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Some geological results from the first five Danish exploration wells in the North Sea

Dansk Nordsø A-1, A-2, B-1, C-1, and D-1

BY
Leif Banke Rasmussen

DANSK SAMMENDRAG

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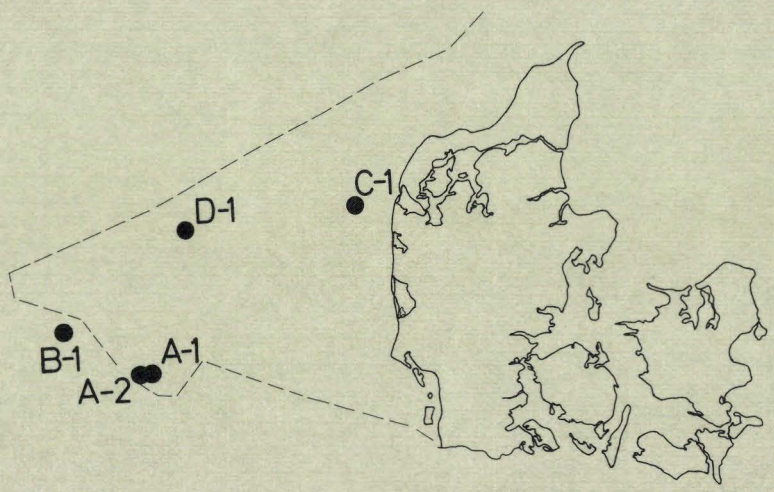

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Contents

Abstract

After an introducing survey of the exploration for hydrocarbons on the Danish continental shelf during the period from 1963 to 1968 a lithological and chronostratigraphical description of the first five exploration wells is given. The results are preliminary and they are based on investigations carried out by the staff of the Department of Subsurface Geology at the Geological Survey of Denmark.

Deposits of Permian, Triassic, Jurassic, Cretaceous, Tertiary and Quaternary age are proved to occur in the borings. Stratigraphical investigations of the very thick Tertiary sequence in the central part of the North Sea show, that the main part of the sedimentation took place during the younger Miocene (Upper Miocene).

Outline of the exploration history

The preliminary investigations for Danish exploration wells in the North Sea were commenced in 1963, after the concession for prospection and extraction of hydrocarbons from the Danish shelf area had been granted in July 1962 to ship-owner A. P. Møller and the companies led by him. After the granting of the concession A. P. Møller then formed »Dansk Undergrunds Consortium« (Danish Subsurface Consortium, abbreviated D. U. C.) in cooperation with foreign oil companies such as Gulf, Shell, and later Standard Oil Company of California and Texaco. In June 1963 D. U. C. commissioned a seismic exploration off the west coast of Jutland, to be carried out by Western Geophysical Company of America. These investigations covered two lines along the entire west coast of Jutland, together with a few transverse lines. The same geophysical company carried out more comprehensive reflection seismological investigations in the summer of 1964 over a close network of measuring lines over the Danish continental shelf. An even closer network was measured in the Skagerrak.

During 1965 numerous additional seismic lines were measured in the North Sea, still by the same company, so that the number of measured lines not only became closer, but was also extended to cover the southern and western part of the Danish continental shelf. From 1966 to 1968 the net was drawn even closer. These investigations were carried out by Mandal Industries Co., Ltd., Geophysical Services Intercontinental Limited, Gulf's survey ship "Gulfrex", and Seismographic Services Ltd., in addition to Western Geophysical Co. of America.

An aeromagnetic investigation of the Danish land area and adjoining waters was carried out in 1963 by Hunting Surveys Limited, London, using a Gulf Magnetometer. These data were processed by Gulf Research and Development Company, Pittsburg, Pennsylvania, USA. In addition, the entire North Sea area including the eastern half containing the Danish continental shelf was investigated aeromagnetically by Aero Service Corporation, USA, in 1962–63. A set of 32 sheets covering Denmark and adjacent waters, and a set of 16 sheets, covering the eastern North Sea, resulted from these investigations. All sheets are on a scale of 1 : 100,000.

No gravimetric investigations were carried out on the Danish continental shelf area before 1969, apart from some scattered measurements made by Deutsches Hydrographisches Institut.

The seismic and the aeromagnetic measurements together formed the foundation for a general picture of the geological structure of the North Sea area. The aeromagnetic results formed the basis for an evaluation of the thickness of the sediment covering and the depth to the basement. The seismic measurements provided a basis for the mapping of the structures. Three reflecting surfaces were sufficiently pronounced to be mapped: 1. A horizon near the base of Upper Cretaceous, 2. A horizon near the base of the Triassic, and 3. The surface of the pre-Zechstein. After velocity surveys had been carried out in the first deep borings in the area it became possible to identify these reflection horizons approximately and to map them.

On the basis of the geophysical data it was possible already in 1966 to construct an overall picture of the structural conditions on the Danish continental shelf. It became evident, for example, how far the Ringkøbing–Fyn High extends westwards, and many salt structures were found in the areas north, west, and south of the High. A survey of the results was made in 1967 by Heybroek *et al.* on a map showing the extent of Zechstein deposits and the occurrence of salt structures in the North Sea. This map was incorporated in a structural map by Sorgenfrei 1969, which is reproduced as fig. 3 in this paper.

A summary of the geophysical and geological exploration of the North Sea up until 1969 is given in Sorgenfrei's work, mentioned above, and this exploration will therefore not be treated here. A number of the scattered investigations made in the years prior to this exploratory activity, however, include parts of the Danish shelf area. This is true, for example, of Colette's gravimetric investigations in 1955–57, and some of Bungenstock, Cloos and Hinz's geophysical measurements.

Investigation procedures by the Geological Survey

Drilling activity on the Danish shelf commenced in 1966 with the boring of Dansk Nordsø A-1 from the drilling ship "Glomar IV" (see fig. 1). From the very start of the drilling operations a geologist from the Geological Survey of Denmark (»Danmarks Geologiske Undersøgelse«, hereafter abbreviated D. G. U.) was stationed on the ship to follow the progress of the

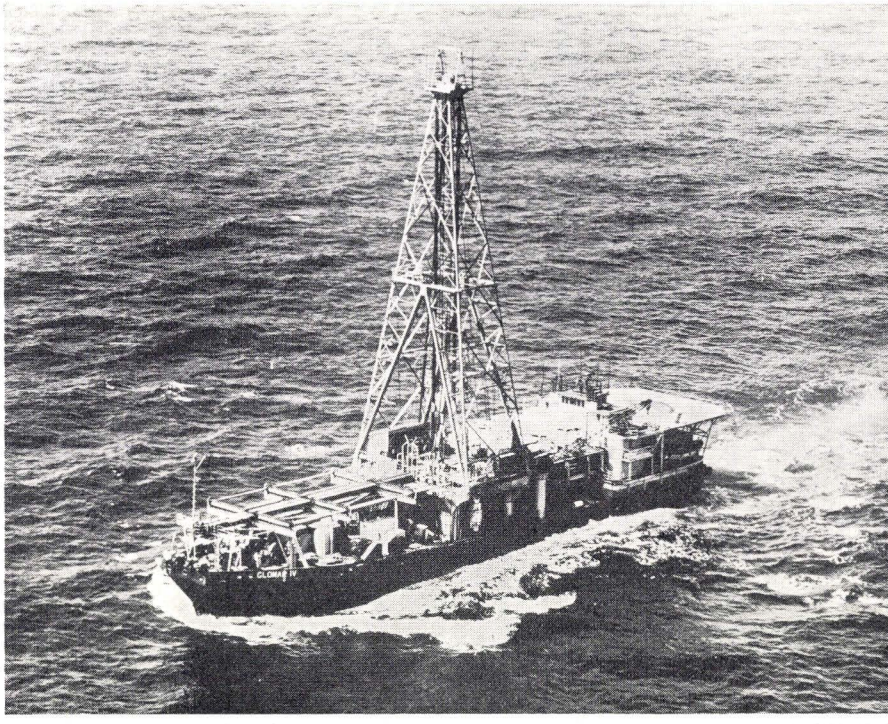

Fig. 1. The drilling ship »Glomar IV«. A. P. Møller Ltd.

work and to collect samples for D. G. U. It was found to be of great importance to be able to follow all the technical details and thus to be able to collect important material as a supplement to the reports which A. P. Møller as concessionaire is required to send to the institute. The posting of a site geologist was continued for the following borings made from the drilling platform "Mærsk Explorer" (see fig. 2), but unfortunately D. G. U. was obliged to cease this activity as from May 1st, 1968, as the result of a wage disagreement which caused the Ministry to forbid service on the drilling platform. Since then D. G. U. was able to carry on the investigations solely upon samples and reports sent in by the concessionaire.

As more than 5 years have now elapsed since the completion of the first five Danish North Sea borings, D. G. U. has thought the time appropriate to publish the results of the geological investigations which the geologists of the institute's Department of Subsurface Geology have made so far upon the samples from these borings.

However, these results are still preliminary; detailed investigations of the

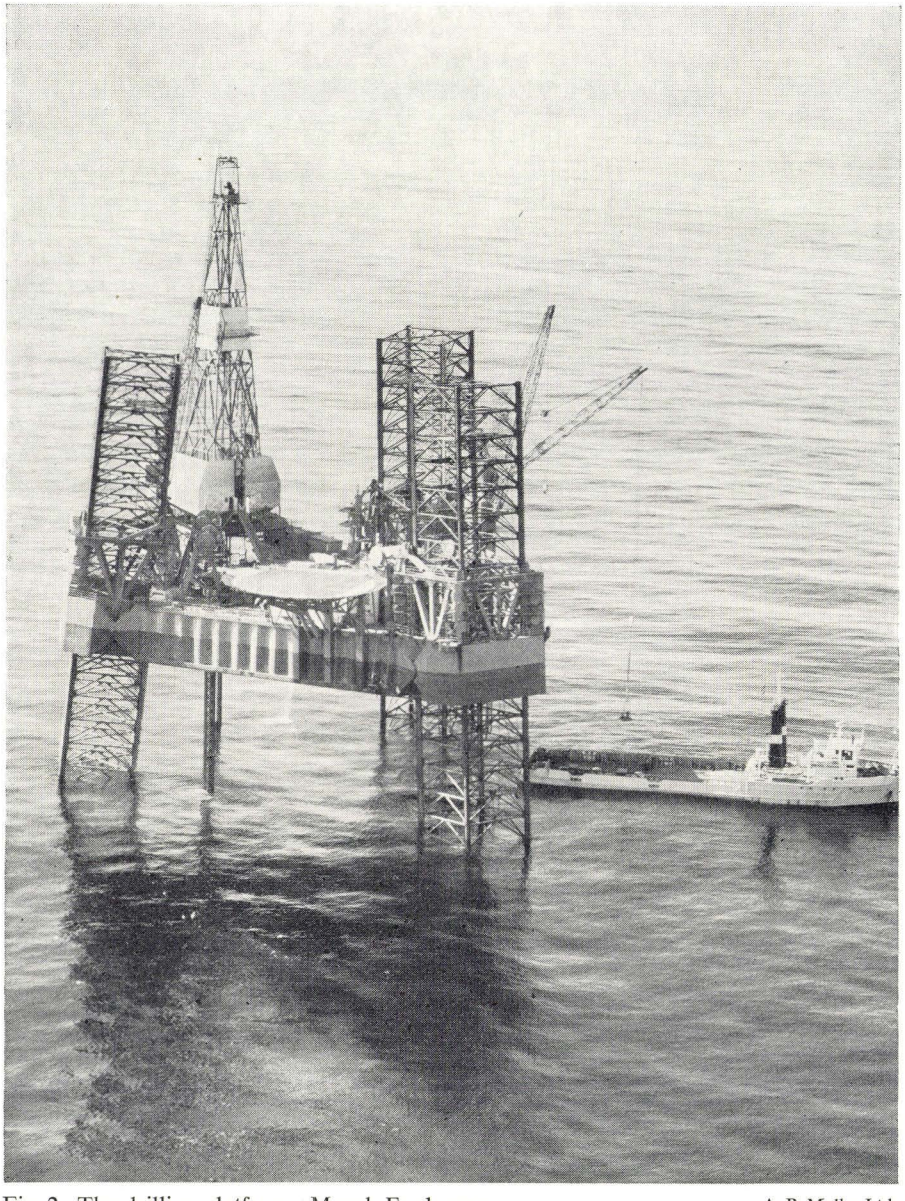

Fig. 2. The drilling platform »Mærsk Explorer«. A. P. Møller Ltd.

strata from several periods are in progress at present, based chiefly upon the foraminifera and ostracods in the samples. It is intended to publish the results of these investigations in the form of special treatises, whose publication can not, however, be expected in the immediate future. In the time

elapsing until their publication, D. G. U. hopes to be able to satisfy the interest of the public, and in particular of fellow scientists, by publishing this survey.

In the accounts of the individual borings which follow, the general technical information on drilling contractors, drilling equipment, and casings, together with locational indications and elevations of the sea bed, drilling platform and kelly bushing, has been obtained from D. U. C.'s data. These are practically identical with the information from the half-yearly reports from A. P. Møller.

The lithological, biostratigraphical, and chronostratigraphical studies, on the other hand, have been carried out by geologists at D. G. U. Similar investigations, of course, were also carried out by D. U. C. Geologists were stationed on both drilling ship and drilling platform from Gulf Oil of Denmark and from a logging firm which had special responsibility for collecting and describing all drilling samples, and for entering up the technical data together with the sample descriptions on logs which were placed at the disposal of D. G. U. Furthermore, the samples and bedding series were examined and dated on the basis of the microfossil content by a foreign specialist firm working for D. U. C.: Robertson Research Company Ltd. The chronostratigraphical results obtained by this firm were communicated to D. G. U. via A. P. Møller's half-yearly report. Although there is thus a considerable mass of report data available from D. U. C., the stratigraphical results published in this article are predominantly based upon the investigations made by D. G. U. All the firms working for D. U. C. produced excellent work, but as regards the stratigraphy, D. G. U. has the advantage of having more time available for detailed investigations.

Quality and depth estimates of the samples

The quality of the samples is of great importance. All the borings were carried out by rotary drilling, and thus the samples are almost all ditch samples. In the 5 borings described here only a few cores were taken: none in A-1, 8 in A-2 (intervals 5841′–5963′ and 5990′–6104′), 1 in B-1 (11815′–11875′), 1 in C-1 (10494′–10519.5′), and 3 in D-1 (4684′–4737′, 10921′–10979′, and 11338′–11367′). All the rest are ditch samples, and these were as a rule taken at intervals of 10′ in the lower strata and often up to 30′ in the higher strata, on account of the high drilling speed in the softer upper

layers. As a result of caving from sections of the hole, which were not covered by a casing, there was thus a considerable contamination of many different rock-fragments in the samples, whilst often, as a result of the high drilling speed, high mud pressure, etc., only little material came up from the softer strata. When additional problems of lag distance and lag time are also taken into consideration, it will be realized that a lithological section based only on the drilling depth "read off" by the driller is full of numerous and often quite considerable deviations from the true depths. It must also be kept in mind that strata boundaries are usually difficult to determine from ditch samples alone, and that the individual layers themselves may be impossible to detect in ditch samples taken at large intervals.

The various types of Schlumberger logs are a considerable help for determining strata boundaries, and *in the following descriptions of the sections, the depths found with the help of these logs are printed in italics.*

It must also be stressed that depths in metres are calculated from sea level, whilst the depths in (English) feet (usually printed in brackets) are measured from the kelly bushing. The depths measured in metres have in fact been *converted* from feet after subtracting the elevation of the kelly bushing, since all depths were measured in feet during the drilling operation; the depths on the various Schlumberger logs were also indicated in feet.

Dansk Nordsø A-1

Position: About 220 km W of Esbjerg
55°24′17″ N–05°03′42″ E

Contractor: Global Marine Inc.

Equipment: Drilling ship "Glomar IV" with rig type National 1625 DE

Drilling: Commenced 27th August 1966
Completed 23rd September 1966 at a depth of 1801 m below sea level (= 5941′ below kelly bushing)

Casing: 36″ to 76 m (249′)
20″ to 201 m (662′)
13 3/8″ to 968 m (3177′)

Elevations: Sea floor: – 44.5 m (177′)
Kelly bushing: + 9.4 m (31′)

Well site geologists from D.G.U.

Ole Bruun Christensen	($^{25}/_{8}$–$^{8}/_{9}$,	0′– 660′)
Arne Dinesen	($^{8}/_{9}$–$^{22}/_{9}$,	660′–4786′)
Ole Bruun Christensen	($^{22}/_{9}$–$^{25}/_{9}$,	4786′–5941′)

Lithological sequence

Drawn up on the basis of sample descriptions and evaluations made by the well site geologists.

0–44 m (*31′–177′*)	Water
44–52 m (*177′*–202′)	Sand
52–271 m (202′–920′)	Clay, grey, silty in places. Occurrences of lignite. Further down predominantly silt and abundant mollusc shells. (Ler, gråt, stedvis finsandet. Forekomster af kullag. Nedadtil overvejende finsand og talrige molluskskaller).
271–*478* m (920′–*1599′*)	Clay, grey, with beds of silt and sand. Abundant mollusc shells in places. (Ler, gråt, med lag af finsand og sand. Stedvis talrige molluskskaller).
478–512 m (*1599′*–1710′)	Sand and gravel. Occurrences of silty clay. (Sand og grus. Forekomster af finsandet ler).
512–759 m (1710′–2520′)	Clay, grey, dark in places, with beds of silt and brownish siltstone. (Ler, gråt, stedvis mørkt, med lag af finsand og brunlig finsandsten).
759–841 m (2520′–2790′)	Clay, dark grey, micaceous. Occurrences of silt. Brownish concretions in places. (Ler, mørkegråt, glimmerholdigt. Forekomster af finsand. Stedvis brunlige konkretioner).
841–1115 m (2790′–3690′)	Clay, grey, probably with beds of siltstone. (Ler, gråt, antagelig med lag af finsandsten).
1115–*1237* m (3690′–*4090′*)	Clay, dark grey or with a brownish tint, hard in places (claystone). Lowermost glauconitic. (Ler, mørkegråt eller med brunlig tone, stedvis hård (lersten). Nederst glaukonitholdigt).
1237–1463 m (*4090′–4830′*)	Claystone, dark brownish-grey (brownish-black). (Lersten, mørk brunliggrå (brunligsort)).

1463–1750 m (*4830′–5773′*)	Claystone, grey, more rarely brownish-grey and greenish-grey. (Lersten, grå, sjældnere brunliggrå og grønliggrå).
1750–*1760* m (5773′–*5805′*)	Claystone, greenish-grey and grey, with volcanic tuff. (Lersten, grønliggrå og grå, med vulkansk aske).
1760–1777 m (*5805′–5860′*)	Claystone, grey. (Lersten, grå).
1777–1801 m (*5860′*–5941′)	Limestone, white, with chert. (Kalksten, hvid, med flint).

Chronostratigraphy

Drilling stopped in strata of Danian age after having penetrated approx. 480 m of Quaternary deposits and approx. 1320 m of Tertiary sediments. A chronostratigraphical subdivision, based on investigations on the foraminifera by Inger Bang, Arne Dinesen, and Arne Buch, has the following appearance:

44– 478 m	Quaternary and Pliocene (? Scaldisian)
478–1237 m	Pliocene and Upper Miocene
1237–1463 m	Middle Miocene–Upper Oligocene
1463–1563 m	(? Upper Oligocene –) Middle Oligocene
1563–*1760* m	Eocene
1760–1777 m	Paleocene
1777–1801 m	Danian

Supplementary remarks concerning the stratigraphy

The lowermost beds in the boring, from 1801–1777 m, were laid down during the Danian. At the top of this interval Inger Bang has demonstrated a definitely Upper Danian pelagic foraminiferal fauna.

The overlying sediments, from 1777–1760 m, which appear to consist predominantly of grey claystone, must be presumed to belong to the Selandian (Paleocene), although the foraminiferal fauna does not give unambiguous proof of this determination.

The interval 1760–1750 m comprises a zone which on the basis of comparisons with Schlumberger logs (SP, Gamma Ray, Interval Transit Time and Resistivity-Conductivity) from the Dansk Nordsø A-1 and a number of other boreholes in the western part of the Danish shelf area, seems to belong to a series containing beds of volcanic ash (tuff), which has been found in the ditch samples. This series is also known from the Danish mainland, and is ascribed to the lowermost part of the Eocene.

Just above 1750 m there occurs a thick series of clay or claystone containing agglutinating foraminifera, for example *Haplophragmoides walteri,* whose highest occurrence is found at 1563 m (5160′). Arne Dinesen (1968) refers this series to the Eocene, but points out, however, that the section passes smoothly up into beds containing *Turrilina alsatica* and *Rotaliatina bulimoides,* which indicate that the Middle Oligocene has been reached. The upper boundary of the occurrence of these forms is found at about 1518 m (5010′).

Continuing upwards, more grey claystone is found up to 1463 m. This section is especially characterized by quite large quantities of *Sigmoilina tenuis* (according to Dinesen, 1968). At present it can not be established definitely whether the upper part of this *Sigmoilina* zone should be dated to Middle or to Upper Oligocene.

However, above 1463 m an interval is found extending up to 1237 m in which *Asterigerina guerichi* s.l. together with planktonic forms, characterizes the foraminiferal fauna. This species occurs in great numbers, and Dinesen indicates the possibility that its presence in the samples just below the depth of 1463 m may be due to caving, since the lighter claystone is here succeeded by dark shaly micaceous clay. The lowest part of this interval may have been deposited in the Upper Oligocene, but further up there is no doubt that Miocene sediments have been reached.

The uppermost beds in the interval 1463–1237 m contain identifiable molluscs. The very uppermost sediment in the interval consists of dark, sometimes black, shaly claystone, which must be regarded as a consolidated black clay of the same type as the Danish Hodde Clay (Rasmussen 1966, p. 16). The exact thickness of this black shale in the Dansk Nordsø A-1 borehole is unknown. It contains the following mollusc species a.o.: *Limopsis lamellata, Astarte aff. gracilis, Cardita chamaeformis, Dentalium aff. dolfussi, Lyrotyphis sejunctus, Hinia aff. fuchsi, Admete fusiformis, Gemmula zimmermanni,* and *Brachytoma obtusangula.* This fauna is well-known from the Danish Hodde Clay (see Rasmussen 1966 and 1968) and is clearly Middle Miocene. It is also known from the contemporaneous Reinbek Stufe in North Germany. We can thus date these beds immediately below 1237 m with certainty to Middle Miocene.

The boundary between the Middle Miocene claystone and the overlying layers is clearly marked on the Gamma Ray logs from the Dansk Nordsø A-1 and other boreholes in the area. It is also possible that it will be identifiable on the seismograms and thus will become an important correlatable horizon. Above the claystone, a thin layer of glauconitic clay is found which undoubtedly corresponds to the glauconitic clay found above the Hodde Clay on the Danish mainland, where it forms the lower part of the Upper Miocene Gram

Clay (Rasmussen 1966, p. 17). This glauconitic clay must therefore be taken to be Upper Miocene in age. Above the glauconitic zone in the A-1 borehole predominantly dark grey micaceous clay is found. It is possible that silt and even sand may occur in this series. A few molluscs were found in the samples from this series, including several shells of *Astarte trigonata,* which is known from the sandy Upper Miocene strata (Deurnian) in Belgium and Holland, and which is also a well-known index fossil (under the name of *Astarte reimersi*) for the Upper Miocene Gram Clay in Denmark and North Germany. Other mollusc species in these layers from the A-1 can occur in Miocene, Pliocene, and Quaternary deposits. Gram Clay of the composition as known from the Danish mainland has not been demonstrated with certainty in this borehole.

There is no doubt that marine Pliocene beds overlie the Upper Miocene deposits in the A-1 borehole. A specimen of the Pliocene gastropod *Terebra inversa* was found in one of the uppermost samples from the Upper Miocene section (see plate 1, figs. 3–4), and its presence here may be attributed to caving from strata lying higher up. It has not yet been settled where the boundaries between Upper Miocene and Pliocene, and Pliocene and Quaternary lie in this borehole, but the latter boundary is presumed to lie at ca. 480 m.

The overlying Quaternary deposits have not been subdivided in greater detail as yet. The greater part of the ca. 480 m thick series consists of marine strata which are often very shelly. One of the commonly occurring molluscs is the nuculid *Acila cobboldiae* (see plate 1, figs. 5–8), well-known from the Icenian of Holland.

On the basis of his studies on the megaspores of two *Azolla* species (*A. tegeliensis* and *A. filiculoides*) Finn Bertelsen (1972) has subdivided the layers from 379 to 44 m thus:

44– 49 m	Holocene and Weichselian
49–170 m	Elsterian and "Cromerian"
170–271 m	? Menarpian, Waalian, and ? Eburonian
271–379 m	Tiglian and Pretiglian

Occurrence of hydrocarbons

Traces of gas were noted in the mud of the boring in the lowermost part of the clay and shale series above the Danian limestone. Whilst boring was in progress in the latter, an outbreak of gas occurred, and faint oil spots were observed on some of the limestone fragments. By means of a gasdetector the gas was shown to consist predominantly of methane. It also contained some ethane and smaller amounts of propane and butane.

Dansk Nordsø A-2

Position: About 210 km W of Esbjerg
55°24′23″ N–05°03′36.5″ E

Contractor: Zapata Off-Shore Company

Equipment: Drilling platform "Mærsk Explorer" with rig type Oilwell E-3000

Drilling: Commenced 30th July 1967
Completed 15th September 1967 at a depth of 3360 m below sea level (= 11143′ below kelly bushing).

Casing:

42″	to	110 m	(360′)
20″	to	208 m	(683′)
$13^{3}/_{8}$″	to	1062 m	(3483′)
$9^{5}/_{8}$″	to	2024 m	(6641′)

Elevations:

Sea floor:	− 44.2 m	(145′)
Kelly bushing:	+ 36 m	(118′)

Well site geologists from D. G. U.

Arne Dinesen	($^{26}/_{7}$–$^{3}/_{8}$,	0′– 1500′)
Finn Nyhuus Kristoffersen	($^{3}/_{8}$–$^{11}/_{8}$,	1500′– 4710′)
Ole Bruun Christensen	($^{11}/_{8}$–$^{17}/_{8}$,	4710′– 5930′)
Arne Buch	($^{17}/_{8}$–$^{24}/_{8}$,	5930′– 6645′)
F. Lyngsie Jacobsen	($^{24}/_{8}$–$^{31}/_{8}$,	6645′– 7500′)
Arne Dinesen	($^{31}/_{8}$– $^{7}/_{9}$,	7500′– 9735′)
Finn Bertelsen	($^{7}/_{9}$–$^{14}/_{9}$,	9735′–10760′)
Olaf Michelsen	($^{14}/_{9}$–$^{21}/_{9}$,	10760′–11110′)
Peter Hougaard	($^{21}/_{9}$–$^{28}/_{9}$,	11110′–11143′)

Lithological sequence

Drawn up on the basis of descriptions by the site geologists and internal reports by Arne Buch, Finn Bertelsen, and Olaf Michelsen.

0–44 m (*118′–263′*)	Water
44–193 m (*263′*–750′)	Clay and sand. Occurrence of lignite. (Ler og sand. Forekomster af lignit).
193–266 m (750′–990′)	Clay and sand with mollusc shells. Occur-

	rences of lignite in places. (Ler og sand med molluskskaller. Stedvis forekomster af lignit).
266–375 m (990′–1350′)	Clay, light grey, in places with beds of sand. (Ler, lyst gråt, stedvis med sandlag).
375–*476* m (1350′–*1680′*)	Clay and sand, grey, fossiliferous. (Ler og sand, gråt, fossilførende).
476–549 m (*1680′*–1920′)	Sand, more or less coarse-grained. (Sand, mere eller mindre grovkornet).
549–586 m (1920′–2040′)	Clay, grey, in places sandy. (Ler, gråt, stedvis sandet).
586–*1237* m (2040′–*4175′*)	Clay and silt, grey to brownish, often micaceous. Silty and calcareous beds in places. Downwards glauconitic. (Ler og finsand, gråt til brunligt, ofte glimmerholdigt. Stedvis lersten og kalkholdige lag. Nederst glaukonitholdigt).
1237–1476 m (*4175′–4960′*)	Claystone, dark brownish-grey, further down predominantly light grey to greenish-grey. (Lersten, mørk brunliggrå, nedefter overvejende lysegrå-grønliggrå).
1476–1755 m (*4960′–5875′*)	Claystone, dark greenish-grey. (Lersten, mørk grønliggrå).
1755–1759 m (*5875′–5889′*)	Claystone, siltstone and thin beds of volcanic tuff. (Lersten, finsandsten og underordnede lag af vulkansk aske).
1759–1761 m (*5889′–5896′*)	Claystone, olive green (Lersten, olivengrøn).
1761–1766 m (*5896′–5914′*)	Claystone, reddish-brown. (Lersten, rødbrun).
1766–1768 m (*5914′–5918′*)	Claystone, brownish-grey. (Lersten, brunliggrå).
1768–1778 m (*5918′–5950′*)	Claystone, greyish-black. (Lersten, gråsort).
1778–1828 m (*5950′–6115′*)	Limestone with chert. (Kalksten med flint).
1828–2128 m (*6115′–7100′*)	Chalk, white, with chert. (Kridt, hvidt, med flint).
2128–2168 m (*7100′–7230′*)	Limestone, white, and beds of grey or greenish claystone. (Kalksten, hvid og lag af grå eller grønlig lersten).
2168–2175 m (*7230′–7255′*)	Marlstone, brownish-red. (Mergelsten, brunlig rød).
2175–2241 m (*7255′–7470′*)	Claystone, grey, lower down shaly. (Lersten, grå, nedadtil skifret).

2241–2341 m (*7470′*–7800′)	Claystone, dark grey, with beds of siltstone. (Lersten, mørkegrå, med lag af finsandsten).
2341–2433 m (7800′–8100′)	Claystone, grey, calcareous. (Lersten, grå, kalkholdig).
2433–*2831* m (8100′–*9405′*)	Claystone and shale, predominantly grey to dark grey, with horizons of siltstone; further down with beds of brownish claystone. (Lersten og lerskifer, overvejende grå-mørkegrå, med horisonter af finsandsten; nedadtil med lag af brunlig lersten).
2831–2988 m (*9405′*–9920′)	Claystone and shale, grey and brownish, with beds of brownish siltstone. (Lersten og lerskifer, grå og brunlig, med lag af brunlig finsandsten).
2988–*3027* m (9920′–*10050′*)	Siltstone and fine-grained sandstone, light grey, with thin beds of coal. (Finsandsten og finkornet sandsten, lysegrå, med tynde kullag).
3027–3253 m (*10050′*–10792′)	Claystone, greenish-grey and redbrown, with beds of anhydrite, especially lower down. (Lersten, grønliggrå og rødbrun, med lag af anhydrit, især nedadtil).
3253–3360 m (10792′–11143′)	Rock-salt, clear, with anhydrite and beds of red-brown and grey claystone. (Stensalt, klar, med anhydrit og lag af rødbrun og grå lersten).

Chronostratigraphy

The chronostratigraphical subdivision was carried out by Arne Buch, Arne Dinesen, Inger Bang, Erik Stenestad, who have all examined the foraminiferal content of the samples, and Ole Bruun Christensen, who has based his investigations upon ostracods.

The investigations have given the following preliminary subdivision:

44– 430 m Quaternary
430–1828 m Tertiary
1828–2168 m Upper Cretaceous
2168–2175 m Lower Cretaceous
2175–2241 m Lower Cretaceous and Upper Jurassic

2241–2831 m Upper Jurassic
2831–3027 m Upper and Middle Jurassic
3027–3360 m Triassic

Supplementary remarks concerning the stratigraphy

Triassic: From the lowermost part of the section referred to the Triassic two distinct Meso-Triassic miospore assemblages have been recovered (Finn Bertelsen internal report 1974). The oldest assemblage from the interval 3350–3344 m containing such forms as *Striatobietites balmei, Microcachryidites sittleri* and *Lueckisporites triassicus* suggests a Lower – Middle Anisian age. The youngest assemblage which occurs just above the basal rock salt member in the interval 3253–3244 m includes *Porcellispora longdonensis, Aratrisporites* spp. and *Illinites chitonoides* – but not *Ovalipollis* – and is referred to Upper Anisian – Ladinian. Thus the lowermost part of the profile lithologically as palynologically compares with the marginal evaporitic beds of the southern North Sea area which are correlated with the German Middle Muschelkalk (Geiger & Hopping 1968). The uppermost part of the section which proved to be barren is from general appearance and composition of the strata referred to Lower – Middle Keuper.

Jurassic: The age determination of the series from 3027–2175 m has been made by O. Bruun Christensen on the basis of the ostracods.

Lower Cretaceous: The interval referred to Lower Cretaceous in this boring has been age determined from both ostracods (O. Bruun Christensen) and foraminifera (Arne Buch), but a detailed chronostratigraphical subdivision of the interval has not been made as yet.

Upper Cretaceous: Erik Stenestad (personal communication) assumes that all stages from Upper Maastrichtian to Turonian are present in the boring, but since the Upper Cretaceous samples have been greatly affected by caving, no further subdividing of the series has been possible during the preliminary investigation.

Tertiary: Investigations of the foraminiferal content of the Tertiary series have been made by Inger Bang (Danian, *1778–1828* m), Arne Dinesen (Lower Tertiary, *1237–1778* m), and Arne Buch (Upper Tertiary, *430–* 723 m). A synthesis of these investigations permits the following subdivision of the Tertiary deposits in the boring:

430– 476 m Pliocene (Scaldisian)
476– 586 m Pliocene and ? Upper Miocene
586–*1237* m Upper Miocene

1237–1476 m Middle Miocene, possibly Lower Miocene and Upper Oligocene
1476–1628 m (? Upper Oligocene –) Middle Oligocene
1628–*1759* m Eocene
1759–1778 m Paleocene
1778–1828 m Danian

The foraminifera from the Danian section are being studied by Inger Bang.

As regards the section from 1778–1759 m there are apparently only few faunistic indications of the Paleocene age of the deposits, apart from their position in the profile. Amongst the agglutinating foraminifera found to be present are *Spiroplectammina spectabilis* and *Rzehakina sp.*

In the overlying layers 1759–1628 m predominantly agglutinating foraminifera are found in the lowermost part; this is also characteristic of the Eocene strata in the A-1 boring, as mentioned p. 13. Higher in this interval typical Middle Oligocene foraminifera such as *Turrilina alsatica* and *Rotaliatina bulimoides* occur. The uppermost occurence of *Sigmoilina tenuis* is recognized at 1476 m.

Using Schlumberger logs it is possible to set the boundary between Middle Miocene and Upper Miocene, which is well-defined in A-1, at *1237* m. The entire series from *1476–1237* m contains abundant foraminifera, and is particularly characterized by *Asterigerina guerichi* s. 1., which occurs in great numbers, together with planktonic forms (including *Globigerinoides trilobus).*

As in the A-1 borehole, a glauconitic zone appears closely above the depth of 1237 m, and corresponds with the basal layer of the Gram Formation in Jutland. The overlying marine deposits up to 586 m contain foraminifera well-known from the Danish Upper Miocene localities. The dominating species are certain *Florilus* species, *Melonis pompilioides* and *Textularia decrescens.*

In the interval from 586 to *476* m the foraminifera content decreases sharply going upwards, and some samples contained no specimens. The interval appears to go over gradually to non-marine strata.

However, there are numerous foraminifera in the marine layers between *476* and *430* m. Forms such as *Sigmoilina schlumbergeri, Pseudoeponides pseudotepidus,* and *Bulimina aculeata* make a Scaldisian age probable.

Quaternary: The interval from *430* m and upwards has also been examined by Arne Buch on the basis of the foraminiferal content. The uppermost beds from 44 to 193 m only contain a few specimens, probably representing predominantly redeposited marine material, which may be chiefly non-marine. However, the section from *430* to 193 m is marine with numerous foraminifera referring it to the Icenian – for example *Elphidiella hannai,* which do-

minates in the section 375–275 m, and *Elphidium clavatum*. In the section *430*–375 m *Elphidium oregonense* occurs amongst other species; this species is characteristic of the Amstelian in Holland.

Finn Bertelsen (1972) has used the megaspores of *Azolla tegeliensis* and *A. filiculoides* to subdivide the Quaternary section of this boring as follows:

44– 46 m Holocene and Weichselian
46–171 m Elsterian and "Cromerian"
171–269 m ?Menarpian, Waalian and ?Eburonian
269–375 m Tiglian and Pretiglian

This stratigraphical terminology refers to the chronostratigraphy of the Quaternary of Holland.

Occurrence of hydrocarbons

Gas and oil were found in this boring in the Danian limestone. Ten production tests were made in all; the first one failed. The other tests, which were mainly carried out by acid treatment, gave only small quantities of oil, but did yield quantities of natural gas.

Dansk Nordsø B-1

Position: About 280 km W of Esbjerg
55°42′32″ N – 04°02′09″ E

Contractor: Zapata Off-Shore Company

Equipment: Drilling platform "Mærsk Explorer" with rig type Oilwell E-3000

Drilling: Commenced 30th October 1967
Completed 6th January 1968 at a depth of 3617 m below sea level (= 11985′ below kelly bushing)

Casing: 42″ to 99 m (325′)
20″ to 217 m (713′)
13 3/8″ to 1068 m (3504′)
9 5/8″ to 2344 m (7691′)

Elevations: Sea floor: – 41.2 m (135′)
Kelly bushing: + 35.7 m (117′)

Well site geologists from D. G. U.

Olaf Michelsen	($^{2}/_{11}$– $^{9}/_{11}$, 1400′– 3780′)
Finn Bertelsen	($^{9}/_{11}$–$^{16}/_{11}$, 3780′– 6460′)
Peter Hougaard	($^{16}/_{11}$–$^{23}/_{11}$, 6460′– 7720′)
Arne Dinesen	($^{23}/_{11}$–$^{30}/_{11}$, 7720′)
F. Lyngsie Jacobsen	($^{30}/_{11}$–$^{16}/_{12}$, 7740′–10730′)
F. Nyhuus Kristoffersen	($^{16}/_{12}$–$^{20}/_{12}$, 10730′–11080′)
Arne Dinesen	($^{20}/_{12}$– $^{4}/_{1}$, 11080′–11810′)
Finn Bertelsen	($^{4}/_{1}$ – $^{6}/_{1}$, 11815′–11985′)

Lithological sequence

Drawn up on the basis of descriptions by well site geologists and from reports by Finn Bertelsen and Olaf Michelsen, together with A. P. Møller's half-yearly reports to D. G. U.

0–41 m (*117′–252′*)	Water
41–238 m (*252′*–900′)	Sand, often silty, alternating with beds of clay. Predominantly grey in colour. Lignite in places. (Sand, ofte finsandet, vekslende med lag af ler. Farverne overvejende grålige. Stedvis lignit).
238–943 m (900′–3210′)	Clay, sticky, greenish-grey, with beds of silt; lowermost micaceous. (Ler, fedt, grønliggråt, med lag af finsand; nederst glimmerholdigt).
943–1381 m (3210′–4650′)	Clay, further down predominantly claystone, brownish-grey to olive grey; uppermost with silty beds. (Ler, nedadtil overvejende lersten, brunliggråt-olivengråt; øverst med siltholdige lag).
1381–*1442* m (4650′–*4850′*)	Claystone, grey-brown to olive grey; lowermost somewhat silty. (Lersten, gråligbrun-olivengrå; nederst noget finsandet).
1442–1933 m (*4850′*–6460′)	Claystone, grey-brown, further down often olive grey. Occurrences of limestone or marl in a few places. (Lersten, gråbrun, nedefter ofte olivengrå. Visse steder forekomster af kalksten eller mergel).
1933–1982 m (6460′–6620′)	Shale, greenish-grey, with occurrences of limestone. (Lerskifer, grønliggrå, med forekomster af kalksten).
1982–2024 m (6620′–6760′)	Shale, brownish-grey, with occurrences of li-

	mestone. (Lerskifer, brunliggrå, med forekomster af kalksten).
2024–2148 m (6760′–7100′)	Shale, grey or brownish, with limestone. (Lerskifer, grå eller brunlig, med kalksten).
2148–2152 m (7100′–7180′)	Shale, red-brown. (Lerskifer, rødbrun).
2152–2162 m (7180′–7210′)	Shale, red-brown, and grey to greenish-grey claystone. (Lerskifer, rødbrun, og grå til grønliggrå lersten).
2162–*2192* m (7210′–*7300′*)	Claystone, grey, with beds of volcanic tuff. (Lersten, grå, med lag af vulkansk aske).
2192–2210 m (*7300′–7370′*)	Claystone, greyish and brownish. (Lersten, grålig og brunlig).
2210–2274 m (*7370′–7580′*)	Limestone, white, with chert. (Kalksten, hvid, med flint).
2274–2305 m (*7580′–7680′*)	Claystone, red-brown. (Lersten, rødbrun).
2305–2317 m (*7680′–7720′*)	Claystone, dark grey. (Lersten, mørkegrå).
2317–2348 m (*7720′–7820′*)	Limestone and marl, greyish. (Kalksten og mergel, grålig).
2348–2378 m (*7820′–7920′*)	Shale, grey. (Skifer, grå).
2378–2390 m (*7920′–7960′*)	Clay, grey-green. (Ler, grågrønt).
2390–2402 m (*7960′–8000′*)	Clay, red-brown. (Ler, rødbrunt).
2402–2530 m (*8000′–8420′*)	Clay, grey-green; occurrences of limestone and marl. (Ler, grågrønt; forekomster af kalsten og mergel).
2530–2640 m (*8420′–8780′*)	Shale, dark grey. (Skifer, mørkegrå).
2640–2756 m (*8780′–9160′*)	Clay, dark brown. (Ler, sortbrunt).
2756–2988 m (*9160′–9920′*)	Clay, grey (lowermost brownish); with occurrences of dolomite. (Ler, gråt (nederst brunligt); med forekomster af dolomit).
2988–3009 m (*9920′–9990′*)	Alternating beds of brownish shale, silt, sand, and light marl. (Vekslende lag af brunlig skifer, finsand, sand og lys mergel).
3009–3030 m (*9990′–10060′*)	Claystone, red-brown, with some anhydrite and dolomite. (Lersten, rødbrun, med lidt anhydrit og dolomit).
3030–3061 m (*10060′–10160′*)	Claystone, greyish. Scattered occurrences of anhydrite and dolomite. (Lersten, grålig. Spredte forekomster af anhydrit og dolomit).
3061–3078 m (*10160′–10215′*)	Claystone, red-brown, and anhydrite. Lowermost siltstone. (Lersten, rødbrun, og anhydrit. Nederst finsandsten).

3078–3404 m (*10215′–11285′*) Rock-salt, alternating with anhydrite, dolomite, and limestone. (Stensalt, vekslende med anhydrit, dolomit og kalksten).

3404–3573 m (*11285′–11842′*) Claystone, red-brown, in places with red-brown siltstone. (Lersten, rødbrun, stedvis med rødbrun siltsten).

3573–3617 m (*11842′–11985′*) Basalt, brownish, with feldspar phenocrysts up to 5 mm in size, and secondary mineral fillings particularly of calcite. (Basalt, brunlig, med op til 5 mm store feldspatfenokryster og sekundær mineraludfyldninger af især kalkspat).

Chronostratigraphy

Compiled from investigations of the foraminifera made by Arne Buch, Arne Dinesen, Erik Stenestad, Ole Bruun Christensen, and Inger Bang. Correlation investigations carried out by Finn Bertelsen and Olaf Michelsen have also been utilized.

On this basis the following chronostratigraphical subdivision has been made:

41–2210 m Quaternary and Tertiary
2210–2274 m Upper Cretaceous
2274–2530 m Lower Cretaceous
2530–3009 m Jurassic
3009–3078 m Triassic
3078–3404 m Upper Permian (Zechstein)
3404–3617 m Lower Permian (Rotliegendes)

Supplementary remarks concerning the stratigraphy

Lower Permian: A description by F. Lyngsie Jacobsen (internal report) and a radiometric dating (K/Ar) by Ole Larsen (1972) of the basalt in the lowest part of the boring indicate an age of 212 ± 14 million years (sample No. 4256, marked Nordsøen "2" in Larsen 1972). Both the dating and the situation of the basalt in the section indicate a Rotliegendes age. The red-brown claystone from 3573–*3404* m, above the basalt, probably belongs to the same geological period.

Upper Permian: The evaporite series from *3404–3078* m is of a character indicating that it belongs to the Zechstein.

Triassic: The only 69 m thick series above the Zechstein evaporites has pre-

cisely those lithological qualities which characterize the Triassic deposits of North Europe. Although no fossils have as yet been found from this section, it must be regarded as most probably having been deposited during the Triassic.

Jurassic: An examination has been made by Ole Bruun Christensen of the ostracods of the Jurassic series. This examination has demonstrated the presence of both Portlandian and Kimmeridgian, and possibly also of Middle Jurassic.

Lower Cretaceous: This section has not yet been subdivided in greater detail.

Upper Cretaceous: The strata from the Upper Cretaceous are greatly reduced in this boring in relation to the normal situation on the Danish mainland. In an internal report (1968) E. Stenestad subdivided the section as follows:

2210–2229 m Maastrichtian
2229–2253 m Campanian
2253–2274 m Santonian

It is as yet unclear whether strata from Turonian and Cenomanian are present in the boring.

Tertiary: The Tertiary series has been investigated on the basis of its foraminifera by Inger Bang, Arne Dinesen, Arne Buch, and Finn Nyhuus Kristoffersen. The possibilities for making correlations with the A-1 and A-2 borings are rather poor, but from the preliminary investigations the following stages are assumed to be present, although the boundaries have not yet been finalized:

ca. 751–ca. 796 m Pliocene
ca. 796–ca. 824 m Pliocene and Upper Miocene
ca. 824–ca. 1443 m Upper Miocene
ca. 1443–ca. 1510 m Middle Miocene, possibly Lower Miocene, and Upper Oligocene
ca. 1510–ca. 1619 m (? Upper Oligocene) – Middle Oligocene
ca. 1619–ca. 2192 m Eocene
ca. 2192–ca. 2210 m Paleocene

It remains an open question as to whether strata from the Danian are completely absent in this boring. Inger Bang (internal report) has found a number of Globigerinae of Danian age in the sample from around 2210 m, together with the otherwise predominating Upper Senonian foraminifera. This might suggest that a thin bed of Danian lies above the Cretaceous, or that such a layer has been broken down together with the uppermost Upper Cretaceous layers in the vicinity of the site.

Quaternary: More detailed subdivision of this section has not as yet been carried out, but according to preliminary investigations by Arne Buch (internal report) there are also thick beds of marine Lower Pleistocene (Icenian) age in this boring.

Preliminary studies made by Finn Bertelsen (internal report 1974) suggest that it will be possible to subdivide the Quaternary series in the same way as has been done for A-1 and A-2, since both *Azolla filiculoides* and *A. tegelienses* have been found in the samples. These have not yet been investigated systematically, however.

Occurrence of hydrocarbons

No gas or oil was found in this boring.

Dansk Nordsø C-1

Position: About 30 km W of Thyborøn
56°36′41.5″ N – 07°40′00″ E

Contractor: Zapata Off-Shore Company

Equipment: Drilling platform "Mærsk Explorer" with rig type Oilwell E-3000

Drilling: Commenced 19th January 1968
Completed 27th February 1968 at a depth of 3169 m below sea level (= 10519′ below kelly bushing)

Casing: 42″ to 89 m (291′)
20″ to 216 m (710′)
13 3/8″ to 1068 m (3504′)

Elevations: Sea floor: – 27.4 m (90′)
Kelly bushing: + 37.2 m (122′)

Well site geologists from D. G. U.

Peter Hougaard	(25/1– 1/2, 3100′–3770′)
Olaf Michelsen	(1/2– 8/2, 3770′–6720′)
F. Lyngsie Jacobsen	(8/2–15/2, 6720′–9300′)
Peter Hougaard	(15/2–22/2, 9300′–10140′)
O. Bruun Christensen	(22/2–29/2, 10140′–10519′)
Finn Bertelsen	(29/2– 3/3, Borehole investigations)

Lithological sequence

The summarized bore section shown has been drawn up on the basis of the reports and descriptions by the well site geologists, together with the half-yearly report from A. P. Møller.

0–27 m (*122′–212′*)	Water
27–85 m (*212′*–400′)	Sand and gravel. (Sand og grus).
85–109 m (400′–480′)	Clay, olive grey. (Ler, olivengråt).
109–*167* m (480′–*670′*)	Sand, coarse, further down more fine-grained and with brown clay. (Sand, groft, nedadtil mere finkornet og med brunt ler).
167–350 m (*670′*–1270′)	Clay, dark brown, micaceous, in places with concretions and occurrences of lignite. (Ler, mørkebrunt, glimmerholdigt, stedvis med konkretioner og forekomster af brunkul).
350–393 m (1270′–1410′)	Clay, light brown to grey, glauconitic, with occurrences of sandstone. (Ler, lysebrunt til gråt, glaukonitholdigt, med forekomster af sandsten).
393–*420* m (1410′–*1500′*)	Clay, grey-brown, glauconitic. (Ler, grå-brunt, glaukonitholdigt).
420–481 m (*1500′*–1700′)	Clay, grey-green or light green. (Ler, grå-grønt eller lysegrønt).
481–*505* m (1700′–*1800′*)	Clay, greenish, with beds of grey shale and brownish clay. Possibly with beds of volcanic tuff in the lowermost part. (Ler, grønligt, med lag af grå skifer og brunligt ler. Muligvis nederst med lag af vulkansk aske).
505–533 m (*1800′*–1870′)	Shale, grey. (Lerskifer, grå).
533–*575* m (1870′–*2010′*)	Marl, light grey, lowermost going over to grey shale. (Mergel, lysegrå, nederst gående over i grå lerskifer).
575–644 m (*2010′–2235′*)	Limestone, light grey-white, in places silicified and with chert. (Kalksten, lysegrå-hvid, stedvis forkislet og med flint).
644–923 m (*2235′*–3150′)	Chalk, white, with chert. (Kridt, hvid, med flint).
923–1079 m (3150′–3660′)	Limestone, white, with pyrite and some chert, in places with beds of grey-greenish clay. (Kalksten, hvid, med pyrit, og lidt flint, stedvis med lag af grå-grønligt ler).

1079–*1130* m (3660′–*3828′*)	Limestone, white, with thin beds of greyish-green shaly clay. (Kalksten, hvid, med tynde lag af gråliggrønt skifret ler).
1130–1136 m (*3828′*–3850′)	Claystone, coloured in various shades of grey. (Lersten, grå i nuancer).
1136–1170 m (3850′–3960′)	Claystone, grey or red-brown, in places with beds of siltstone. (Lersten, grå eller rødbrun, stedvis med lag af finsandsten).
1170–1205 m (3960′–4075′)	Claystone, grey. (Lersten, grå).
1205–1364 m (4075′–4595′)	Claystone, grey, brownish in part, with beds of grey or brownish siltstone and in places thin beds of limestone. (Lersten, grå, stedvis brunlig, med lag af grå eller brunlig siltsten og stedvis tynde kalkstenslag).
1364–1374 m (4595′–4630′)	Siltstone, dark grey-brown, and grey claystone. (Siltsten, mørk gråbrun og grå lersten).
1374–1414 m (4630′–4760′)	Siltstone, grey-brown, with thin beds of red-brown claystone. (Siltsten, gråbrun, med underordnede lag af rødbrune lersten).
1414–1816 m (4760′–6080′)	Claystone, alternating with siltstone in varying reddish, brownish and greenish colours. Occurrences of anhydrite and a few beds of limestone. (Lersten, vekslende med siltsten varierende i rødlige, brunlige og grønlige farver. Forekomster af anhydrit og enkelte lag kalksten).
1816–1969 m (6080′–6580′)	Claystone, brownish or reddish, in places grey or greenish, with beds of red-brown sandstone and occurrences of anhydrite. (Lersten, brunlig eller rødlig, stedvis grå eller grønlig, med lag af rødbrun sandsten og forekomster af anhydrit).
1969–*2533* m (6580′–*8432′*)	Siltstone or sandstone, reddish, with patches of red-brown claystone. (Finsandsten eller sandsten, rødlig, med partier af rødbrun lersten).
2533–2548 m (*8432′–8480′*)	Claystone, brownish, with occurrences of anhydrite. (Lersten, brunlig, med forekomster af anhydrit).

2548–2996 m (*8480'*–9950')	Rock-salt, clear, in places with anhydrite. (Stensalt, klart, stedvis med anhydrit).
2996–3057 m (9950'–10150')	Anhydrite, white. (Anhydrit, hvidt).
3057–3064 m (10150'–10175')	Anhydrite with beds of rock-salt. (Anhydrit med stensaltlag).
3064–3096 m (10175'–10280')	Rock-salt and anhydrite. (Stensalt og anhydrit).
3096–3127 m (10280'–10380')	Anhydrite, white. (Anhydrit, hvid).
3127–3133 m (10380'–10400')	Shale, grey. (Lerskifer, grå).
3133–*3159* m (10400'–*10485'*)	Limestone, dolomitic, grey, often bedded. (Kalksten, dolomitisk, grå, ofte lagdelt).
3159–3169 m (*10485'*–10519')	Trachyte, reddish-grey, with phenocrysts of alkali feldspar. (Trachyt, rødlig-grå, med fenokryster af alkalifeldspat).

Chronostratigraphy

On the basis of internal communications from Arne Dinesen, Inger Bang, Erik Stenestad, Arne Buch, and Ole Bruun Christensen, and from comparisons with the lithological descriptions, it is possible to construct the following preliminary chronostratigraphy of the boring:

27– *167* m	Quaternary
167– *644* m	Tertiary
644–*1130* m	Upper Cretaceous
1130–*1286* m	Lower Cretaceous
1286–*1401* m	Upper Jurassic
1401–*2533* m	Triassic
2533–*3159* m	Upper Permian (Zechstein)
3159–*3169* m	Pre-Zechstein

Supplementary remarks concerning the stratigraphy

Pre-Zechstein: The trachyte at the bottom of the boring has been determined and described by F. Lyngsie Jacobsen (internal report) and dated radiometrically (K/Ar) by Ole Larsen (1972, sample No. 4214, named Nordsøen "1") to 281 ± 8 mill. years. This dating most probably suggests a Lower Permian (Rotliegendes), age, but the great age could also indicate Carboniferous or an even older Palaeozoic period.

Upper Permian and Triassic: The strata from 3159–1401 m have been dated on the basis of their great similarity with other Zechstein and Triassic sections in the North Sea basin.

Jurassic: O. Bruun Christensen (internal report 1968) has dated the series 1401–1286 m to the Upper Jurassic from the ostracod content. Beds from the Portlandian, Kimmeridgian and Oxfordian seem to be present. The folowing can be named from the species found: *Mandelstamia rectilinea, Galliaecytheridea dissimilis, G. wolburgi, G. gracilis,* and *Macrodentina pulchra.*
Lower Cretaceous: The interval from 1286 to 1130 m has been investigated by O. Bruun Christensen (ostracods) and Arne Buch (foraminifera). All stages appear to be present, including the Berriasian, from which several characteristic ostracods are known (Bruun Christensen 1968): *Mandelstamia sexti, Orthonotacythere speetonensis, Paracypris caerulea, Cytherelloidea anomala,* and others. Of younger Lower Cretaceous ostracods may be named: *Cythereis senckenbergi, Protocythere hannoverana, Acrocythere hauteriviana, Cythereis acuticostata, Schuleridea hammi,* and others. More detailed subdivision of this section has not yet been completed.
Upper Cretaceous: A preliminary investigation of the Upper Cretaceous layers from 1130–644 m has been carried out by E. Stenestad on the basis of the foraminifera, and seems to indicate that all the stages are present in the boring. Subdivision of the section has not yet been carried out.
Tertiary: The Tertiary strata of the boring have been investigated chiefly by Inger Bang and Arne Dinesen, using the foraminifera. A preliminary survey of the chronostratigraphy of this section is as follows:

167–420 m ? Miocene and Upper Oligocene
420–481 m Middle Oligocene
481–505 m Eocene
505–550 m Paleocene
550–644 m Danian

The limestone from 644 to 550 m contains a pelagic foraminiferal fauna, which according to Inger Bang (internal communication) is of Danian age, whilst the samples from 550–521 m contain Paleocene foraminifera.

In a sample taken at 511 numerous pyritirized diatoms and some fish remains have been found, and since the tendency of the Schlumberger curves suggests the presence of beds containing volcanic tuff immediately above a depth of 505 m, the boundary between Paleocene and Eocene has been placed at 505 m. Planktonic foraminifera typical of the Røsnæs Clay (e. g. *Globigerina patagonica*) have been found in the samples immediately above this depth. The clay beds extending up to about 481 m seem to correspond to the Lillebælt Clay as it is known from the Danish mainland.

The beds above ca. 481 m contain *Turrilina alsatica* and must be taken to be Middle Oligocene. The boundary Upper/Middle Oligocene is assumed

to lie at about 420 m, since a sample from this depth contains a maximum of *Asterigerina guerichi* and the topmost occurrence of *Rotalia bulimoides*.

Miocene beds may possibly occur close under the Quaternary series. However, no faunistic evidence for this assumption has been found.

Occurrence of hydrocarbons

No gas or oil was found in the boring.

Dansk Nordsø D-1

Position: About 160 km W of Thyborøn
56°25′29.7″ N – 05°31′52.2″ E

Contractor: Zapata Off-Shore Company

Equipment: Drilling platform "Mærsk Explorer" with rig type Oilwell E-3000

Drilling: Commenced 27th March 1968
Completed 21st May 1968 at a depth of 3526 m below sea level (= 11689′ below kelly bushing)

Casing: 42″ to 112 m (366′)
20″ to 223 m (732′)
$13^{3}/_{8}$″ to 1008 m (3308′)

Elevations: Sea floor: – 48.8 m (160′)
Kelly bushing: + 37.2 m (122′)

Well site geologists from D. G. U.

Finn Bertelsen	($^{26}/_{3}$– $^{3}/_{4}$, 0′–3150′)
Arne Dinesen	($^{4}/_{4}$–$^{10}/_{4}$, 3150′–3557′)
Peter Hougaard	($^{11}/_{4}$–$^{18}/_{4}$, 3557′–5690′)
Thomas Eriksen	($^{18}/_{4}$–$^{24}/_{4}$, 5690′–6270′)
Olaf Michelsen	($^{25}/_{4}$– $^{2}/_{5}$, 6270′–9340′)

For the remainder of the drilling no geologists from D. G. U. were present.

Lithological sequence

Descriptions of the samples were made by the geologists at the site, with the exception of the interval from 8790′ to 11367′, which was examined in Co-

penhagen by Peter Hougaard. The correlations with other borings by means of Schlumberger logs has been carried out by Olaf Michelsen, who has also produced a comprehensive lithological summary. The lithological section below has been constructed mainly on the basis of D. G. U.'s investigations.

0–49 m (*122′–282′*)	Water
49–356 m (*282′–1320′*)	Clay, grey, quite sticky, alternating at intervals with sand and in places gravel. (Ler, gråt, ret fedt, vekslende i intervaller med sand og stedvis grus).
365–568 m (*1320′–1985′*)	Clay, grey, quite sticky, micaceous, slightly pyritic. (Ler, gråt, ret fedt, glimmerholdigt, svagt pyritholdigt).
568–748 m (*1985′*–2575′)	Clay, dark brownish, sticky, slightly calcareous, in places micaceous and with glauconite. (Ler, mørkt, brunligt, fedt, svagt kalkholdigt, stedvis glimmerholdigt og med glaukonit).
748–751 m (2575′–2585′)	Limestone, light grey-yellow. (Kalksten, lys grågul).
751–957 m (2585′–3260′)	Clay, dark grey-brown, sticky, micaceous, in places glauconitic. (Ler, mørk gråbrunt, fedt, glimmerholdigt, stedvis glaukonitisk).
957–1039 m (3260′–3530′)	Sand, fine to medium-grained, with beds of glauconitic silt in places and brown clay. (Sand, fint-mellemkornet, med lag af stedvis glaukonitisk finsand og brunt ler).
1039–1167 m (3530′–3950′)	Shale, grey to greenish-grey, calcareous down to ca. 3680′, non-calcareous thereafter. (Lerskifer, grå til grønliggrå, kalkholdig til ca. 3680′, derefter kalkfri).
1167–1182 m (3950′–4000′)	Shale, brownish-grey, micaceous, non-calcareous. (Lerskifer, brunliggrå, glimmerholdig, kalkfri).
1182–*1206* m (4000′–*4079′*)	Shale, grey, with beds of volcanic tuff. (Lerskifer, grå, med lag af vulkansk aske).
1206–1261 m (*4079′*–4260′)	Chalk, white, with beds of white or yellowish limestone and chert. (Kridt, hvidt, med lag af hvid eller gullig kalksten og flint).
1261–1389 m (4260′–4680′)	Chalk and limestone, in places silicified, with chert. (Kridt og kalk, stedvis forkislet, med flint).

1389–1429 m (4680′–4810′)	Chalk, white, hard, in places silicified; slight content of silt. 1391–1407 m (4684′–4737′) with content of black, non-calcareous shale as stylolites in mm-thin beds at intervals of 5–15 cm. 1423–1426 m (4790′–4800′) with some greenish non-calcareous shale. (Kalk, hvid, hård, stedvis forkislet; svagt indhold af silt. 1391–1407 m (4684′–4737′) med indhold af sort, kalkfri skifer som styloliter i mm tynde lag med 5–15 cm's mellemrum. 1423–1426 m (4790′–4800′) med lidt grønlig, kalkfri skifer).
1429–*1463* m (4810′–*4920′*)	Chalk, whitish, soft, with some light grey to greenish-grey micaceous shale and some brownish chert. (Kalk, hvidlig, blød, med lidt lysegrå-grønliggrå, glimmerholdig skifer og lidt brunlig flint).
1463–1472 m (*4920′*–4950′)	Marl, light grey, greenish-grey and brown-orange. (Mergel, lysegrå, grønliggrå og brun-orange).
1472–*1511* m (4950′–*5060′*)	Shale, micaceous, often calcareous; uppermost yellow-brown, further down brown-grey and lowermost greenish-grey; some light marl. (Lerskifer, glimmerholdig, ofte kalkholdig; øverst gulbrun, nedefter brungrå og nederst grønliggrå; lidt lys mergel).
1511–1546 m (*5060′–5195′*)	Clay, grey-black, with light streaks, at times calcareous. (Ler, sortgråt, med lyse slirer, undertiden kalkholdigt).
1546–1554 m (*5195′*–5220′)	Claystone, predominantly light grey; further down red-brown, pyritic and calcareous. (Lersten, overvejende lysegrå, nedefter rødbrun, pyrit- og kalkholdig).
1554–1560 m (5220′–5240′)	Claystone, predominantly red-brown. (Lersten, overvejende rødbrun).
1560–1566 m (5240′–5260′)	Silt. (Finsand).
1566–*1688* m (5260′–*5660′*)	Claystone, silty, red-brown, at times calcareous, with lighter and more silty patches. (Lersten, siltholdig, rødbrun, undertiden kalkholdig, med lysere og mere siltede partier).

1688–1694 m (*5660′*–5680′)	Claystone, reddish-brown, with some anhydrite. (Lersten, rødligbrun, med lidt anhydrit).
1694–1703 m (5680′–5709′)	Anhydrite. (Anhydrit).
1703–3282 m (5709′–10890′)	Rock-salt, chiefly white to transparent, with anhydrite, and between 1750 and 1800 m with beds and occurrences of potassium minerals. (Stensalt, hovedsagelig hvidt til gennemsigtigt, med anhydrit, og mellem 1750 og 1800 m's dybde med lag og forekomster af kalisalte).
3282–*3319* m (10890′–*11012′*)	Dolomite, brownish to grey. (Dolomit, brunlig til grå).
3319–3468 m (*11012′*–11530′)	Siltstone, coarse-grained, red-brown, bedded, non-calcareous, in places somewhat clayey. (Finsandsten, grovkornet, rødbrun, lagdelt, kalkfri, stedvis noget leret).
3468–3508 m (11530′–11630′)	Claystone, red-brown to chocolate brown, with reddish sandstone. (Lersten, rødbrun til chokoladebrun, med rødlig sandsten).
3508–3526 m (11630′–11689′)	Eruptive. (Vulkanit).

Chronostratigraphy

The preliminary chronostratigraphical subdivision of the layers penetrated by the boring is based on investigations of the foraminifera, made by Arne Buch, Arne Dinesen, F. Nyhuus Kristoffersen and Inger Bang for the Tertiary section. Erik Stenestad has studied the foraminifera of the Upper Cretaceous section and O. Bruun Christensen has examined the ostracods in the samples from the Lower Cretaceous and Upper Jurassic. Age determinations of the Triassic and Permian series are based upon the lithological similarity of these with other known sections.

The boundaries between the individual chronostratigraphical units in the summary below have been established taking both the biostratigraphical and lithological data into consideration. The depth measurements arrived at by D. U. C. on the basis of the Schlumberger logs have also been taken into account. However, the stated depths must on the whole be treated with caution, since there are many detailed investigations still to be made before the depths can be regarded as final.

49– 365 m Quaternary
365–1206 m Tertiary
1206–1463 m Upper Cretaceous
1463–1511 m Lower Cretaceous
1511–1546 m Upper Jurassic
1546–1688 m Triassic
1688–3319 m Upper Permian (Zechstein)
3319–3526 m Lower Permian (Rotliegendes)

Supplementary remarks concerning the stratigraphy

Lower Permian: The eruptive at the bottom of the borehole has been dated radiometrically (K/Ar) by Ole Larsen (1972) to 237 ± 16 mill. years, and thus appears to be of Lower Permian age (Rotliegendes, sample No. 4258, named Nordsøen "3" by Ole Larsen 1972, p. 92).

Upper Permian and *Triassic:* This series, which includes an evaporite series from 3319–1688 m and a multicoloured anhydrite-containing claystone and siltstone series from 1688 to 1546 m, corresponds with well-known strata of similar appearence from Zechstein and Triassic, respectively, and has therefore been referred to these periods.

Upper Jurassic: In the interval from 1546 to 1511 m O. Bruun Christensen (internal report) has observed ostracods which refer these beds, at any rate partially, to the Portlandian.

Lower Cretaceous: Both Arne Buch (by means of foraminifera) and O. Bruun Christensen (on the basis of the ostracods) have established (internal reports) that the section from 1511 to 1463 m includes layers of Lower Cretaceous age. Amongst the ostracods present are the species *Schuleridea praethoerenensis, Mandocythere frankei, Apatocythere spinosa,* and *Acrocythere hauteriviana.* Deposits of Hauterivian and Valanginian age, and perhaps also Barremian, appear to be present at any rate. It is more doubtful whether layers of Albian age are represented.

Upper Cretaceous: The Upper Cretaceous section, from 1463 to 1205 m, has been investigated by E. Stenestad (internal report), who has subdivided the series chronostratigraphically as follows:

1205–1435 m Lower Maastrichtian
1435–1456 m Campanian
1456–1463 m Santonian

The beds consist of hard, locally silicified limestone, and thus it was necessary to determine some of the foraminifera from thin sections. The uppermost occurrence in the samples of a number of forms was decisive for the chronostratigraphical subdivision. The following species in particular were used: *Heterohelix striata, H. dentata, H.* cf. *complanata, Gyroidinoides* cf. *octocamerata, G.* cf. *pontoni, Stensioeina pommerana, Eouvigerina ?cretae, ?Rugoglobigerina rugosa, Neoflabellina* sp. and *?Heterolepa* sp.

Tertiary: No beds of Danian age seem to occur in the borehole.

Traces of volcanic tuff have been found in a ditch sample from 1197 m (4050′), and since the Schlumberger correlations suggest that the base of the tuff-containing series lies at 1200 m (4060′), the presence of a thin bed of Paleocene shale may be assumed in the interval 1206–1200 m.

The preliminary investigations of the foraminiferal content, made by Arne Dinesen and Finn Nyhuus Kristoffersen suggest the following subdivision:

	365– 568 m	(?Pliocene-) Upper Miocene
	568–ca. 795 m	Middle Miocene – Upper Oligocene
ca.	795–ca. 886 m	Upper Oligocene
ca.	886–ca. 1033 m	Upper Oligocene – Middle Oligocene
ca.	1033–ca. 1051 m	Middle Oligocene
ca.	1051– 1200 m	Eocene

The preliminary boundaries for these sections have been set up on the basis of 1) *Pararotalia* sp. 1 (top at ca. 795 m), 2) a horizon characterized by *Bolivina* sp. (at ca. 886 m), 3) *Turrilina alsatica* (top at ca. 1033 m), and 4) stronger representation of agglutinating foraminifera (at ca. 1051 m).

From the Middle Miocene section some molluscs, which are typical for the Hodde Clay, have been recognized. Four of these specimens, from the sample from 649–658 m (2250′–2280′) are pictured on plate 2, figs. 2–5. The species concerned are *Limopsis lamellata, Dentalium* aff. *dolfussi, Hinia fuchsi,* and *Fusiturris flexiplicata.*

The remaining Miocene and the Quaternary sections have not yet been subdivided in detail, but the boundary between Middle Miocene (Hodde Formation) and Upper Miocene appears on the Schlumberger Resistivity Curve at 568 m (1985′).

Occurrence of hydrocarbons

No gas or oil was found in the boring.

Outline of the geological results

The structural regions in the Danish shelf area will be well-known from the map published by Heybroek *et al.* (1967), and reproduced in partially re-edited form by Sorgenfrei (1969), whose fig. 7 (map 4) is reproduced in reduced size as fig. 3 in this paper. The most important structure is the Ringkøbing–Fyn High, which extends out from Jutland towards the central part of the North Sea, separating the Norwegian–Danish Basin and the Danish Embayment to the north from the German Basin to the south, whilst the East Dogger Bank Graben immediately west of the High runs in NNW–SSE direction, forming a marked depression area. This area is especially characterized by its markedly thick Caenozoic sequence.

All of the five boreholes discussed here are situated away from the High. The boreholes A-1, A-2, and B-1 are located on or near to salt structures in the East Dogger Bank Graben, whilst C-1 and D-1 are sited in structures quite close and to the north of the High, on the southern flank of the Norwegian-Danish Basin and the Danish Embayment (se maps, figs. 3 and 4).

Five borings are, of course, an insufficient basis for wide-ranging conclusions about the regional geology, but certain features do show up in the sequences, however.

The oldest beds reached in the boreholes B-1, C-1, and D-1, may all be of Lower Permian age. However, the trachyte in borehole C-1 may quite possibly be older (Carboniferous or older), but Lower Permian eruptives are well-known from the eastern and southern margins of the North Sea: the rhomb porphyry series of the Oslo District in South Norway, the eruptives in the Rødby borehole on Lolland (Denmark), the thick eruptive series in a great number of boreholes in N. E. Germany (DDR) and corresponding eruptives in several boreholes in N. W. Germany and Holland.

Lower Permian sandstone as it occurs in the southern part of the North Sea on the British and Dutch continental shelf, where it often contains gas, has not been found in the boreholes described here. However, it is possible that the red-brown claystone immediately above the igneous rock in B-1 and C-1 was deposited in Lower Permian (Rotliegendes). The coarse-grained siltstone from 3319–3468 m in D-1 may be an appendage to the Rotliegend sandstone formation, but it lies on the southern flank of the Norwegian-

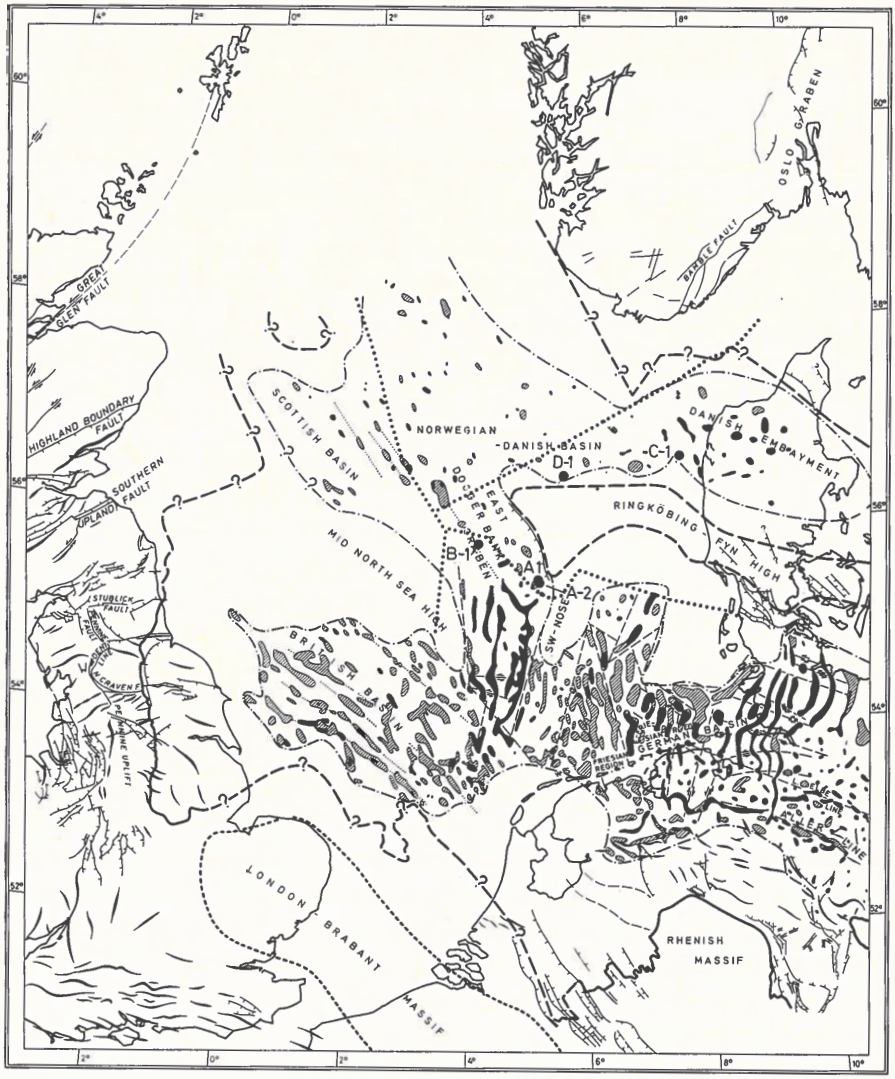
NORTH SEA AREA.
THE ZECHSTEIN BASIN AND THE MAIN POST-CALEDONIAN STRUCTURAL FEATURES
Boundary of the present extension of the Zechstein
Boundary of halokinesis
Potential boundary of London-Brabant Massif
Salt pillows (salt anticlines and interdomal features)
Salt piercements (salt walls and piercement domes)
Well
Anticlines
Fault
Undefined faults
Boundary of national shelf areas
Wrench (tear) fault
Potential wrench fault
Structural trend
Compiled by THEODOR SORGENFREI 1969
0 50 100 150 200 Km
GREAT GLEN FAULT
HIGHLAND BOUNDARY FAULT
SOUTHERN UPLAND FAULT
STUBLICK FAULT
CRAVEN F.
PENNINE UPLIFT
SCOTTISH BASIN
NORWEGIAN - DANISH BASIN
MID NORTH SEA HIGH
SOUTH EAST BASIN
SW-HOSE
OSLO GRABEN
PARRETT FAULT
DANISH EMBAYMENT
RINGKÖBING - FYN HIGH
D-1
C-1
B-1
A-1
A-2
BRITISH BASIN
LONDON BRABANT MASSIF
RHENISH MASSIF

Fig. 3

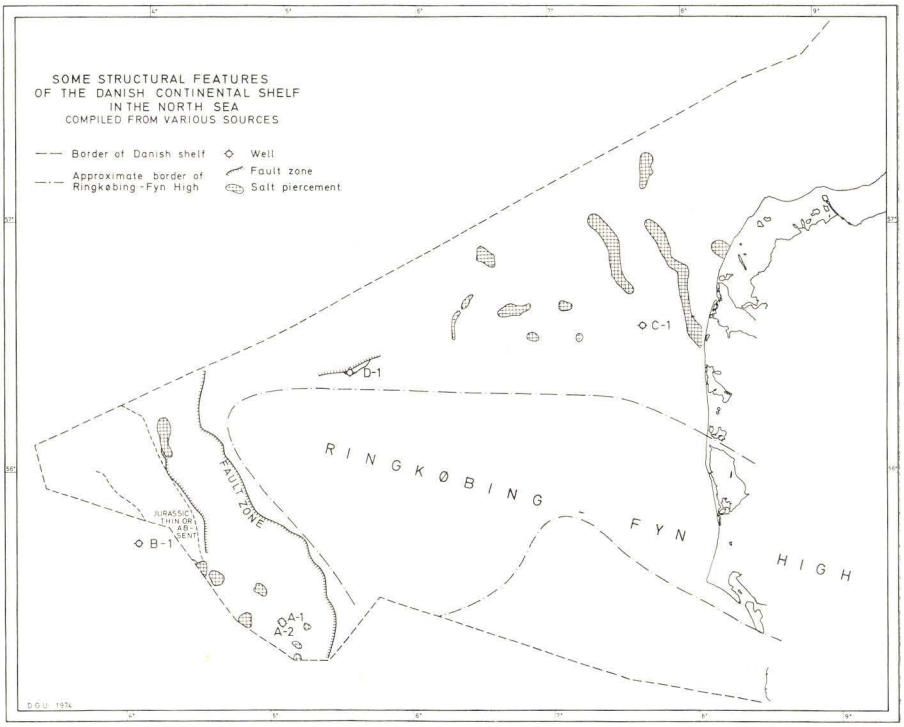

Fig. 4

Danish Basin, from which no finds of the red-brown Rotliegend sandstone have been reported as yet. It must be emphasized, however, that there is no question of any exact datings for the occurrences in the Danish boreholes, but only of an estimate on the basis of the position of the strata.

Upper Permian evaporite series have been found in the boreholes B-1, C-1, and D-1, all of which penetrated below the Triassic. All the boreholes lie inside the North European Zechstein basin and also in the area which has been affected by halokinesis, where numerous salt piercements, salt pillows, and other salt structures have been demonstrated.

Deposits from the Jurassic and Lower Cretaceous occur in all the borings except for A-1, which stopped in beds of Danian age. A closer study of the deposits from these periods is in progress. For the moment it seems striking that Lower Jurassic (Lias) deposits are absent in the five boreholes, and that deposits from the Upper Jurassic occur. The white Upper Cretaceous limestone and (in the uppermost part of the series) chalk beds have also been found in the boreholes, which may prove after further investigations to contain all stages of the Upper Cretaceous.

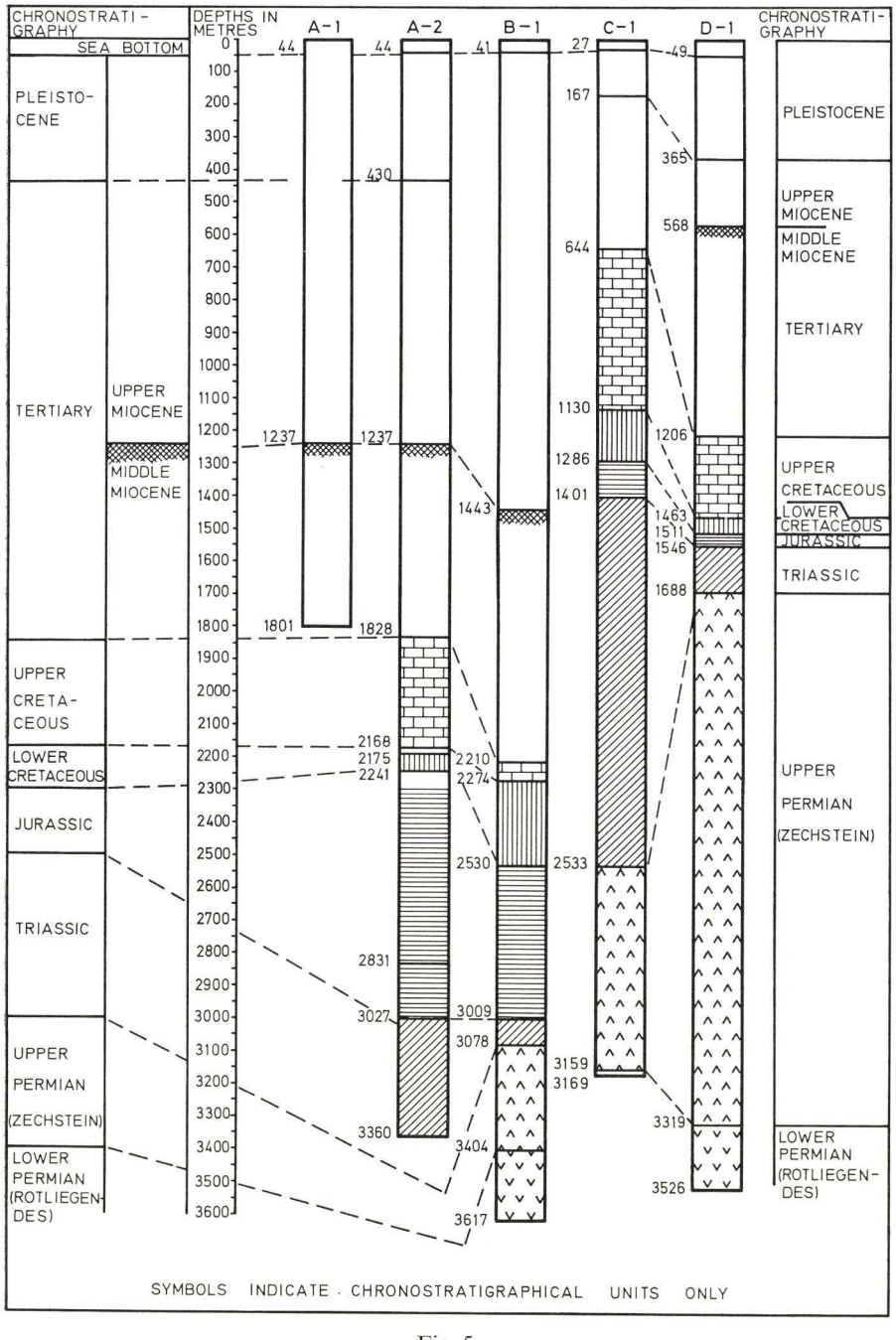
CHRONOSTRATI-GRAPHY
DEPTHS IN METRES
A-1
A-2
B-1
C-1
D-1
CHRONOSTRATI-GRAPHY
SEA BOTTOM
PLEISTO-CENE
TERTIARY
UPPER MIOCENE
MIDDLE MIOCENE
UPPER CRETA-CEOUS
LOWER CRETACEOUS
JURASSIC
TRIASSIC
UPPER PERMIAN (ZECHSTEIN)
LOWER PERMIAN (ROTLIEGEN-DES)
PLEISTOCENE
UPPER MIOCENE
MIDDLE MIOCENE
TERTIARY
UPPER CRETACEOUS
LOWER CRETACEOUS
JURASSIC
TRIASSIC
UPPER PERMIAN (ZECHSTEIN)
LOWER PERMIAN (ROTLIEGEN-DES)
SYMBOLS INDICATE CHRONOSTRATIGRAPHICAL UNITS ONLY

Fig. 5

Particular interest attaches to the Tertiary series, which in the central part of the North Sea reaches a thickness unusual for Northern Europe. According to Heybroek *et al.* (1967, map fig. 5; cf. Sorgenfrei 1969, fig. 8, p. 184) the base of the Tertiary occurs maximally at depths below 3500 m. In the Danish part of the continental shelf it may be expected to extend down to depths below 3000 m.

In the five boreholes discussed here, however, the base of the Tertiary has not been found deeper than 2210 m below sea level (in B-1). The thickness of the Tertiary sequence in B-1 is over 1600 m and in A-1 and A-2 around 1400 m. These three boreholes lie furthest to the west and could thus be expected beforehand to have appreciably thicker Tertiary series than the two other boreholes. Of the latter, the Tertiary series in C-1 with a thickness of 477 m expresses the "normal" Danish bed thickness, whilst the series in D-1, 841 m thick, shows a tendency towards increasing thickness which corresponds accurately with the position of this borehole.

It is evident from the preliminary stratigraphical investigations that the older Tertiary series (comprising Danian, the rest of the Paleocene, Eocene, and older Oligocene) has a considerably smaller thickness than the younger Tertiary series (comprising younger Oligocene, Miocene and Pliocene). The thickness of these layers in A-1 is approximately 340 and 1000 m respectively, although the Danian was not penetrated. The corresponding figures for A-2 are 352 and about 1040 m. Unfortunately the older Tertiary series in B-1 has not yet been separated bio- and chronostratigraphically from the younger Tertiary, but the thickness of the younger Tertiary in this boring probably is even higher than in A-1 and A-2.

From the preliminary stratigraphical investigations of A-1, A-2, and B-1, the time interval in which the majority of the sedimentation occurred can be defined even more closely since the deposits from the Pliocene and Upper Miocene fill 759 m in A-1, 807 m in A-2, and more than 800 m in B-1, whilst the corresponding figures for the thickness of the Middle Miocene – Upper Oligocene interval in A-1 and A-2 are only 226 m and 239 m. Since the thickness of the Pliocene beds scarcely exceeds 125 m in any of the borings, the Upper Miocene beds must thus comprise more than 600 m of the total Tertiary series. This suggests that the rate of subsidence of the central part of the North Sea was greatest during the Upper Miocene.

The Quaternary series in the most westerly boreholes amounts to more than 500 m in B-1, more than 400 m in A-1, and 386 m in A-2. A considerable proportion of this series is marine and was sedimented during the older Quaternary, or more precisely, the Icenian.

The geological features mentioned here are only a few of the results which can be obtained from these boreholes. The analyses of the micro-

faunas which are now in progress can be expected both to revise and to extend these observations, whilst more certain regional conclusions must of course be based upon many more bore sequences than the five described here.

Acknowledgements. The author of this paper is highly indebted to many colleagues, who have contributed with internal reports and informal informations.

Director *Mogens Rørvig* of the exploration office at A. P. Møller, Ltd., has kindly placed the two fotos of "Glomar IV" and "Mærsk Explorer" respectively at our disposal.

Mr. *O. Neergaard Rasmussen* has done the photographical work for plates 1 and 2. Mrs. *Inge Martin-Legène* and Mrs. *Helle Raben* have drawn the figures 3 and 4.

The translation into English was done by Mr. *M. Robson,* B. A.

Finally, Mr. *Arne Dinesen* has done a great work by controlling the depth figures and a main part of the text.

All named and unnamed helpers are thanked cordially.

Dansk sammendrag

Nogle geologiske resultater af de første fem danske olieboringer i Nordsøen. Dansk Nordsø A-1, A-2, B-1, C-1 og D-1

Geofysiske undersøgelser udførtes på den danske kontinentalsokkel i Nordsøen allerede 1963, og i 1966 indledtes egentlige borearbejder med boringen Dansk Nordsø A-1, som blev boret fra boreskibet »Glomar IV« (se fig. 1). En ny boring, Dansk Nordsø A-2, kom først igang det følgende år, og dennegang fra boreplatformen »Mærsk Explorer« (fig. 2), som også var basis for de øvrige tre boringer, som er omtalt i nærværende arbejde.

For hver af de fem boringer, som beskrives, oplyses først beliggenheden (position), boreentreprenøren (contractor), boreudstyret (equipment), borearbejdets (drilling) påbegyndelse (commenced) og afslutning (completed), forerør (casing) og koter (elevations) for havbund (sea floor) og kelly bushing (bøsningen omkring den øverste del af borestammen).

Den danske læser, som ønsker lidt nærmere oplysninger om de tekniske forhold ved en dybdeboring, og især om problematikken ved prøvetagning og bestemmelse af prøvedybder, henvises til mine oversigtsartikler i bøgerne om boringerne Rønde nr. 1 og Nøvling nr. 1 (trykt som henholdsvis D. G. U. III. række, nr. 39 og 40).

I nærværende arbejde er der også redegjort for D. G. U.'s geologvagt på borestedet (rubrikken: "Well site geologists from D. G. U."), tjenesteperiode og de boreintervaller, som den pågældende dækkede.

Den gennemborede lagserie beskrives nærmere i afsnittet "Lithological sequence". Dybderne i meter er regnet fra havoverfladen, medens dybderne i parentes, angivet i engelske fod, er regnet fra kelly bushing, hvorfra borefolkene målte dybderne, når de udtog prøver. De dybdetal, som er trykt med kursiv, angiver dybder, der er verificerede ved hjælp af Schlumberger målingerne. I afsnittet er hvert lithologisk afsnit beskrevet på engelsk, men den fuldstændige beskrivelse følger efter den engelske på dansk i parentes.

I nær tilknytning til lithostratigrafien følger endelig et chronostratigrafisk afsnit, og straks derefter et andet afsnit med supplerende bemærkninger til stratigrafien ("Supplementary remarks concerning the stratigraphy"). I det første afsnit gives en oversigt over de i boringen trufne geologiske perioder, medens det næste afsnit giver mere detaljerede oplysninger om baggrunden for dateringerne.

En oversigt over de stratigrafiske resultater fremgår iøvrigt af fig. 5. Derudover skal der her meddeles visse hovedtræk af de geologiske resultater.

De strukturelle regioner i det danske sokkelområde vil være velkendte fra de publicerede kort hos Heybroek *et al.* (1967), gengivet i delvis omredigeret form af Sorgenfrei (1969), hvis fig. 7 (map 4) er reproduceret i reduceret størrelse som fig. 3 i nærværende artikel. Den væsentligste struktur er Ringkøbing–Fyn Højderyggen, der strækker sig fra Jylland ud mod den centrale del af Nordsøen og afgrænser det nordfor liggende Norsk-Danske Bassin og Det Danske Sænkningsområde fra det sydfor liggende Tyske Bassin, medens Øst-Doggerbanke Graven umiddelbart vest for højderyggen strækker sig i NNV–SSØ'lig retning som et markant sænkningsområde. Dette er især karakteriseret ved meget tykke kænozoiske lagserier.

Alle de fem boringer, som er omtalt i nærværende arbejde, ligger uden for højderyggen. Boringerne A-1, A-2 og B-1 er placeret på eller opad saltstrukturer i Øst Doggerbanke Graven, medens C-1 og D-1 blev udført på strukturer ret tæt nord for selve højderyggen, på sydflanken af Norsk-Danske Bassin og Det Danske Sænkningsområde (se kortene fig. 3 og 4).

Et antal af kun fem boringer er naturligvis utilstrækkeligt til videregående regional-geologiske slutninger, men visse hovedtræk afspejler sig dog i profilerne.

De ældste lag, som er nået i boringerne B-1, C-1 og D-1, er muligvis alle af nedre permisk alder. Trachytten i C-1 kan dog meget vel være ældre (karbon eller ældre). Nedre permiske vulkanitter er imidlertid velkendte fra Nordsøens østlige og sydlige omgivelser. Det gælder således Oslofeltets rhombeporfyrserier i Syd-Norge, vulkanitterne i Rødby-boringen på Lolland (Danmark), de tykke vulkanitserier i en lang række boringer i Nordøst-Tyskland (DDR) og tilsvarende eruptiver i flere boringer i Nordvest-Tyskland og Holland.

Nedre permisk sandsten, som forekommer i den sydlige del af Nordsøen på den engelske og hollandske sokkel, hvor den ofte er gasførende, er ikke konstateret i de boringer, som er beskrevet her. Derimod er det muligt, at den rødbrune lersten umiddelbart over vulkanitten i B-1 og C-1 er aflejret i nedre perm (rotliegendes). En mulig pendant til rotliegend sandstensformationen er den grovkornede finsandsten fra 3319–3468 m i D-1, som imidlertid befinder sig på sydflanken af Norsk-Danske Bassin, hvorfra der ikke hidtil er oplyst fund af den rødbrune rotliegend sandsten. Det må dog understreges, at der ikke er tale om nogen egentlig datering af forekomsterne i de danske boringer, men kun om et skøn på grundlag af lagenes position.

Øvre permiske evaporitserier er konstateret i boringerne B-1, C-1 og D-1,

som alle nåede ned under trias lag. Alle boringerne ligger inden for det nordeuropæiske zechstein bassin og endvidere i det område, som er påvirket af halokinesis, og hvor der er påvist talrige salt piercements, salt pillows og andre saltstrukturer.

Aflejringerne fra jura og nedre kridt er påvist i alle boringerne, undtagen A-1, der standsede i danien lag. Et nærmere studium af aflejringerne fra disse perioder er i gang. Foreløbigt er det påfaldende, at nedre jura (lias) ikke synes at være tilstede, og at aflejringer fra øvre jura gør sig markant gældende. De fra det danske landområde så velkendte øvre kretaciske hvide kalksten og, øverst i serien, kridtlag er også truffet i boringerne, som muligvis ved nærmere undersøgelse vil vise sig at indeholde alle øvre kridts etager.

En særlig interesse knytter sig til den tertiære lagserie, som i den centrale del af Nordsøen opnår en for Nord-Europa usædvanlig stor mægtighed. Ifølge Heybroek *et al.* (1967, kortet fig. 5; cf. Sorgenfrei 1969, fig. 8, p. 184) findes tertiærets basis maksimalt på dybder under 3500 m. I den danske del af kontinentalsoklen vil den kunne forventes helt ned på dybder under 3000 m.

I de foreliggende fem boringer er tertiærets basis dog ikke truffet dybere end 2210 m under havoverfladen (i B-1). Tykkelsen af de tertiære lag er i B-1 over 1600 m og i A-1 og A-2 omkring 1400 m. Disse tre boringer ligger længst mod vest og måtte derfor på forhånd forventes at have betydeligt tykkere tertiærserier end de to øvrige boringer. Af disse udtrykker C-1's tertiær på 477 m den »normale« danske tertiær-lagmægtighed, medens D-1 med sine 841 m tertiær viser en tendens til tiltagende tykkelse, som helt svarer til denne borings beliggenhed.

Af de foreløbige stratigrafiske undersøgelser fremgår det tydeligt, at den ældre tertiære lagserie (omfattende danien, det øvrige paleocæn, eocæn, og ældre oligocæn) har en betydeligt mindre samlet mægtighed end den yngre tertiære serie (omfattende yngre oligocæn, miocæn og pliocæn). I A-1 er tykkelsen af disse lag henholdsvis ca. 340 og 1000 m, idet dog danien-lagene ikke blev gennemboret. I A-2 er de tilsvarende værdier henholdsvis 352 m og 1040 m. Desværre er det ældre tertiær i B-1 endnu ikke nærmere adskilt bio- og chronostratigrafisk fra det yngre tertiær, men tykkelsen af yngre tertiær er i denne boring formodentlig større end i A-1 og A-2.

Det er muligt udfra de foreløbige stratigrafiske undersøgelser i A-1, A-2 og B-1 yderligere at indkredse det tidsinterval, hvor den overvejende del af sedimentationen har fundet sted, idet aflejringerne fra pliocæn og øvre miocæn omfatter 759 m i A-1, 807 m i A-2 og mere end 800 m i B-1, medens de tilsvarende tal for tykkelsen af intervallet mellem miocæn – øvre oligocæn i A-1 og A-2 udgør henholdsvis 226 m og 239 m. Da de pliocæne lags tyk-

kelse næppe overstiger 125 m i nogen af boringerne, omfatter de øvre miocæne lag således mere end 600 m af den samlede tertiære lagserie. Dette tyder på, at sænkningen af den centrale del af Nordsøen har været størst i øvre miocæn tid.

Den kvartære lagserie i de vestligste boringer udgør over 500 m i B-1, over 400 m i A-1 og 386 m i A-2. En væsentlig del af denne serie er marin og aflejret i ældre kvartær, nærmere betegnet Icenien.

De her nævnte geologiske træk er kun enkelte af de resultater, som kan uddrages af boringerne. Den igangværende bearbejdelse af mikrofaunaerne forventes at ville både korrigere og uddybe iagttagelserne, ligesom mere sikre regionale slutninger naturligvis må støtte sig til mange flere boreprofiler, end de fem som er nærmere omtalt her.

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Plates

Plate 1

Figs. 1–2. *Astarte trigonata reimersi* Semper × 4.3
Loc.: Dansk Nordsø A-1. Depth: 658–667 m (2190′–2220′)
Left valve. Fig. 1: Exterior. Fig. 2: Interior
Age: Upper Miocene

Figs. 3–4. *Terebra inversa* Nyst × 4.1
Loc.: Dansk Nordsø A-1. Depth: 649–658 m (2160′–2190′)
Specimen lacking lower part of shell (basis)
Fig. 3. Apertural view
Fig. 4. Rear view
Age: Pliocene (Scaldisian)

Figs. 5–6. *Acila cobboldiae* J. Sowerby × 4.1
Loc.: Dansk Nordsø A-2. Depth: 412 m (1470′)
Rigth valve. Fig. 5: Exterior. Fig. 7: Interior
Age: Lower Pleistocene (Icenian)

Fig. 7. *Acila cobboldiae* J. Sowerby × 3.9
Loc.: Dansk Nordsø A-2. Depth: 412 m (1470′)
Left valve, exterior
Age: Lower Pleistocene (Icenian)

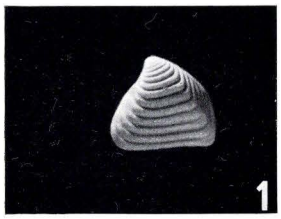
Fig. 8. *Acila cobboldiae* J. Sowerby × 1.7
Loc.: Dansk Nordsø A-2. Depth: 494 m (1740′)
Rigth valve, interior
Age: Lower Pleistocene (Icenian)

Fig. 9.
Molluscan assemblage sorted out from Dansk Nordsø A-1, sample 868–878 m (2880′–2910′). × 1.5
Age: Upper Miocene
Among the species a fragment of *Astarte trigonata reimersi* is seen in the upper right corner of the picture

Fig. 10.
Molluscan assemblage sorted out from Dansk Nordsø A-2, sample 650 m (2250′). × 1.5
Age: Upper Miocene
A defective rigth valve of *Astarte reimersi* dominates the upper half of the picture. Among the other specimens a fragment of the bryozoa *Cupuladria* is seen together with other mollusc fragments, and a large *Hinia*

All depths in metres are measured from sea level, while the depths in feet are measured from kelly bushing

Phot. O. Neergaard Rasmussen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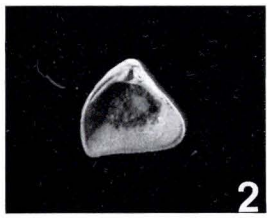
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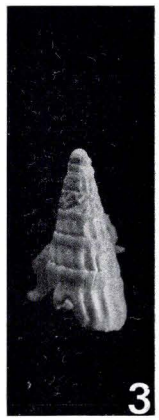
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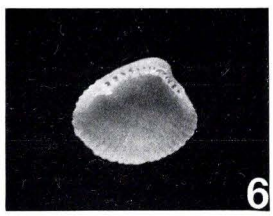
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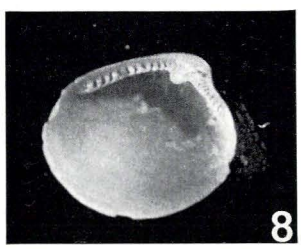
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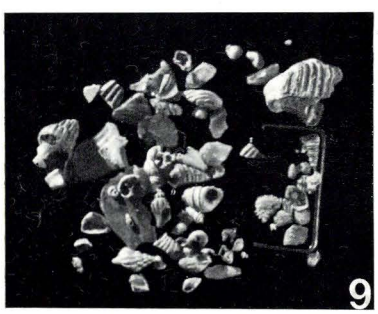
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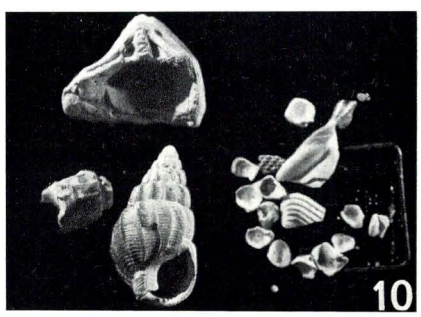
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Plate 2

Fig. 1.

Molluscan assemblage sorted out from Dansk Nordsø A-1, sample: 777–786 m (2580′–2610′). × 3.3
Age: Upper Miocene
In the upper right corner a left valve of *Astarte trigonata reimersi*. Among the other species there are more specimens of *Turritella tricarinata* (Brocchi), fragments of a *Hinia*, an otolite etc.

Fig. 2. *Dentalium* sp. aff. *D. dollfusi* v. Koenen × 4.6
Loc.: Dansk Nordsø D-1. Depth: 649–658 m (2250′–2280′)
Age: Middle Miocene

Fig. 3. *Turris (Fusiturris) flexiplicata* (Kautsky) × 4.5
Loc.: Dansk Nordsø D-1. Depth: 649–658 m (2250′–2280′)
Age: Middle Miocene

Fig. 4. *Hinia fuchsi* (v. Koenen) × 7.4
Loc.: Dansk Nordsø D-1. Depth: 649–658 m (2250′–2280′)
Age: Middle Miocene

Fig. 5. *Limopsis lamellata* Lehmann × 4.8
Exterior of right valve
Loc.: Dansk Nordsø D-1. Depth: 649–658 m (2250′–2280′)
Age: Middle Miocene
The specimens pictured on figs. 2–5 are all from the same ditch sample from Dansk Nordsø D-1 and they are all characteristical species in the Danish Hodde Formation

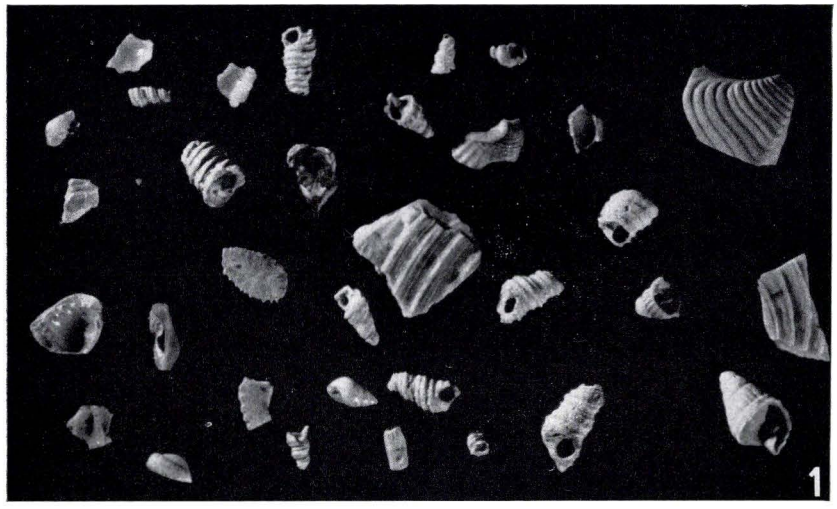
Fig. 6.

Molluscan assemblage sorted out from Dansk Nordsø A-1, sample 841–850 m (2790′–2820′)
× 1.5
Age: Upper Miocene
A left valve of *Cardita orbicularis* Sowerby is seen in the center of the picture. Two other shells of the same species are also present. Furthermore there are a few shells of *Turritella tricarinata* (Brocchi) visible.

The assemblage points chronostratigraphically to the older part of the Upper Miocene.

All depths in metres are measured from sea level, while the depths in feet are measured from kelly bushing.

Phot. O. Neergaard Rasmussen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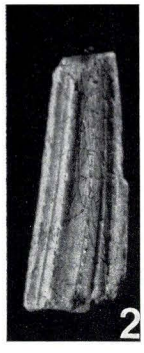
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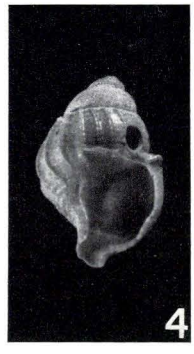
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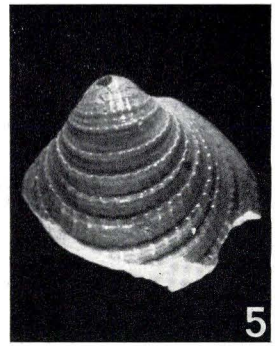
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