 10 and earliest Ypresian. So perhaps the Mo-clay reaches into NP 10 and thereby bridges the boundary between Paleocene and Eocene, viz. the NP zones 9 and 10. This is a very peculiar coincidence if my hypothesis 1973, 1974 is correct that the entire Mo-clay Formation was deposited within about 60,000 years. Hansen's dinoflagellate study does away with Martini's suggestion (1977) that the Mo-clay and ash series span Early Paleocene (NP 4) to Early Eocene (NP 10), about 7 million years. This correlation is based upon a very dubious designation of silicoflagellates low in the Mo-clay and from a deep-sea drilling near New Zealand to the same species although they have marked differences. Another dubious identification of a silicoflagellate by Martini (1974) concerns the intraformational stratigraphy of the Mo-clay and was spotted by Perch-Nielsen (1976: 31). Hansen (1979) is in agreement with Jacqué & Thouvenin (1975; see Costa & Müller, 1978, for a complication with a new *W. astra* zone between the two mentioned above).

DEPOSITION TIME

From a viewpoint of sedimentation rates Martini's suggestion also seems unlikely. This may even be said of Sharma's (1969) estimate of about 3 million years (as indicated by Spjeldnæs, 1975: 297), based on three reversed magnetic episodes detected in the series of ash layers. The ash series, when recorded in the non-diatomaceous facies in southern Denmark, generally takes up much less than 20 m, the rest of the Eocene deposits being more than six times as thick but consisting of even more finegrained sediment.

The Mo-clay Formation in northwest Jutland is 50 - 60 m thick, and the ash series is distributed throughout the formation. Much of the diatomaceous sediment consists of alternating dark and light lamina, about 1 - 2 mm thick per couplet. In 1973 and 1974 I suggested that these couplets were annual *varves*, therefore by extension that the whole deposition had taken no more than 60,000 years. This very high sedimentation rate, one mm per year, is just what is found in the modern analogue I compared with: diatomaceous ooze off California (Emery & Hülsemann, 1962; Calvert 1966a, b; Soutar & Isaac, 1969) in anoxic basins some hundred metres deep on the shelf.

I suggested (1973, 1974) a possible test of the 'varv-idea' by sedimentological studies; detailed sedimentological investigations were carried out by Gunver Petersen, Copenhagen (unpublished thesis, 1978). Although she does support the anoxic basin model, she does not confirm the hypothesis about annual varves as regular couplets, but suggests diatom blooms with irregular intervals over longer time in a local basin only.

Also Perch-Nielsen (1976: 32) believes the deposition time of 60,000 years to be too short. Her argument is that with silicoflagellates she can divide the Mo-clay into five subzones, and that such subzones are more likely to have a mean length of over half a million than of 10,000 - 15,000 years. For such an argument to be valid the length of the (sub-)zones must be correlated to ideas of mean duration of longevity of palaeontological species. This is sometimes said in the literature in very ideal cases to be about 0.5 million years (for fast changing ammonites perhaps down to 0.2 million years), but this is backcalculated from the duration of range zones situated on top of each other in suitable intervals (absolutely dated or interpolated). Nobody has, I believe, any extensive experience with silicoflagellate 'species' longevity, and further Perch-Nielsen's (sub-)zones are mostly concurrent range zones, based on first occurrence of single taxa with extensive overlaps and a group which in her opinion (1976: 32) has 'usually only rather local correlative value'. This may well mean that some of these species 'float' out and in of this part of the basin with unpredictable (perhaps short) intervals, which are by no means correlated with 'species' longevity. There is mostly only a difference of one or two species beteen the subzones.

Sharma's (1969) argument for over 3 million years for the entire Mo-clay deposition is also based upon estimates of 'mean length of zones', in this case geomagnetic reversals, which in the well-known and most recent sections occur with a frequency of about 0.5 million years. Extrapolating this to the Mo-clay one needs six times as much time for the whole deposition. But in fact this only counts for magnetic 'epochs', not for the much smaller so-called 'events' which may last in the order of magnitude of 10,000 years. Could Sharma have picked up six of those, undetected in Heirtzler's (1968) polarity scale?

Anyway, using Heirtzler's scale for the Paleocene - Early Eocene on the Mo-clay reversals would give results stratigraphically even more grotesque than those of Martini.

Unfortunately none of these two 'zonal' tests seems crucial.

THE ENVIRONMENTAL MODEL

The model of the North Sea basin during this latest Paleocene (to E. Eocene?) episode, in short, is based on the following facts (Bonde, 1973, 1974):

- Mo-clay is a 50 - 60 m thick diatomite, only found in northern Jutland and to a large degree composed of mm-thin laminae;
- the formation contains about 200 ash layers, which can be recognized in southern Denmark (in a 'plastic clay' facies), they decrease in thickness towards the south; the volcanic source area is probably Skagerrak (fig. 1, 2 in Pedersen et al., 1975);
- fossils are often well-preserved, undisturbed by scavengers and are dominantly pelagic, oceanic and planctonic forms, such as most fishes which include the most common species of macrofossils (Bonde, 1966), the diatoms and pteropods (Benda, 1972, Stolley, 1899), chelonids and a leather back turtle (Nielsen, 1959);
- there is a terrestrial component: rare bird fragments (Hoch, 1975), quite abundant insects (winged, see Larsson, 1975), trunks, branches, and some leaves and fruits (Koch, 1960);
- benthic species are fairly rare, apart from one gastropod *'Fusinus'* (Bonde, 1974) and a brittle

star (Rasmussen, 1972), in one or two levels; a starfish (ibid.), four pelecypods, a naticid snail and '*Pectinaria*-like' tubes are much rarer; crustacean and/or other burrows are not uncommon in several horizons. All of these fossils are found in the non-laminated Mo-clay.

Accordingly the following palaeoenvironment model is suggested (Bonde 1973, 1974), figs. 1 - 3:

- The distribution of ash (and insects: Illies, 1949) is assumed to indicate dominating (or frequently strong) northern winds (from NE over N to NW).
- A north-south surface current was generated and because of Coriolis force it diverged off-shore along Norway's coast producing a slow coastal upwelling as compensation (fig. 1).
- The upwelling recirculates most nutrient in the photic layer, therefore supporting an extremely rich planktonic life (cf. Cushing, 1971) in a narrow zone (100 - 300 km) along the coast; the Mo-clay area is considered the far southern end of this zone which produced the diatomite, diatoms being only moderately abundant in the rest of the basin (Untereozän 1, Bettenstaedt, 1949; basal London Clay, Davis & Elliott, 1957; Scania, Cleve-Euler & Hessland, 1948; North Sea, Jacqué & Thouvenin, 1975).
- The benthic fauna in the same beds is very sparse and/or specialized (e.g. agglutinated foraminifera) which may be explained by the nutrient-impoverished N-S current sinking below the lighter freshwater run-off (fig. 2) from south and west; the current is especially depleated of nutrient because much of this is removed by the north-going countercurrent just below the upwelling system. This is an anti-estuarine, Mediterranean-like circulation, see Brongersma-Sanders (1971) and fig. 3.
- Because of Coriolis force, affecting both water and wind, the water probably piled up along the western basin margin (fig. 1), therefore causing sinking and recirculation. The wind stress also piled up the water at the southern margin with the lighter river water on top (fig. 3); the north-going freshwater with mixing obviously must have affected the N-S surface current and must have stopped the upwelling system somewhere north of the Ringkøbing-Fyn-High (R-F, fig. 3).
- The high production in the photic zone of the upwelling area uses lots of nutrients and oxygen, and with the countercurrent a stable, layered system is created, which can withhold fairly stagnant water in deeper parts of this shelf basin (like on the Californian shelf to-day, Emery & Hülsemann, 1962). Very little oxygen is mixed with this bottom water (which may even represent a pocket of the oxygen poor water found at medium depths (cf. Calvert, 1966a, b)). This is strongly indicated by the well-laminated, benthos-free diatomite. Under such conditions varved sediment can be produced at high rate (ibid.), and no calciferous microfossils are preserved, because the stagnant water becomes slightly acidic.
- Opening of the 'Channel' around mid London Clay time (Davis & Elliott, 1957), may, because of warm Atlantic water influx, have changed much of the circulation pattern (as inferred from Ramsay's, 1971, fig. 3 a branch of a 'proto-Gulf-stream' must have reached the 'Channel'). The high productive upwelling zone was destroyed at least in its southern area, where fine clay was deposited instead - apparently the more 'normal' condition for the basin in Early Eocene. Spjeldnæs (1975: 299) points out how 'abnormal' the situation was in fact, with the very small amount of clastics coming from the Scandinavian land and explains this by assuming a mangrove belt to catch the coarse sediment along the N(E) margin of the basin, as is known only from one Cretaceous locality in Scania. However, this does not explain how one of the best known examples of fossil mangrove flora, that of late London Clay times (Davis & Elliott, 1957) is combined with a large amount of clastic material (sand, silt, clay) and water transported terrestrial fossils. My climatic model could take these differences into account, as it predicts a semi-arid, but foggy coastal zone of Scandinavia because of off-shore divergence in the air (fig. 1, and Bron-

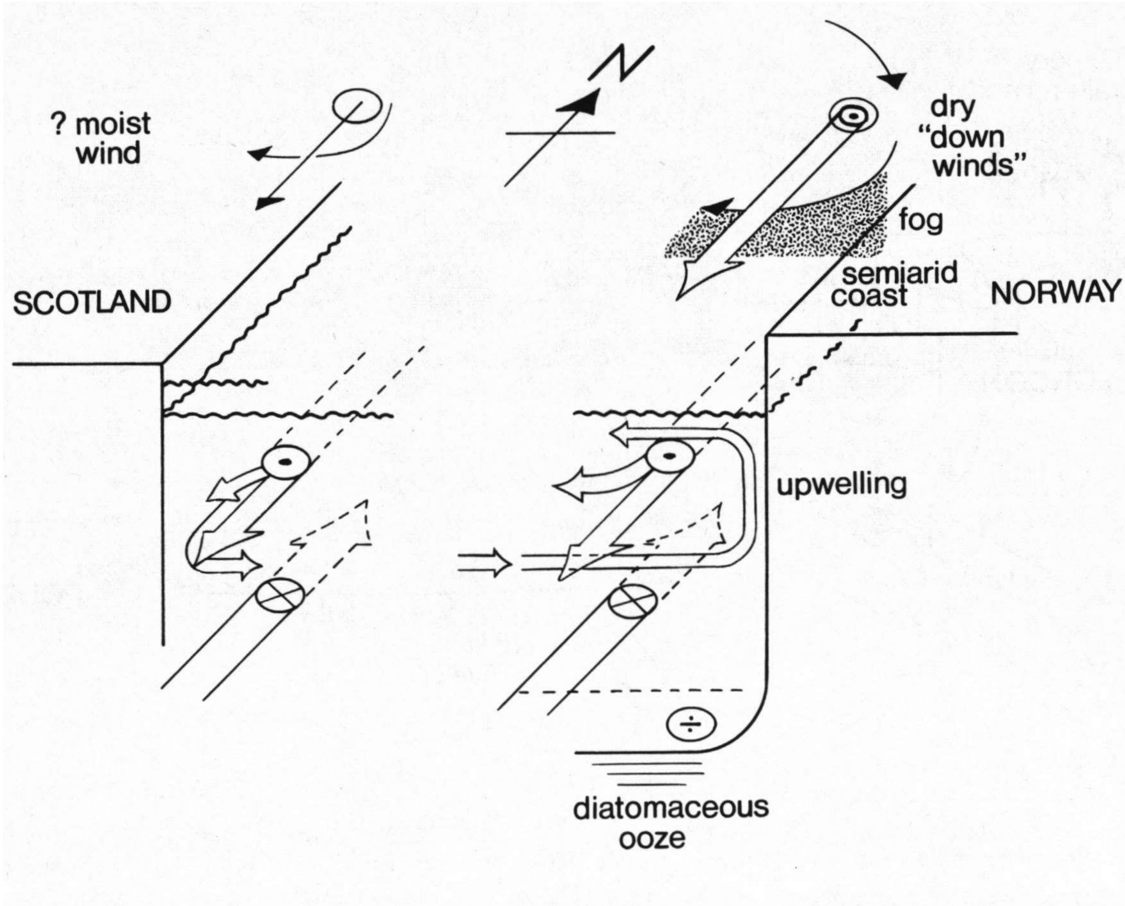

Fig. 1. Northern part of the 'North Sea' basin in (and after?) 'Mo-clay time'. Eastside: northern winds generate a N-S surface current with diverges off shore and creates slow upwelling. Countercurrent below this system and stagnant water and a belt with laminated ooze. The symmetrical 'down wind' system causes semi-arid coast climate with fog. Westside: the same windsystem may tend to be moist and to pile up water, which must sink.

Het noordelijk deel van het 'Noordzee'bekken in (en na?) de 'Mo-clay tijd'. Oostzijde: noordelijke winden veroorzaken een N-Z gerichte oppervlaktestroming, die zeewaarts afbuigt en een langzame opwelling veroorzaakt. Onder dit systeem bevindt zich een tegenstroom, stilstaand water en een gordel van gelaagd slib. Het symmetrische 'valwind' systeem veroorzaakt een semi-aride kustklimaat met mist. Westzijde: hetzelfde windsysteem kan wellicht vocht aanvoeren en water opstuwen, dat zal zinken.

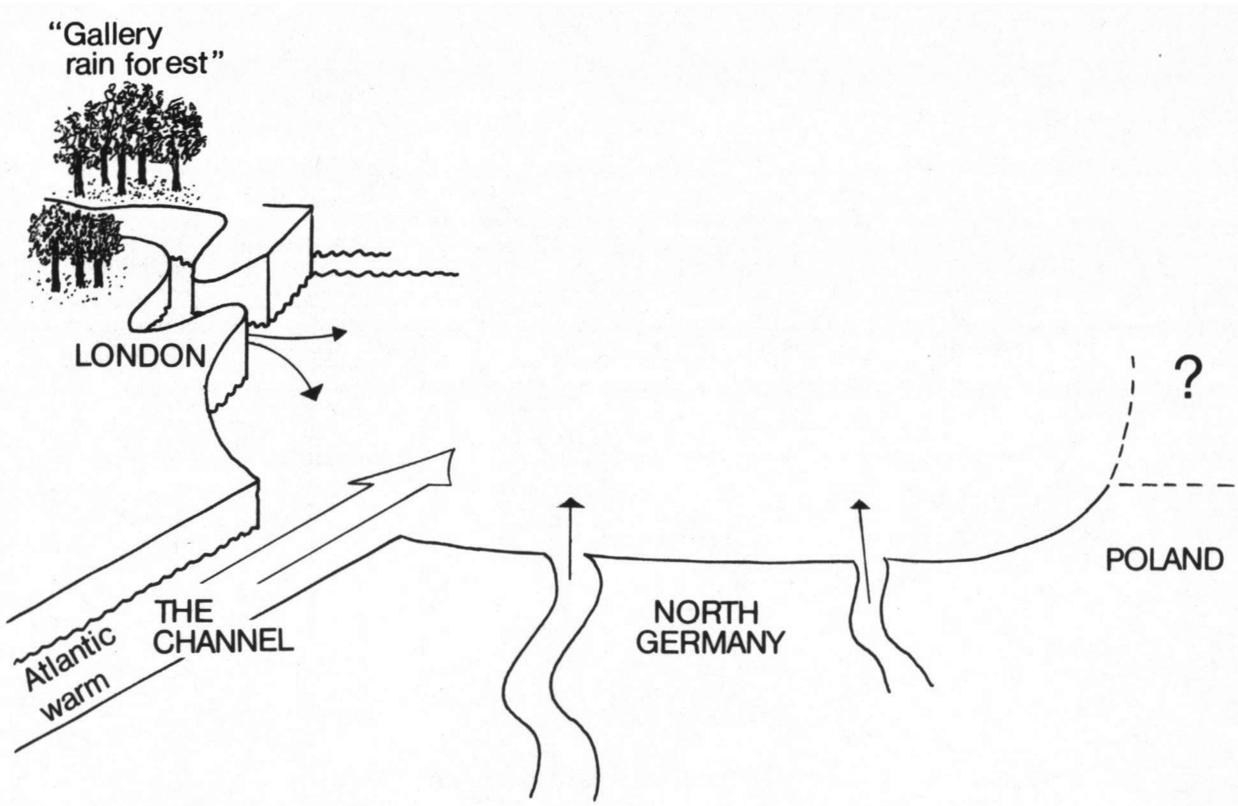

Fig. 2. Southern part of the basin immediately after 'Mo-clay time', that is in 'Late London Clay time' with initial opening of the 'Channel'. Water piling up, rain forest, river run-off and warm Atlantic current is shown.
Mangrove is known from the 'London coast'.

Zuidelijk deel van het bekken direct na de 'Mo-clay tijd', dus in de 'late London Clay tijd', met beginnende opening van het 'Kanaal'. De opstuwing van het water, het regenwoud, de uitstroming van een rivier en de warme Atlantische stroming zijn aangegeven.
Mangroven zijn bekend van de kust 'bij Londen'.

gersma-Sanders, 1971) produced by the northern winds, while the same winds after passing the ocean must have given rain over the land in west and south, whereby Daley's (1971) very humid 'gallery (rain-)forests' along the rivers might be explained. How compatible my picture of the northern coast is with Larsson's (1975) ecological inferences based upon the insects remains to be seen: he mentions meadows and slowly moving streams and low vegetation, but distinctly not forests, and steppe is mentioned in connection with the beetles.

- The entire model with upwelling above anoxic bottom water only needs a few hundred metres of water depth, because such coastal upwellings take place in the upper 200 m of the water. So I cannot agree with Spjeldnæs (1975: 300) that the model is unusual, modern coastal upwelling does occur on the shelf, and is the condition under which pure diatomites are produced because of the recirculation of the nutrient (Cushing, 1971). The prediction about the diatomite belt along the Norwegian coast has not (yet) been confirmed, presumably the drillings have so far

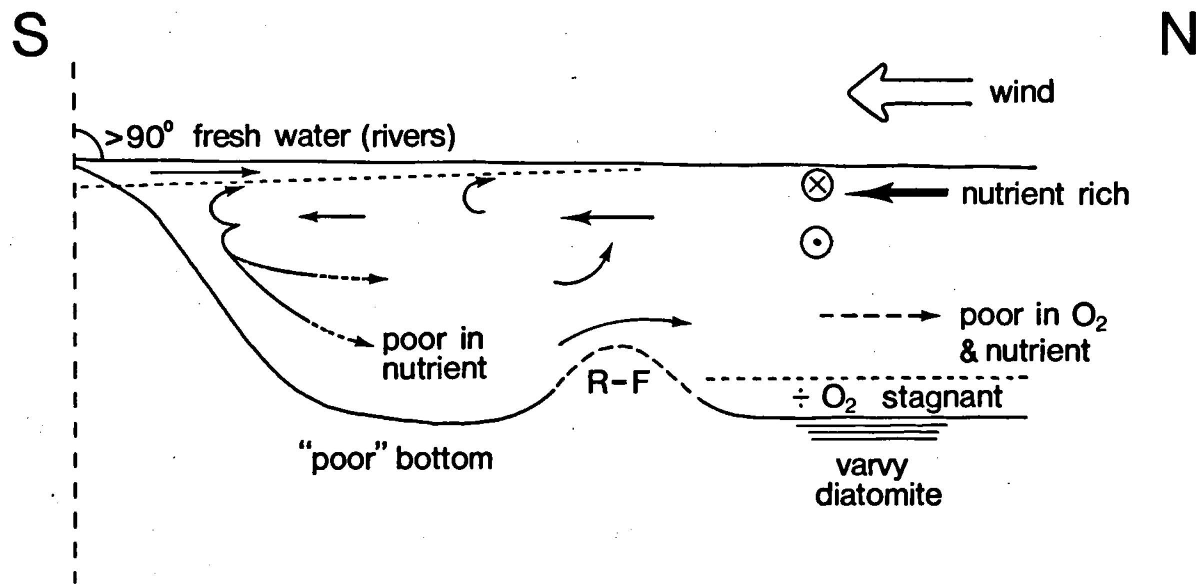

Fig. 3. N-S section in the eastern part of the basin in 'Mo-clay time'. Anti-estuarine circulation caused by the wind-generated nutrient rich surface current with upwelling recirculating most nutrient near the surface. Some nutrient is carried north by the countercurrent. The oceanic surface current with less nutrient left sinks below the lighter river run-off in the southern end where windstress tends to pile up the water. The bottom below the 'poor' sinking water has an impoverished fauna. Some distance north of the Ringkøbing-Fyn-High (R-F) at a few hundred metres depth, a body of stagnant water with no oxygen causes lack of bottom fauna and therefore laminated sediment (Mo-clay). This body of water is kept in place by the stable, stratiphied system above it.

N-Z profiel in het oostelijke deel van het bekken in de 'Mo-clay tijd'. De wind veroorzaakt een anti-estuariene circulatie bestaande uit een voedselrijke oppervlaktestroming, voedselrijk water circuleert door opwelling nabij het oppervlak, terwijl een deel ervan door de tegenstroming naar het noorden wordt gevoerd. De oceanische oppervlaktestroming waarin de hoeveelheid voedingsstoffen is verminderd zinkt onder het lichtere instromende rivierwater in het zuidelijke deel, waar door de wind het water neiging tot opstuwen vertoont. De bodem onder het 'arme' omlaagzakkende water heeft een verarmde fauna. Op enige afstand ten noorden van het Ringkøbing-Fyn-Hoog (R-F), op een diepte van enkele honderden meters, is een zuurstofloze, stagnerende watermassa de oorzaak van het ontbreken van een bodemfauna, waardoor een gelamineerd sediment wordt afgezet (Mo-clay). Deze watermassa wordt op zijn plaats gehouden door het stabiele, gelaagde systeem erboven.

been too far off the coast.[2]

- The temperature regime indicated in my model is subtropical which is in agreement with Daley (1971) and Buchardt (1978). I believe the microfaunal evidence of lower temperature and/or greater depth in Untereozän 1, as indicated by Bettenstaedt et al. (1960) and repeated by Göke (1972), may have very little to do with temperature and rather more with the nutrient-poor bottom conditions mentioned above (perhaps in connection with deepening of the sea).

THE FISH FAUNA

Finally a few comments on the Mo-clay fish fauna (cf. Bonde, 1966):

The presence of the sharks *Striatolamia striata* (Winkler) and *Palaeohypotodus rutoti* (Winkler) in the ash series (also at Røsnæs, see Petersen et al., 1973) is indicative rather of latest Paleocene than Eocene (cf. e.g. Herman, 1975; Ward, 1978).

The two most common teleosteans of the Mo-clay were found in the North Sea drillings (about 2000 m below the bottom surface) in dark mudstones of the formation immediately *below* the ash series. These catches were done in the Forties Field (Thomas et al., 1975: 114, in unit III), one specimen is a complete 10 cm long osmeroid (smelt; Bonde, 1966, no. 4, called 'coregonin') with an entire little argentinoid (Ibid., no. 2: 'clupavid') in the stomach. Also in two Norwegian drillings: the same two species found in Well 25/10-2 (Esso, see fig. 4), which is close to the type section of the ash bearing Balder Formation in 25/11-1 (Esso - see N. P. D. Paper no. 2, 1976 and Deegan & Scull, 1977); a so far unidentified fish in Elf Field (15/4-1) in the ash series at only about 600 m depth (K. Ulleberg, pers. comm.). All these fishes are from the Viking Trough area. Fish remains just below the inferred ash series are mentioned from the Danish well C-1 30 km west of Limfjorden (Rasmussen, 1974: 29).

Finally some remarks on the striking similarity between the L. Paleocene oceanic fish faunas of the Mo-clay and of Danatinski Series in Turkmenistan (Danilchenko, 1968): In 1975 (Bonde: 278) I mentioned that the 'chirocentrid' *Opsithrissops*, from Turkmenistan almost certainly is a *Brychaetus*-like osteoglossid, which may well be identical with the species in the Mo-clay (Bonde, 1966, no. 6), a postcranial skeleton presumably of this species has recently been identified; these Early Tertiary osteoglossids are unusual in being marine (cf. Patterson, 1972); Nolf (1978) has identified a marine L. Paleocene osteoglossid otolith from Belgium. The Mo-clay probably contains a chanid (not mentioned by me in 1966, badly preserved) like the one in Turkmenistan. The Mo-clay veliferid (fig. in the above mentioned 'VARV') is very close to *Danatinia*. An *Archaeus*-like carangid is common to both faunas and so is a *Sardinella*-like clupeid, while the *Protorhamphosus* with its quite different, terminal mouth probably is not closely related to *Rhamphosus* from the Mo-clay (Nielsen, 1960) and Monte Bolca.

[2] In the Danish North Sea well C-1 30 km west of the Limfjorden tuff is said 'possibly' to be indicated in clay and/or shale at about 500 metres' depth (Rasmussen, 1974: 26), and just below in a 'grey shale' at 511 metres many pyritized diatomes were found (Ibid.: 29). In a survey report received after finishing this manuscript the drillings about 100 km off shore west-northwest of the 'Mo-clay area' are described (Rasmussen, 1978: Geological aspects of the Danish North Sea sector. Danm. Geol. Unders., Rk. 3, 44: 85 pp). These wells, K-1 and F-1, provide possible tests of the prediction of an elongate diatomite zone towards northwest parallelling the presumed coast. There are no cores from the relevant parts of these boreholes, but the ash series is indicated in sediments called in the summary descriptions 'clay' and 'claystone' (Ibid.: 34, 63), and nothing is mentioned about diatoms. Apparently this conflicts with the model. However, dr. I. Bang from the Survey has kindly assured me that in fact there is proper Mo-clay (diatomite) and undoubted volcanic ash in the interval just above 500 m in C-1, and that she has identified Mo-clay in one of the two recent drillings, too. So presumably my prediction has not (yet) been falsified anyway. Gunver Pedersen (thesis, 1978), however, strongly argues for a model with a small local basin with upwelling due to bottom topography (salt diapirs) like the alternative suggested by Bonde (1973, 1974: 32) as less heuristic.

Fig. 4. Teleostean fish (with eye region, snout and jaws missing) related to smelts (Osmeroids) from a drilling core from the well 25/10-2 (Esso) in the Viking Trough west of Stavanger near the border of the British sector. This species is the second most abundant species from the Mo-clay and is in the core preserved in a dark grey laminated siltstone (mudstone) at a depth of 6555 feet (presumably below KB) that is almost 2,000 m below the bottom, and a little below the ash series (kindly on loan from Norwegian Petroleum Directorate, drs. Ulleberg and Bergsager). Photo by Jan Aagaard.

Een aan de smelten (Osmeroiden) verwante beenvis, waarvan het ooggedeelte, de snuit en de kaken ontbreken, afkomstig uit een boorkern van de boring 25/10-2 (Esso) in de Viking trog, ten westen van Stavanger, nabij de grens van de Britse sector. Deze soort is de op één na algemeenste van de Mo-clay en is bewaard gebleven in een donkergrijs gelamineerde 'siltstone' (kleisteen) op een diepte van 6555 voet (vermoedelijk onder KB), d.w.z. bijna 2000 m onder de bodemoppervlakte, en iets onder de vulkanische aslagen (bereidwillig ter beschikking gesteld door het N. P. D., dr. Ulleberg en dr. Bergsager). Opname Jan Aagaard.

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REFERENCES

(BGSD = Bull. geol. Soç., Denmark)

Andersen, S. A., 1937a. De vulkanske askelag i vejskæringen ved Ølst og deres udbredelse i Danmark. - Danm. geol. Unders. (2) 59: 53 pp. (Engl. summ.).

Andersen, S. A., 1937b. Et vulkanområdes livshistorie. - Geol. Fören. Stockholm, Förhandl. 59: 317 - 346. (Engl. summ.).

Andersen, S. A., 1938. Die Verbreitung der Eozänen vulkanischen Ascheschichten in Dänemark und Nordwestdeutschland. - Zeitschr. für Geschiebeforsch. und Flachlandsgeologie 14 (4): 179 - 207.

Benda, L., 1972. The diatoms of the Moler Formation of Denmark (Lower Eocene). In: Simonsen, R. (ed.): First symposium on recent and fossil marine diatoms. - Nova Hedwigia, Beih. 39: 251 - 266.

Bergström, J. & B. Sundquist, 1978. Kritberggrunden. In: Kornfält. K.-A. et al.: Description to the map of solid rocks and the aeromagnetic map, Kristianstad SO. - Sver. Geol. Unders., (Ser. Af). 121: 55 - 99.

Bettenstaedt, F., 1949. Paläogeographie des nordwestdeutschen Tertiär mit besonderer Berücksichtigung der Mikropaläontologie. In: Bentz, A. (ed.): Erdöl und Tektonik in Nordwestdeutschland: 143 - 172. (Hannover)

Bettenstaedt, F., H. Fahrion, H. Hiltermann & W. Wick, 1962. Tertiär Norddeutschlands: 339 - 378. In: Arbeitskreis deutscher Mikropaläontologen: Leitfossilien der Mikropaläontologie. 2 vols., 432 pp. & pls. (Berlin)

Bonde, N., 1966. The Fishes of the Mo-clay Formation (Lower Eocene). - BGSD 16: 198 - 202.

Bonde, N., 1973. Fiskefossiler, diatomiter og vulkanske askelag. - Dansk geol. Foren., Årsskr. f. 1972: 136 - 143.

Bonde, N., 1974. Palaeoenvironment as indicated by the 'Mo-clay Formation' (Lowermost Eocene of Denmark). - Tertiary Times, 2 (1): 29 - 36.

Bonde, N., 1975. Origin of higher groups. - Colloq. internat. C.N.R.S. (Paris), 218: 293 - 324.

Brongersma-Sanders, M., 1971. Origin of major cyclicity of evaporites and bituminous rocks: An actualistic model. - Marine Geol. 11: 123 - 144.

Buchardt, B., 1978. Oxygene isotope palaeotemperatures from the Tertiary period in the North Sea area. - Nature: 121 - 123.

Bøggild, O. B., 1918. Den vulkanske aske i Moleret. - Danm. geol. Unders., (2) 33: 159 pp. +atlas. (Résumé en francais).

Calvert, S. E., 1966a. Origin of diatom-rich, varved sediments from the Gulf of California. - J. Geol. 74: 546 - 565.

Calvert, S. E., 1966b. The accumulation of diatomaceous silica in the sediments of the Gulf of California. -- Geol. Soc. Amer. Bull. 77: 569 - 596.

Childs, F. B. & P. E. C. Reed, 1975. Geology of the Dan field and the Danian North Sea. - Danm. geol. Unders., (3) 43: 24 pp.

Ciuk, E., 1977. Lithostratigraphic data of Polish Tertiary sediments (except for the Carpathians and the Carpathian foredeep). Schemes compiled for I.G.C.P. 124:,8 pp.

Cleve-Euler, A., 1941. Alttertiäre Diatomeen und Silicoflagellaten im Inneren Schwedens, gefunden von Åke Berg, beschrieben von A. Cleve-Euler. - Paläontographica, 92, Abt. A.

Cleve-Euler, A. & I. Hessland, 1948. Vorläufige Mitteilung über eine neuentdeckte Tertiärablagerung im Süd-Sweden. - Bull. geol. Inst. Upps. 32: 155 - 182.

Costa, L. I. & C. Müller, 1978. Correlation of Cenozoic dinoflagellate and nannoplankton zones from the NE Atlantic and NW Europe. - Newsl. Stratigr. 7 (2): 65 - 72.

Cushing, D. H., 1971. Upwelling and the production of fish. - Adv. Mar. Biol. 9: 255 - 334.

Daley, B., 1972. Some problems concerning the Early Tertiary climate of southern Britain.-Palaeogeogr., Palaeoclimatol., Palaeoecol. 11: 177 - 190.

Danilchenko, P., 1968. Ryb verkhego paleocena Turkmenii. In: Obruchev: Ocherki po filogenii i sistematike iskopaemykh ryb i bezcheliustnykh: 113 - 156. Isd. Nauka (Moscow).

Davis, A. G. & G. F. Elliott, 1957. The palaeogeography of the London Clay sea. - Proc. Geol. Ass. 68: 255 - 277.

Deegan, C. E. & B. J. Scull, 1977. A standard lithostratigraphic nomenclature for the central and northern North Sea. - Inst. Geol. Sci. Rep. 77/25: 36 pp.

Dinesen, A., D. Michelsen & K. Lieberkind, 1977. A survey of the Paleocene and Eocene deposits of Jylland and Fyn. - Danm. geol. Unders., (Ser. B), nr. 1.

Elliott, G. F., 1971. Eocene volcanics in south-east England. - Nature. Lond. 230: 9 only.

Emery, K. O. & J. Hülsemann, 1962. The relationships of sediments, lift, and water in a marine basin. - Deep-Sea Research 8: 165 - 180.

Gjessing, J., 1978. Norges landformer. Oslo (Universitetsforlaget), 207 pp.

Gripp, K., 1964. Erdgeschichte von Schleswig-Holstein. Neumünster (Wachholtz): 411 pp.

Gry, H., 1940. De istektoniske forhold i Moleret. - BGSD 9: 586 - 627.

Göke, G., 1972. Das Vorkommen von Diatomeen im europäischen Paläogen. - Aufschluss, 23 (11): 378 - 385.

Hansen, J. M., 1979. The age of the Mo-Clay Formation. - BGDS 27 (in press).

Heirtzler, I. R., 1968. Sea floor spreading. - Sci. Amer., 219 (6): 60 - 70.

Herman, J., 1975. Les Selaciens des terrains néocrétacés & paléocènes de Belgique & des contrées limitrophes. Elements d'une biostratigraphie intercontinentale. - Mém. Expl. Cartes geol. & Min. Belgique, 15: 1 - 450.

Hinsch, W., 1958. Tertiaire. Allemagne du Nord. Lexique Stratigraph. Internat. 5 h 1, Paris (Centre Nat. Rech. Scient.), 75 pp.

Hinsch, W., 1974. Das Tertiär im Untergrund von Schleswig-Holstein. - Geol. Jb., A 24: 5 - 34.

Hoch, E., 1975. Amniote remnants from the eastern part of the Lower Eocene North Sea Basin. - Colloq. internat. C.N.R.S. (Paris), 218: 543 - 562.

Illies, H., 1949. Die Lithogenese des Untereozäns in Nordwestdeutschlands. - Mitt. Geol. Staatinst. Hamburg 18: 7 - 44.

Jacqué, M. & J. Thouvenin, 1975. Lower tertiary tuffs and volcanic activity in the North Sea. In: Woodland, A. W. (ed.): 455 - 466.

Koch, E., 1960. Moleret (ref. of lecture on plants). - BGSD 14: 283 - 284.

Krutsch, W. & D. Lotsch, 1958. Uebersicht über die Paläogeographische Entwicklung des zentraleuropäischen Alttertiärs (ohne Tethys-Raum). - Ber. geol. Ges. D. D. R., 3 (2/3): 99 - 110.

Larsen, A. R. & N. O. Jørgensen, 1977. Palaeobathymetry of the lower Selandian of Denmark on the basis of foraminifera. - BGSD 26: 175 - 184.

Larsson, S. G., 1975. Palaeobiology and mode of burial of the insects of the lower Eocene Mo-clay of Denmark. - BGSD 24: 193 - 209.

Madirazza, I. & S. Fregerslev, 1969. Lower Eocene tuffs at Mønster, North Jutland. - BGSD 19: 283 - 318.

Martini, E., 1974. Silicoflagellate zones in the Eocene and early Oligocene. - Senckenb. leth., 54: 527 - 532.

Martini, E., 1977. Neue Daten zum Paläozän und Unter-Eozän im südlichen Nordseebecken. - Newsl. Stratigr., 6: 97 - 105.

McKenna, M. C., 1975. Fossil mammals and early Eocene North Atlantic land continuity. - Ann. Missouri Bot. Gard., 62: 335 - 353.

Miller, U., 1966. Tertiary diatoms in the Kristiansstad Plain. In: Nilsson, K., 1966. - Sver. geol. Unders., (Ser. C), 605: 13 - 15.

Nielsen, E., 1959. Eocene Turtles from Denmark. - BGSD 14 (2): 96 - 114.

Nielsen, E., 1960. A new Eocene teleost from Denmark. - BGSD 14: 247 - 252.

Nilsen, T. H., 1978. Lower Tertiary laterite on the Iceland-Faroe ridge and the Thulean land bridge. - Nature, 274: 786 - 788.

Nolf, D., 1978. Les otolithes de Téléostéens des Formations de Landen et de Heers (Paléocène de la Belgique). - Geol. Palaeontol., 12: 223 - 234.

Pannekoek, A. J., 1956. Geological history of the Netherlands. - Roy. Neth. geol. & min. Soc.

Patterson, C., 1972. The distribution of Mesozoic freshwater fishes. XVII Congr. Int. Zool., Theme I (preprint): 1 - 22.

Pedersen, A. K., J. Engell & J. G. Rønsbo, 1975. Early Tertiary volcanism in the Skagerrak: New chemical evidence from ash-layers in the Mo-clay of northern Denmark. - Lithos, 8: 255 - 268.

Perch-Nielsen, K., 1976. New silicoflagellates and a silicoflagellate zonation in north European Palaeocene and Eocene diatomites. - BGSD 25: 27 - 40.

Petersen, K. S., 1973. Some features in clay with tuff-beds from Lower Eocene on Røsnæs, Danmark. - Danm. geol. Unders., Yearbook 1972: 69 - 78.

Petersen, K. S., E. Hoch & N. Bonde, 1978. A new species of Mytilid bivalve, and vertebrate remains from Lower Eocene marine deposits on Røsnæs, Danmark. - Danm. geol. Unders., Yearbook 1972: 79 - 86.

Ramsay, A. T. S., 1971. Occurrence of biogenic siliceous sediments in the Atlantic Ocean. - Nature, 233: 115 - 117.

Rasmussen, H. W., 1972. Lower Tertiary Crinoidea, Asteroidea, and Ophiuroidea from northern Europe and Greenland. - Biol. Skr. Dan. Vid. Selsk., 19, 7: 1 - 83.

Rasmussen, H. W., 1977.Geologi paa Mols. - Danm. geol. Unders., (Ser. A); 4.

Rasmussen, L. B., 1974. Some geological results from the first five Danish exploration wells in the North Sea. - Danm. geol. Unders., (3), 42: 1 - 46.

Rasmussen, L. B., 1978. Geological aspects of the Danish North Sea sector. - Danm. geol. Unders., (3), 44: 85 pp.

Riise, R., 1978. Lithology. Well 7/12-1. Norwegian Petrol. Directorate, Paper no. 16.

Sharma, P. V., 1969. Early Tertiary field reversals recorded in volcanic ash layers of northern Denmark. - BGSD 19: 218 - 223.

Sorgenfrei, T., 1957. Danemark. Lexique Stratigr. Internat., 2 d. Paris (Centre Nat. Rech. Scient.), 44 pp.

Soutar, A. & J. D. Isaacs, 1969. History of fish populations inferred from fish scales in anaerobic sediments off California. - Calif. mar. Res. Comm. CalCOFI, 13: 63 - 70.

Spjeldnæs, N., 1975. Paleobiogeography and facies distribution in the Tertiary of Denmark and surrounding areas. - Norges geol. Unders., 316: 289 - 311.

Stolley, E., 1899. Ueber Diluvialgeschiebe des London-thons in Schleswig-Holstein und das Alter der Molerformation Jütlands sowie das baltische Eozän überhaupt. - Arch. f. Anthropol. u. Geol. Schlesw.-Holst. II (2): 105 - 146.

Strauch, F., 1970. Die Thule-Landbrücke als Wanderweg und Faunenscheide zwischen Atlantik und Skandik im Tertiär. - Geol. Rundschau, 60: 381 - 417.

Szalay, F. S. & M. C. McKenna, 1971. Beginning of the age of mammals in Asia: The Late Paleocene Gashato fauna, Mongolia. - Bull. Amer. Mus. Nat. Hist., 144 (4).

Thomas, A. N., P. J. Walmsley & D. A. L. Jenkins, 1975. The Forties Field. - Norges geol. Unders., 316: 105 - 120.

Vogt, P. R., 1972. The Faeroe-Iceland-Greenland aseismic ridge and the western boundary undercurrent. - Nature, 239: 79 - 81.

Walmsley, P. J., 1975. The Forties Field. In: Woodland, A. W. (ed.): 477 - 486.

Ward, D., 1978 (in press). A checklist of the sharks, rays and chimaeroids from the English Palaeogene. - Tertiary Res., 2 (2).

Willsm L. J., 1952. Palaeogeographical Atlas of the British Isles and adjacent parts of Europe: 64 pp. (London & Glasgow).

Woodland, A. W. (ed.), 1975. Petroleum and the continental shelf of North-West Europe. Vol. I: Geology.

Wozny, E., 1968. Stratigraphy of the Tertiary of northern Poland. In: Colloque sur l'Eocène; - Mém. Bur. Rech. Min., 58: 683 - 691.

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