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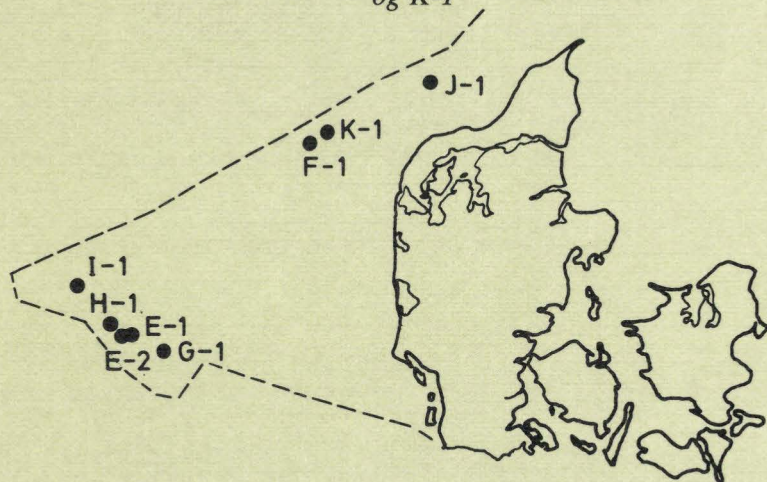
Geological aspects of the Danish North Sea sector

*With a report on the wells Dansk Nordsø E-1, E-2, F-1,
G-1, H-1, I-1, J-1, and K-1*

BY
Leif Banke Rasmussen

DANSK SAMMENDRAG
Geologiske træk fra den danske Nordsø sektor

*Med rapport over boringerne Dansk Nordsø E-1, E-2, F-1, G-1, H-1, I-1, J-1
og K-1*



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Abstract

This paper presents lithological and chronostratigraphical descriptions of geological sections from the following eight Danish North Sea wells: Dansk Nordsø E-1, E-2, F-1, G-1, H-1, I-1, J-1, and K-1, in which deposits of Triassic, Jurassic, Cretaceous, Tertiary and Quaternary age were found. The chronostratigraphy of the well sections is mainly a result of micropalaeontological examination of samples.

The paper gives additional comments on the structural conditions of the Danish North Sea sector with reference to an outline map, and to a number of cross sections through the southern part of the Danish portion of the Central Graben. Some regional structures are given new names.

Introduction

Our knowledge of the geology in the North Sea Region is increasing constantly in present years because of the intensive exploration works in progress. Hundreds of wells are being drilled and thousands of kilometres of seismic lines shot. Though the Danish sector of the North Sea forms only a minor part of the North Sea area as a whole, the exploration of this part of the sea yields a comprehensive and valuable contribution to a geological understanding of the whole region.

In continuation of the publications on the Danish North Sea wells, introduced in 1974 by the survey of the Dansk Nordsø A-1, A-2, B-1, C-1 and D-1 wells, the Geological Survey of Denmark (Danish: Danmarks Geologiske Undersøgelse, abbreviated in the following text as DGU) here presents some geological results from another set of wells. These are the Dansk Nordsø E-1, E-2, F-1, G-1, H-1, I-1, J-1, and K-1 wells, drilled in the years 1968–1970.

The DGU feels it reasonable to publish these results, even though it has not yet been possible to carry out profound investigations of all the geological and geophysical material that has been received from the Concessionaire. Many of the results presented here are new to the public and they are especially considered to be of some importance for the geological discussions. *It must be noted that all references to unpublished internal reports are printed in italics, while references to publications are printed in roman types.*

Concerning the exploration work and its organization, reference is made to the publication on the first 5 Danish North Sea wells (Rasmussen 1974, p. 5 ff.). In the period 1968–1970, as was the case in the foregoing years, the geophysical work was done by Gulf's survey ship »Gulfrex« and by Geophysical Services Intercontinental Limited. All 8 wells reported here were drilled from the platform »Mærsk Explorer« (cf. Rasmussen 1974, p. 8, fig. 2).

Investigations by the Geological Survey

The following report is mainly based on laboratory examinations in the Department of Subsurface Geology at the DGU. The lithological evaluations were made by describing the samples, and only to a limited extent in connection with studies of petrophysical logs. Some more conspicuous log features were taken into consideration, however.

In contrast to the first 5 Danish North Sea wells, no geologists from the DGU were stationed on the drilling platform (see Rasmussen 1974, pp. 6–7) during the drilling of the 8 wells described here. All samples and other data were forwarded to the DGU by the concessionaire. The institute has furthermore received monthly and half-yearly reports including geological and technical information. They have all been used in the following report on the 8 wells.

Due to varying degrees of diagenesis of the sediments and the nature of the sedimentary environment, it has not always been possible to obtain well-preserved fossils from the samples. The micropaleontologists have therefore had varying working conditions for their studies. Some sequences were easier to divide biostratigraphically than others, while yet others were impossible to handle. This heterogeneity must be taken into account together with the fact that many other geological tasks had to be executed by the same staff during the time of the examinations.

The comments on the quality of the samples and depth estimates, which were given in relation to the publication of the first five Danish North Sea wells, are also valid in the present context (see Rasmussen 1974, pp. 9–10).

As was the case in the previous publication, the log-verified depth figures are printed in italics. It is furthermore important to be aware of the fact that *all depths in metres are calculated from sea level, whilst all depths in feet (usually printed in brackets) are measured from the kelly bushing.*

Progress in the knowledge of the geology of the Danish North Sea sector

Since the last report on Danish North Sea wells in 1974, a number of contributions to the geology of the North Sea have been published. The majority of these are collected in the volume edited by A. W. Woodland, containing the geological lectures given at the London Conference in 1975. An outline of the geological history of the whole area was given at the conference by P. A. Ziegler and W. H. Ziegler, and P. A. Ziegler recently revised his outline in the first issue of *GeoJournal* (1977). Reference is here made to this article as a good up to date background for more detailed studies on North Sea geology, including the Danish sector.

Publications since 1974 giving contributions to the geology of this sector are rather few. First of all may be mentioned the paper by Childs and Reed (1975) on the geology of the Dan Field and the Danish North Sea. Palynological and lithological information on the Upper and Middle Triassic in the Dansk Nordsø A-2, F-1, and K-1 wells was given by Bertelsen (1975), while in his treatise of 1975 Michelsen gives a detailed stratigraphical interpretation of the Lower Jurassic section of the Dansk Nordsø F-1, K-1, and J-1 wells. A short survey with abbreviated logs of all wells drilled in the Danish sector until September 1975 was printed in Danish by Michelsen in 1976b, formerly published in December 1975 as part of a report from the Danish government's supervision of the Concessionaire's activities.

Studies of the Jurassic formations in the Danish part of the Danish-Norwegian Basin, including maps, well sections, lithological descriptions and chronostratigraphy, have been made by Michelsen (1976a, 1977, 1978a, b). Similar studies on the Upper Triassic formations have been carried out by Bertelsen (1978a), who has also investigated the Carboniferous in the Dansk Nordsø P-1 well and published his results together with other geological information on the well sequence (Bertelsen 1978b).

Other printed contributions to the geology are the studies by Frost (1977) on the lineaments in the Danish region, including a "map of the major structural elements at the base Zechstein level". Madsen (1975) gave an outline of the geothermal gradient for the whole of the Danish area based on borehole temperature calculations from 13 wells.

In total, all these publications mark a step forward in our knowledge of the geology of the Danish sector. The majority of the results of the investigations,

however, are recorded in many internal (unpublished) reports. A number of these have formed the basis for the following descriptions of the eight North Sea wells.

Structural survey of the Danish North Sea sector

The great quantity of seismic data, together with geological analyses of borehole data and regional studies, has contributed to a more detailed mapping of the structural pattern of the Danish North Sea. J. C. Baartman, of the geophysical staff of the DGU, has compiled the more important structural features on an outline map (1976), which is shown in fig. 1.

In constructing such maps it will always be difficult to include structures of different ages on the same map. In the present case the mapping concentrated primarily on the more pronounced features attached to the pre-Upper Permian surface. However, the many salt-structures caused by halokinesis of the Upper Permian evaporite salt beds are of such importance to the tectonic picture of the Danish area that it was felt necessary to include them.

The resulting map thus depicts the more important or distinct structural deformations of the Paleozoic strata.

The main regional Danish provinces are well known and comprise:

1. The Ringkøbing–Fyn High
2. The Danish–Norwegian Basin
3. The North German Basin
4. The Central Graben (earlier named “East Dogger Bank Graben”).

Though the 8 wells described in this paper are located in only two of these provinces, it seems appropriate to give a review of all four.

The Ringkøbing–Fyn High

This pronounced regional high, stretching east–west across the Danish offshore and onshore areas, from the island of Møn in the east to the central North Sea in the west, has been known for many years as the *Ringkøbing–Fyn High*. It has also been named the *Fyn–Grindsted High*, e.g. in

Heybrook et al. 1967, but the first mentioned name has been so well accepted in the literature that it would be difficult to replace it with another, better, and probably shorter one.

The high is no continuous regional structure. It is undoubtedly divided into separate blocks by intervening troughs or grabens. In the Danish North Sea at least 2 or 3 blocks can be separated: 1. The East North Sea Block, 2. The Holmsland Block and 3. Parts of the Grindsted Block.

The East North Sea Block forms the most westerly unit of the Ringkøbing–Fyn High. It is incompletely known geologically, as no wells have hitherto been drilled in the block, but to judge from seismic shootings, older Paleozoic metamorphics or Precambrian basement is present, in places at 3000 m or possibly even deeper.

Upper Permian deposits are probably absent throughout most of the block, and the Mesozoic sequence is reduced, especially with regard to the Triassic–Jurassic series of strata (cfr. Childs & Reed 1975, p. 12, f. 4, and Michelsen 1978a).

The *Holmsland Block* is another unit, situated immediately west of the west coast of Jylland and separated from the East North Sea Block by the Horns Trough. It is separated from the next block to the east, the *Grindsted Block*, by a less pronounced trough.

The *Grindsted Block* is mostly restricted to the onshore southwestern part of Jylland, but its most westerly part extends to the nearby parts of the North Sea. Precambrian basement rocks have been proved to exist in its subsurface in a well at the town of Grindsted, where gneiss was found at 1599 m (Sorgenfrei & Buch 1964, p. 49). Seismic evidence points to a location of the basement surface at approx. 1800–2000 m in the vicinity of the town of Ringkøbing, close to the west coast of Jylland on the same block (Sorgenfrei 1966). On the Holmsland Block itself, only a few seismic lines have been shot and no wells have been drilled. The depth to the basement in this block seems to be about 3000 m, with a reduced Lower Mesozoic cover.

The *Horns Trough* separating the East North Sea Block and the Holmsland Block is probably a graben, and therefore is often designated the *Horns Graben*. Its boundary to each of the blocks is characterized by normal faults, the most pronounced of which form a fault system to the west. The basement can be expected at depths of about 5000 m, and the surface of the pre-Upper Permian seems to be dipping in a westerly direction. Information (see Michelsen 1976b, p. 127, f. 5) about the sequence at the center of the trough is given by the Dansk Nordsø R-1 well, which was abandoned in Lower Permian volcanics below reddish shales. No Upper Permian was found in this well. Triassic beds lay directly on the Lower Permian, and the Jurassic–Lower Cretaceous sequence was very thin. This was also the case with the Dansk

Nordsø S-1 well, drilled in the continuation of the trough south of the Ringkøbing–Fyn High. The Triassic in this well was not penetrated even after drilling nearly 2000 m., from 1574 m to the total depth of 3780 m. It thus seems likely that the main subsidence of the Horns Trough took place during the Triassic.

The geological conditions in the trough between the Holmsland Block and the Grindsted Block are poorly known. The basement may occur at depths of the order of 4000 m, and results from seismic shootings suggest that a thick series of Palaeozoic deposits rest on the basement.

The Danish-Norwegian Basin

The main portion of the Danish area is covered by the sedimentary sequences of a large basin, filling the region between the Westland Arch and the Sele High to the WNW, the Fennoscandian Shield to the N, the Fennoscandian Border Zone to the NE and the Ringkøbing–Fyn High to the S (see fig. 2. from Michelsen 1978a).

This basin is named the *Danish-Norwegian Basin* or the *Norwegian-Danish Basin*. A major part of the basin was earlier known as the *Danish Embayment*. This name is now replaced by the term: *The Danish Subbasin*.

The geological history of this subbasin has been studied for many years and it must be expected that its continuation towards the NW – below the sea bottom west of Northern Jylland – presents almost similar geological conditions as for the subsurface of NW-Jylland and the Limfjord Region.

This part of the sector is structurally characterized by many salt structures: domes as well as pillows.

The salt dome province of this part of the country continues in a westerly direction and includes the major part of the Danish North Sea sector north of the Ringkøbing–Fyn High and south of the pronounced fault-system, the *Fjerritslev Fault*, running NW from the Limfjord area and crossing the Danish-Norwegian sector border.

The pre-Upper Permian structural pattern is marked by numerous faults and minor grabens or blocks. It is especially worth mentioning that the fault forming the most westerly limit of the Horns Trough can be followed north-eastwards through the basin. How far north it can be traced is doubtful. The Dansk Nordsø C-1 well, described earlier (Rasmussen 1974, pp. 25–30), is placed close to this fault and was stopped in a Paleozoic trachyte. Other Paleozoic – probably Lower Permian – volcanics were found at the bottom of the D-1 well and in the R-1 well in the Horns Trough (Michelsen 1976b, p.

127, f. 5.). It is possible that the Permian volcanism known from the Oslo Region in Norway, the Danish-Norwegian Basin and the Horns Trough is part of the same province.

Another characteristic feature of this part is the thick Mesozoic sequence. The thickness of the Triassic deposits is especially pronounced. They can amount to more than 5000 m in the depocenters, but thicknesses of about 3000–4000 m can be expected in the wider central area of the basin.

The Jurassic sequence shows thicknesses of up to 1200 m. The depocenter is situated in North Jylland (Michelsen 1978a), almost in the same local area as where the Lower Cretaceous depocenter may occur. These last-mentioned deposits may exceed 700 m in total thickness. Another feature shows the Upper Cretaceous, of which the thickest series is found in a NW–SE striking belt across Denmark (see Stenestad 1972, p. 66, fig. 2), where it may exceed 2000 m.

All three wells in the Danish-Norwegian Basin reported on in the present paper, Nordsø F-1, J-1, and K-1, were drilled on structures the development of which was more or less influenced by salt movements. The F-1 well was drilled in the east flank of a salt pillow, while the location of the J-1 well is on the crest of another salt pillow situated close to the Fjerritslev Fault on its downthrown eastern side. The K-1 well was placed on a third dome-like structure, whose pre-Mesozoic geology is less well known.

The North German Basin

South of the Ringkøbing–Fyn High, the so-called North German Basin stretches out to the south, in the Danish area covering the islands of Lolland and Falster, the South Fyn archipelago, the southern part of South Jylland, and the southwestern part of the Danish North Sea sector.

The geological conditions in the Danish part of this basin are known from geophysical and geological investigations carried out in connection with oil exploration in the years 1947–1959.

In the most northerly part of Germany, Hecht, v. Helms & Kehrler (1955) distinguish:

1. The East-Holstein Block («Ostholsteinische Scholle»), mainly characterized by few closed anticlines and by thick Triassic and thin Jurassic sequences.
2. The Middle-Holstein Block («Mittelholsteinische Scholle»), characterized by thorough halokinesis, with numerous salt domes, salt walls or

other salt structures. The faults in the pre-Upper Permian substratum of this block strike mainly NNE–SSW. To judge from the structural map (fig. 1) this area of pronounced halokinesis continues from Holstein westwards into the southern North Sea, and a tongue of the area points north towards the Horns Trough without reaching the Danish sector.

3. The West-Schleswig Block («Westschleswig'sche Scholle») is known as a relatively stable area with few local structures of low relief, often influenced by less pronounced salt movements in the Upper Permian evaporite sequences. The geological conditions in this block are further illustrated by additional well sections (see Hecht, v. Helms & Kehrer, loc. cit., Sorgenfrei & Buch 1964).

The »block« probably continues below the eastern North Sea both in the German and Danish sector. Besides the southern continuation of the Horns Trough there are only two main structural areas in the Danish sector south of the Ringkøbing–Fyn High: one west of the trough and one east of it. They may both be of the same geological nature as the West-Schleswig Block and its Danish continuation. No wells have hitherto been drilled in these parts of the Danish North Sea sector, and the geophysical records are limited too. Only very few, minor faults have been marked on the map (fig. 1).

On the German side a few wells have been drilled, but only very little geological information has been published so far. One of these wells, the onshore Westerland 1 on the north tip of the island of Sylt, may be representative for the area flanking the southern limit of the Ringkøbing–Fyn High. The profile of the well has not yet been published, but some restricted information is found in a few journal notes (Erdöl und Kohle, 19. Jahrg. 1966, p. 480; American Ass. Petr. Geol. Bull., vol. 50, no. 8, 1966, p. 1645).

The well was abandoned in 3945, 5 m in so-called »Precambrian phyllite« below Lower Permian »fine-grained sandstone, siltstone and claystone« from 3319–3843 m.

Corresponding occurrences of probably low-metamorphic older Paleozoic rocks with a high degree of diagenesis have been found in the Danish onshore wells Aabenraa No. 1 and Hønning No. 1 in South Jylland, and similar rocks may perhaps occur below Permian beds in the southeastern part of the Danish North Sea sector.

If conclusions can be drawn from the geological sequences in the West-Schleswig Block, one can expect a thin Lower Cretaceous series, no Jurassic, but relatively thick Triassic and Permian series in this part of the North Sea.

Central Graben

The most important structural feature in the Danish North Sea sector, seen from an economic point of view, is the Central Graben. The term graben is sustained in this context because of its adoption into the geological vocabulary concerning the North Sea. It may be a subject for discussion whether the feature really is a graben, strictly speaking. In the Danish sector, however, it is evident that its eastern boundary up to the Ringkøbing–Fyn High is characterized by a normal fault or fault-system of relatively great order of size. The displacements amount to 5000 m or more.

The main features of the structural conditions in the southern half of the Danish part of the Central Graben are shown in 7 cross-sections, prepared by J. C. Baartman and L. Madsen of the geophysical staff of the D.G.U. These cross-sections are rendered in figs. 4–11 and they have been worked out from seismic lines, close to which wells have later been drilled. The locations of the Dansk Nordsø E-1, E-2, G-1 and H-1 wells, together with the previously published wells (Dansk Nordsø A-1 and A-2), are shown on the sections.

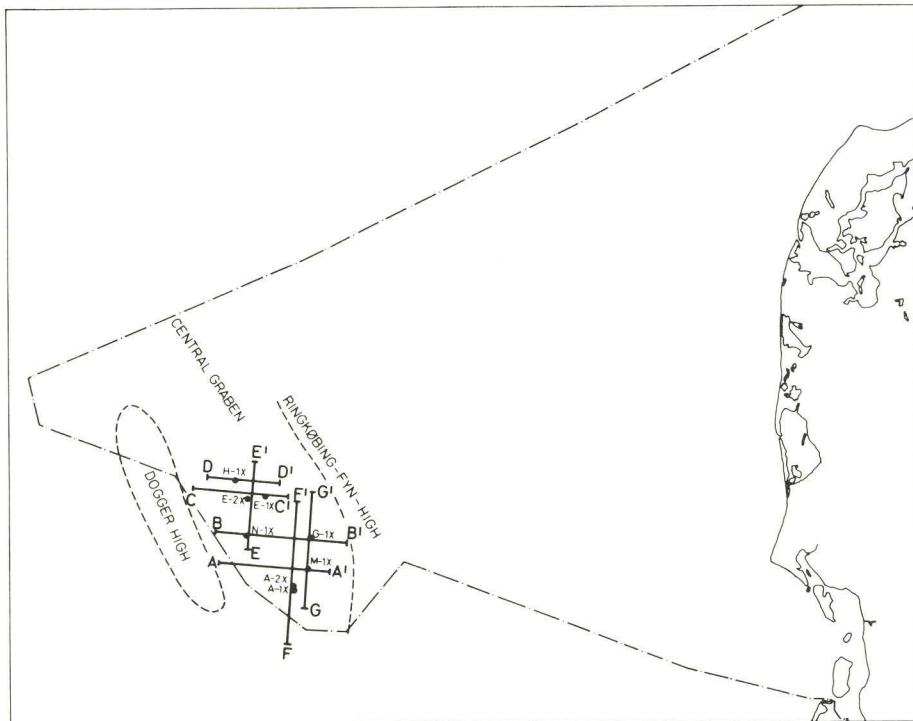


Fig. 3.

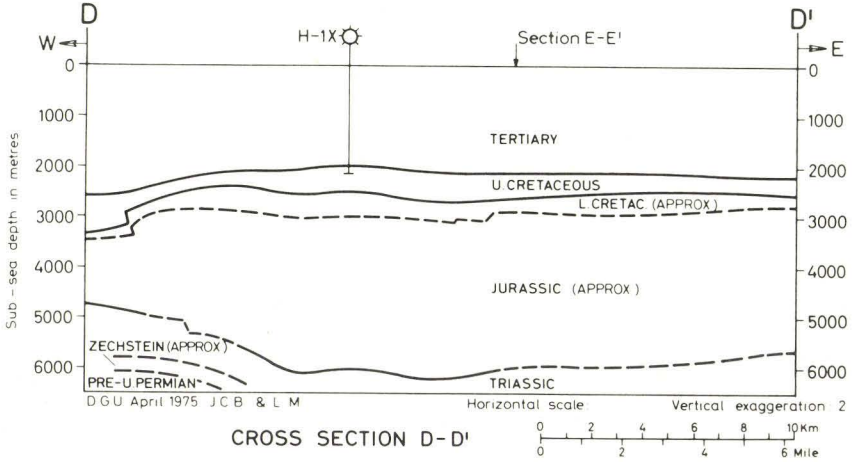


Fig. 4.

It appears from the cross-sections that the pre-Permian subcrop, which forms the floor of the graben, mostly fluctuates between 6000 m and 7000 m below sea level.

It seems evident that a pattern of faults dominates the structural picture of the pre-Upper Permian in the Graben. Some of these faults are undoubtedly older than Upper Permian, and it seems probable that the underlying basement has been split up into minor blocks.

In the western part of the Central Graben there is a structural high, the

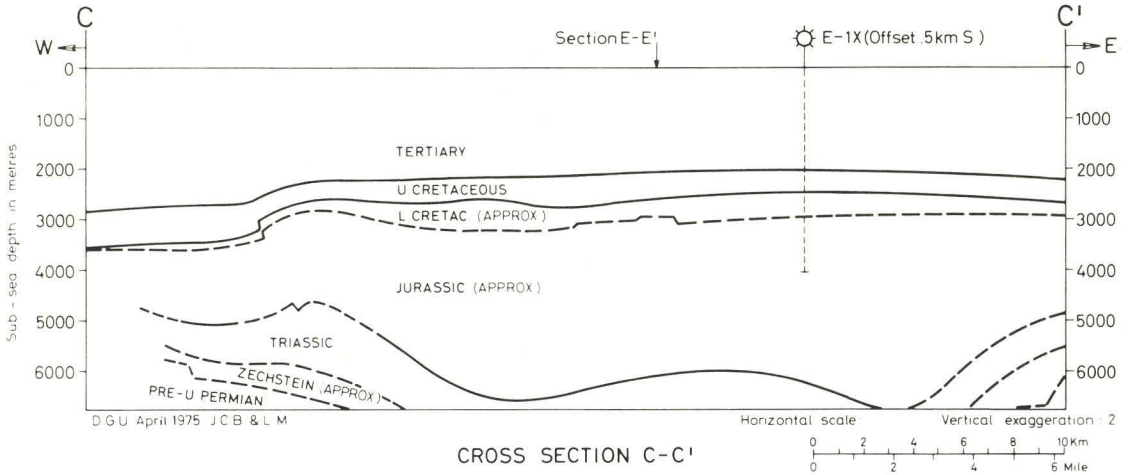


Fig. 5.

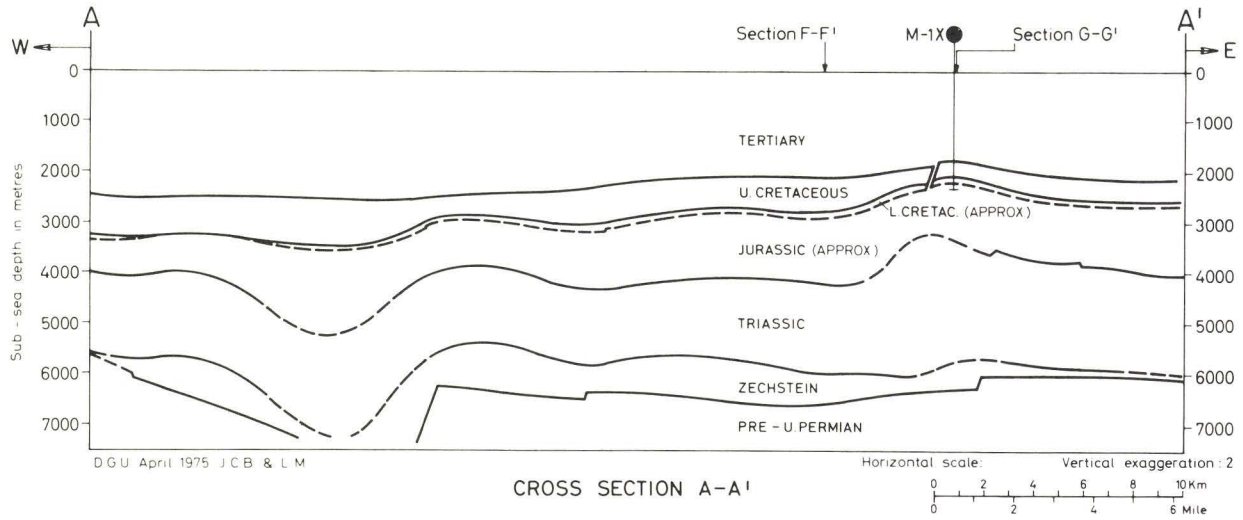


Fig. 6.

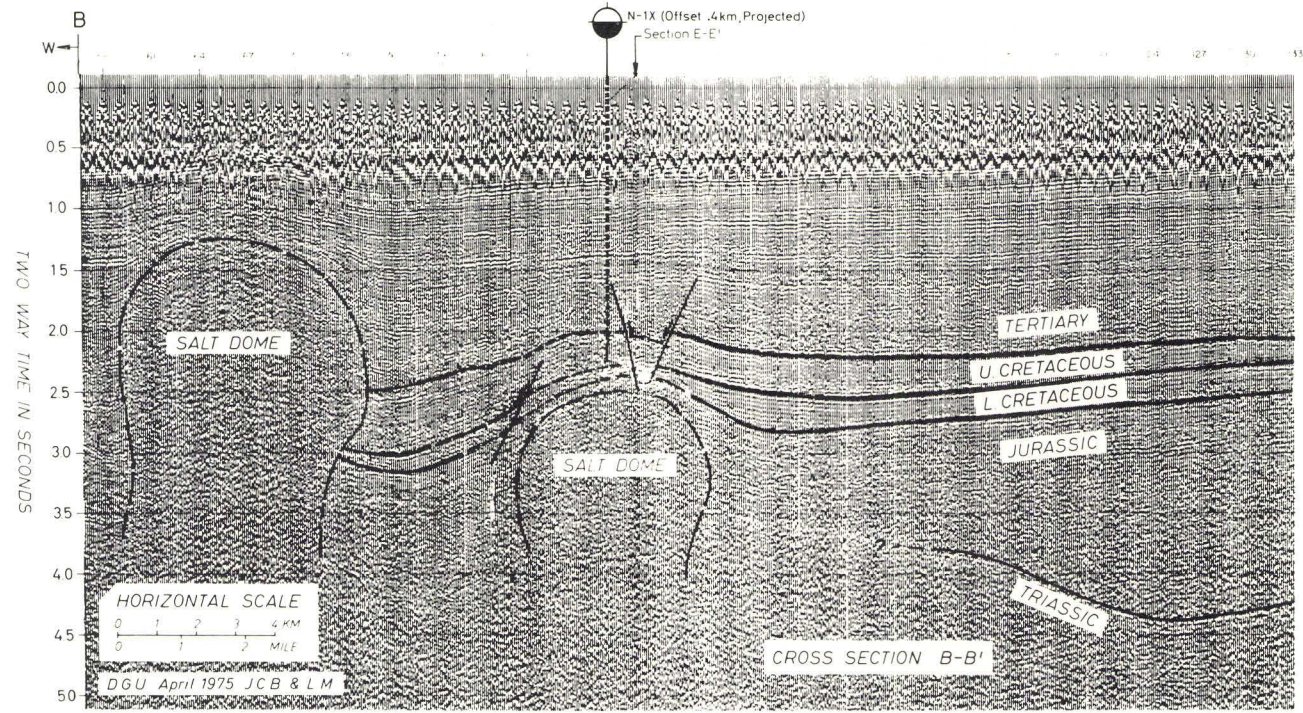


Fig. 7.

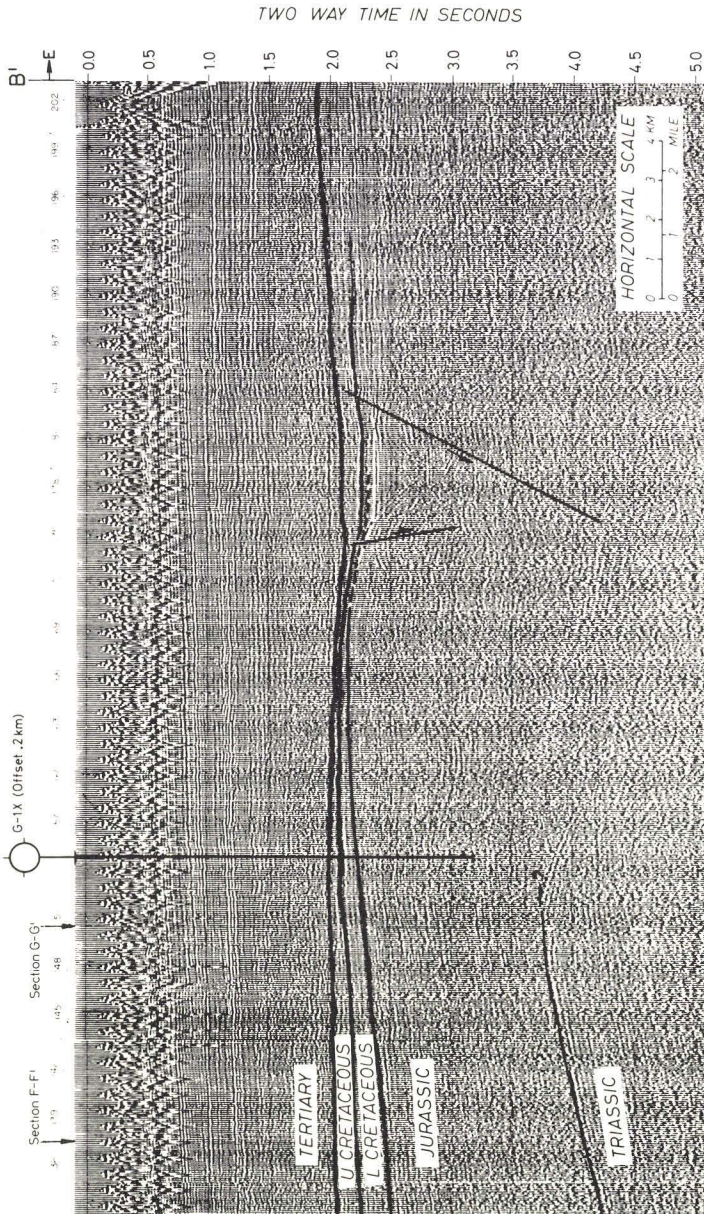


Fig. 8.

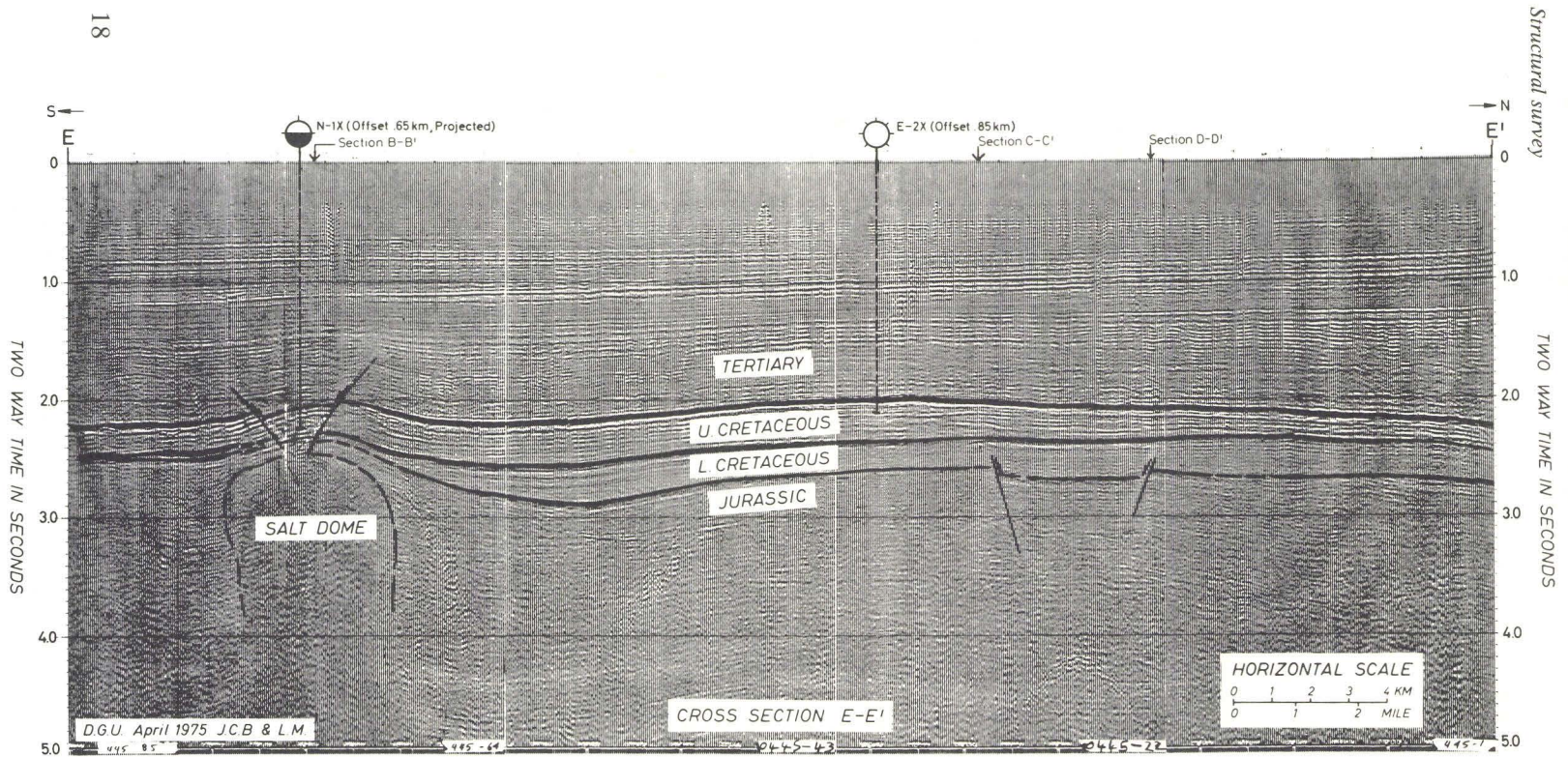


Fig. 9.

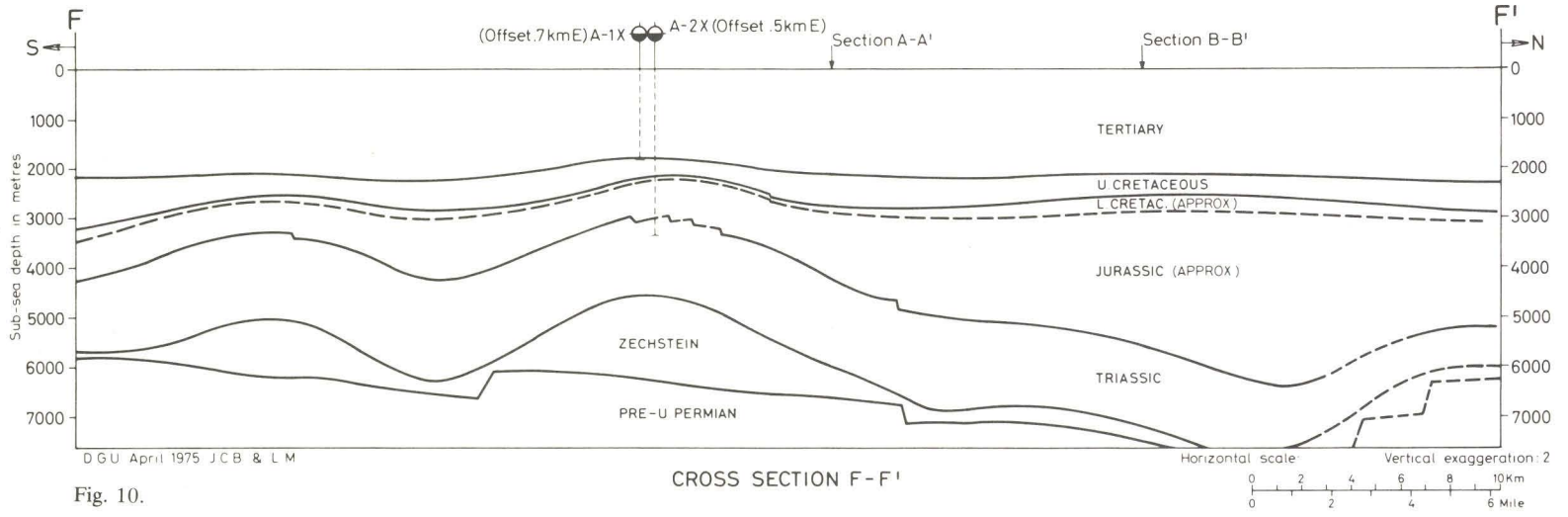


Fig. 10.

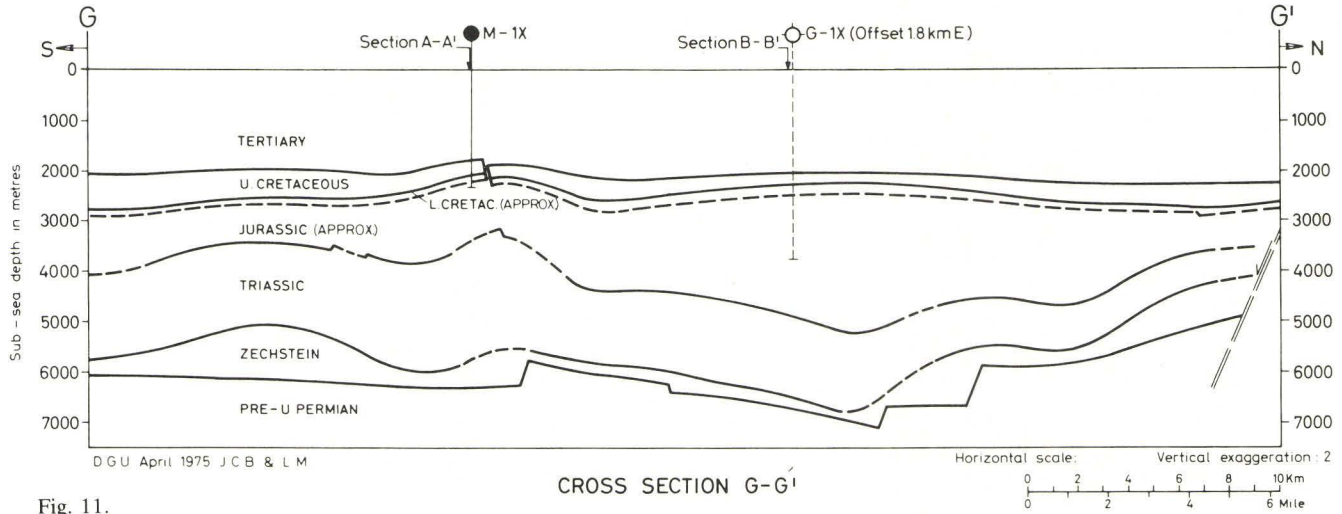


Fig. 11.

northern part of which is situated in the Danish sector. This high, named the *Dogger High*, appears to have a relatively narrow and elongated shape directed NW–SE, almost parallel to the western edge of the Ringkøbing–Fyn High and the axis of the Central Graben.

The proximity of the Dogger High can be traced on the left side of cross-sections D-D', C-C' and A-A', where the pre-Upper Permian reaches depths of between 5000 and 6000 m. The Dansk Nordsø P-1 well, drilled on the northern prolongation of the high in 1973, penetrated 62 m of metamorphic »greenstone« of late Silurian age (Bertelsen 1978a) below the depth of 3394 m below sealevel. This points to a Caledonian origin for the core of the Dogger High.

No wells have been drilled yet in the East North Sea Block. It is therefore impossible to judge whether the older Paleozoic of the block is Caledonian folded or not. It seems likely, however, that the pre-Carboniferous or pre-Devonian of the Central Graben area is Caledonian folded.

Only few of the faults found in the Central Graben could be shown on the structural map (fig. 1). Other structural features are associated with the halokinesis in the Upper Permian sequence. Some 8 salt domes and a couple of salt pillows are shown, but additional structures are probably present. The halokinesis must also be responsible for the varying thicknesses of the Upper Permian Zechstein beds.

Resting on these strata a thick sequence of Mesozoic sediments is present all over the Central Graben. The total thickness amounts to approximately 5000 m. In cross-sections C-C' and D-D' the main part of these beds is of Jurassic age, while further south, in the Danish part of the Graben, the Triassic reaches a considerable thickness too.

The Lower Cretaceous sequences throughout are mostly thin in relation to the Triassic and the Jurassic, but the Cenozoic sediments are again characterized by great thicknesses. The variations are seen in the cross-sections.

Description of wells

Dansk Nordsø E-1

Position: About 230 km W of Esbjerg
55°43'52.4'' N – 0,4° 51' 04.2'' E

<i>Contractor:</i>	Zapata Off-Shore Company
<i>Equipment:</i>	Drilling platform »Mærsk Explorer« with rig type Oil-well E-3000
<i>Drilling:</i>	Commenced 29th May 1968 Completed 17th July 1968 at a depth of 4048 m below sea level (= 13403' below kelly bushing (KB))
<i>Casing:</i>	42'' to 104 m (341') below KB 20'' to 218 m (714') below KB 13 ³ / ₈ '' to 1069 m (3506') below KB 9 ⁵ / ₈ '' to 2454 m (8051') below KB 7'' to 3992 m (13098') below KB
<i>Elevations:</i>	Sea floor: - 37.5 (123') Kelly bushing: + 37.2 m (122')
<i>Sampling:</i>	Cuttings samples were taken at 30' intervals from 300'–7620' and at 20' intervals from 7620'–13398'. Cores were cut in the following intervals: No. 1. 6670'–6727' (recovery: 38') No. 2. 6727'–6780' (recovery: 51½') No. 3. 6780'–6793' (recovery: 6') No. 4. 6793'–6845' (recovery: 52') No. 5. 6845'–6876' (recovery: 30¼') No. 6. 6876'–6930' (recovery: 26') No. 7. 8190'–8237' (recovery: 47') No. 8. 9783'–9792.5' (recovery: 7.3')

A wireline core was cut from 2720'–2876' with 28' of recovery.

A total of 48 Schlumberger sidewall cores were taken at different levels in the interval between 8183' and 13140'.

Lithological log

The following descriptions are mainly based on studies of the cuttings and the cores, carried out and reported by Dinesen.

41 –100 m (257'–450')	Clay, grey, downwards with beds of sand. In places with numerous shells of molluscs. (Ler, gråt, nedefter med lag af sand. Stedvis med talrige molluskskaller).
100–120 m (450'–810')	Sand, grey, in places with a little lignite. Beds of gravel and shells. In the lowermost part a micaceous silt predominates. (Sand, gråt, stedvis med brunkul. Lag af grus og

- anhobninger af molluskskaller. Nederst overvejende glimmerholdigt silt).
- 210–274 m (810'–1020') Silt, grey, often sandy and micaceous. (Silt, gråt, ofte sandet og glimmerholdigt).
- 274–438 m (1020'–1560') Clay, grey, with beds of silt. Many shells of molluscs. (Ler, gråt, med lag af finsand. Mange molluskskaller).
- 438–478 m (1560'–1690') Clay, grey, silty, interbedded with silt, grey, clayey, with shell fragments. (Ler, gråt, finsandet, vekslende med finsand, gråt, leret, med skalfragmenter).
- 478–566 m (1690'–1980') Clay, sand, and gravel. (Ler, sand og grus).
- 566–1242 m (1980'–4197') Clay, grey, at places silty or with beds of siltstone, micaceous. In lowermost part occurrences of glauconitic beds. (Ler, gråt, stedvis finsandet eller med lag af finsandsten, glimmerholdigt. Nederst med glaukonitholdige lag).
- 1242–1645 m (4197'–5520') Claystone, dark brownish grey to black, silty, micaceous. (Lersten, mørk brungrå til sort, finsandet, glimmerholdigt).
- 1645–1965 m (5520'–6570') Shale, dark grey – light grey – greenish grey, more or less calcareous. In lowermost part with variations of greenish and brownish colours. (Lerskifer, mørkegrå – lysegrå – grønliggrå, vekslende kalkholdighed. Nederst variationer af grønlig og brunlige farver).
- 1965–1982 m (6570'–6625') Shale, reddish brown and greenish. (Lerskifer, rødbrun og grønlig).
- 1982–1999 m (6625'–6680') Claystone, partly laminated and with beds of volcanic tuff. (Lersten, stedvis lamineret og stedvis med lag af vulkansk aske).
- 1999–2001 m (6680'–6688') Claystone, greenish grey. (Lersten, grønliggrå).
- 2001–2006 m (6688'–6703') Claystone, reddish brown. (Lersten, rødbrun).
- 2006–2007 m (6703'–6708') Claystone, brownish grey. (Lersten, brunliggrå).
- 2007–2016 m (6708'–6737') Shale, blackish grey. (Lerskifer, sortgrå).
- 2016–2450 m (6737'–8160') Limestone, white. Uppermost in this section

- probably a thin bed of conglomerate. Occurrences of chert. In places some zones impregnated with oil. Lowermost in the section subordinate beds of greenish shale. (Kalksten, hvid. Øverst muligvis et tyndt konglomerat. Forekomster af flint. Stedvis olieimprægnerede zoner. Nederst tillige med underordnede lag af grønlig lerskifer).
- 2450–2453 m (8160'–8170') Marlstone, light brownish grey to light greenish grey. (Mergelsten, lys brunliggrå til lys grønliggrå).
- 2453–2459 m (8170'–8190') Marlstone, reddish brown, slightly silty, with light coloured, greenish spots. In places occurrences of clayey siltstone. (Mergelsten, rødbrun, let finsandet, med lyse grønligpletter. Stedvis forekomster af leret finsandsten).
- 2459–2465 m (8190'–8211') Shale, grey to dark grey, calcareous. Burrows filled with pyritic material. Numerous fish remains and foraminifera. (Lerskifer, grå til mørkegrå, kalkholdig. Gravegange fyldt med pyritholdigt materiale. Talrige fiskerester og foraminiferer).
- 2465–2472 m (8211'–8233') Limestone, light brownish grey to yellowish white, alternating with claystone, light greenish grey to olive-grey, calcareous. (Kalksten, lys brunliggrå til gullig hvid, vekslende med lersten, lys grønliggrå til olivengrå, kalkholdig).
- 2472–2473 m (8233'–8234') Shale, bluish grey, with light grey lamellae. (Lerskifer, blåliggrå, med lysegrå lameller).
- 2473–2474 m (8234'–8237') Limestone, yellowish white, and claystone, olive-grey. (Kalksten, gullig hvid, og lersten olivengrå).
- 2474–2483 m (8237'–8270') Limestone, alternating with claystone as above. Downwards the limestone seems to be the dominating rock. (Kalksten, vekslende med lersten som ovenfor. Nedadtil synes kalkstenen at være den dominerende bjergart).
- 2483–2487 m (8270'–8280') Limestone and claystone as above. The li-

Dansk Nordø E-1

Dansk Nordø E-2

E-1 and E-2

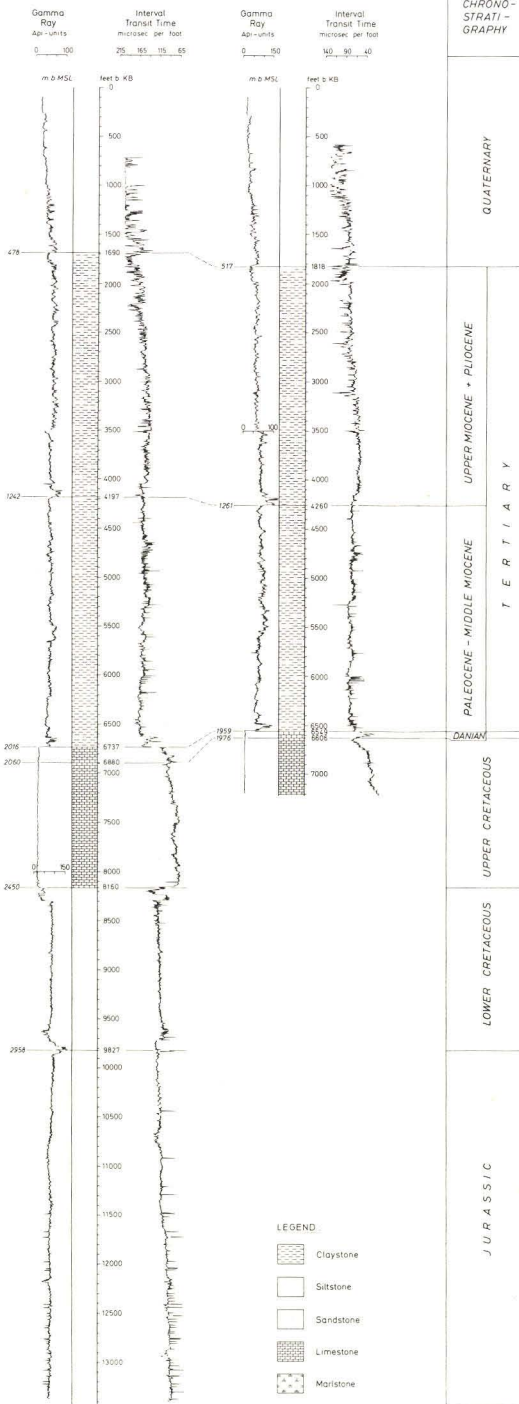


Fig. 12.

- mestone changes in places to a reddish brown colour. (Kalksten og lersten som ovenfor, idet dog kalkstenen stedvis antager en rødligbrun farve).
- 2487–2523 m (8280'–8400') Claystone, light grey, slightly silty, very calcareous. (Lersten lysegrå, let finsandet, stærkt kalkholdig).
- 2523–2572 m (8400'–8560') Shale, grey, calcareous. (Lerskifer, grå, kalkholdig).
- 2572–2895 m (8560'–9620') Shale, dark grey to brownish grey, calcareous throughout and with fluctuating content of silt. Possibly with subordinate beds of siltstone. (Lerskifer, mørkegrå til brunliggrå, gennemgående kalkholdig, med noget svingende indhold af finsand. Muligvis underordnede lag af finsandsten).
- 2895–2901 m (9620'–9640') Marlstone, light whitish grey to brownish, slightly silty, and shale, dark grey. (Mergelsten, lys hvidgrå til brunlig, let finsandet, og lerskifer, mørkegrå).
- 2901–2925 m (9640'–9720') Shale, mainly dark green. (Lerskifer, overvejende mørkegrøn).
- 2925–2945 m (9720'–9783') Shale, dark brownish, very silty, micaceous, probably alternating with dark grey shale. (Lerskifer, mørk brunlig, stærkt finsandet, glimmerholdig, antagelig vekslende med mørk grå lerskifer).
- 2945–2958 m (9783'–9827') Shale, dark grey, with subordinate dark brownish beds, very fossiliferous (bivalves, ammonites, fish remains etc.). (Lerskifer, mørkegrå, med underordnede mørkebrune lag, stærkt fossiltførende (muslinger, ammonitter, fiskerester etc.).
- 2958–4048 m (9827'–13403') Shale, dark grey to blackish grey, at places with brownish tinge, with fluctuating slight content of silt. In the interval 3553–3572 m (11658'–11718') traces of siltstone, light brownish grey, slightly glauconitic. (Lerskifer, mørkegrå til sortegrå, stedvis med brunlige toner, med vekslende, men svagt, indhold af silt. I intervallet 3553–3572 m

(11658'–11718') spor af siltsten, lys brunlig grå, svagt glaukonitisk).

Chronostratigraphy

The preliminary biostratigraphical investigations carried out by Buch, Kristoffersen, Dinesen, Bang, Stenestad, and Christensen (internal reports) have resulted in the following chronostratigraphical subdivision:

- 41– 478 m Quaternary
- 478–2060 m Tertiary
- 2060–2450 m Upper Cretaceous
- 2450–2654 m Lower Cretaceous
- 2654–3041 m Lower Cretaceous/Upper Jurassic
- 3041–4048 m Upper Jurassic

Stratigraphical remarks

Upper Jurassic: In the samples from 10100'–13398' (3041–4047 m) Christensen (1974) found specimens of the ostracod genera *Galliaecytheridea* and *Mandelstamia*. No typical Lower or Upper Kimmeridgian species were found. The beds concerned can only be dated as of Kimmeridgian age, but Portlandian strata are probably also present. This, however, has not yet been proved.

In core No. 8 (9783'–9792') Bertelsen (pers. communication) has found poorly preserved miospore and microplankton assemblages. The presence of taxa such as *Classopollis echinatus*, *Cicatricosisporites* spp. (rare), *Hystriochidium pulchrum* (common in one sample), *Polystephanophorus* cf. *sarjeantii* (rare) and the absence of typical Lower Cretaceous indicators probably indicate an Upper Jurassic (Middle Kimmeridgian or younger) age for the core.

Foraminifera are also present in the samples. In the samples from 13220'–13398' numerous specimens of *Ammobaculites* were found, but detailed studies are still lacking.

Lower Cretaceous: Buch (1975a) subdivides the section from 2450–2654 m chronostratigraphically as follows:

- 2450– 2459 m Albian
- 2459– 2474 m Aptian
- 2474– 2491 m Barremian
- 2491–?2548 m Hauterivian
- ?2548– 2578 m Valanginian

The interval 2578–2654 m (8580'–8830') contains *Trocholina punctata*, pyrite casts of gastropods, characteristic stems of crinoids (“Pentacrinus”) and small specimens of *Epistomina* cf. *caracolla anterior*. Below 2654 m (8830') only agglutinating foraminifera occur in the samples (Buch 1975a).

Upper Cretaceous: The samples from the Upper Cretaceous have yielded a poor foraminiferal fauna, the shells of which are often badly preserved. It has therefore been difficult to carry out a biostratigraphical investigation. Stenestad (1974) has thus only been able to make the following preliminary subdivision:

- 2060– 2195 m Maastrichtian
- 2195–?2304 m Campanian
- ?2304– 2436 m Santonian
- 2433– 2450 m Unknown stage

The Campanian/Santonian boundary was placed where the uppermost occurrence of *Globotruncana linneiana coronata* was found in the samples.

Tertiary: All the Tertiary stages are present in this borehole. They are found to occur in the following intervals:

- 478– 566 m Pliocene
- 566–1645 m Miocene
- 1645–1837 m Oligocene
- 1837–1999 m Eocene
- 1999–2060 m Paleocene (including Danian)

The boundary between the Danian and the Selandian seems to be found at 2016 m (6735') (Bang 1974a).

The remaining Paleocene is overlain by the Eocene tuff bed series, the bottom of which is indicated at 1999 m (6680') on the gamma ray curve.

Middle Oligocene strata are probably present down to about 1837 m (6150'), where *Haplophragmoides walteri* appears for the first time (Dinesen 1974).

It is open to doubt whether Upper Oligocene beds are found in this well or not. The lower boundary of the Miocene is placed where the first specimen of *Sigmoilina tenuis* is found in the samples. This occurs at 1645 m (5520').

The deposits above this depth and up to 566 m (1980') belong mainly to the Miocene, but it can not be precluded that Upper Oligocene beds are included in the sequence. The boundary between the Middle Miocene (Hod-

de Formation) and the Upper Miocene (Gram Formation) is found on the gamma ray log to be present at 1237 m (4180'), while the Pliocene/Upper Miocene limit is placed at 566 m (1980') on the basis of foraminiferal data (by Kristoffersen 1974). The Upper Miocene section in this boring is 671 m thick, which is more than ever shown earlier in Danish North Sea wells.

Quaternary: The 437 m (1435') thick sequence of clays and sands immediately below the sea bed is of Quaternary age. Buch (1974a) derives the following subdivision from studies of the foraminiferal content of the samples:

- 41–274 m Marine and non-marine beds, possibly reworked
- 274–438 m Icenian. (Numerous – 80–90% – specimens of *Elphidiella han-nai*; the total amount of foraminifera is relatively high)
- 438–465 m Amstelian (*Elphidium orogenense* occurs in some number – 6–15%; this species is not present in the overlying samples)
- 465–478 m samples not present

The lower boundary of the Quaternary in this borehole is uncertain.

Occurrence of hydrocarbons

Testings for hydrocarbons were carried out in the following intervals: 2014–2018 m, 2027–2040 m, 2059–2070 m, 2448–2473 m, 2467–2477 m, 2891–2962 m, and 3884–3921 m. The results of these testings showed that only a thin oil zone was penetrated, without any gas cap.

Dansk Nordsø E-2

- Position:* About 230 km W of Esbjerg
55° 42' 32.2" N – 04° 44' 39.3" E
- Contractor:* Zapata Off-Shore Company
- Equipment:* Drilling Platform "Mærsk Explorer" with rig type Oilwell E-3000.
- Drilling:* Commenced 20. August 1968
Completed 6. September 1968 at a depth of 2165 m below sea level (= 7225' below kelly bushing (KB)).
- Casing:* 36" to 100 m (327') below KB
20" to 176 m (577') below KB
13³/₈" to 1064 m (3492') below KB
7" to 2173 m (7129') below KB
- Elevations:* Sea floor: –41.1 m (135')
Kelly bushing: +37.2 m (122')

Sampling: Cuttings samples were taken for each 30' throughout the drilled section.

Cores were cut in the following intervals:

No. 1 6555'–6599' (Recovery 35')

No. 2 6599'–6657' (Recovery 26')

No. 3 6657'–6717' (Recovery 38½')

No. 4 6717'–6775' (Recovery 20')

No. 5 6775'–6833' (Recovery 14½')

No. 6 6833'–6868' (Recovery 31½')

Lithological log

The descriptions are mainly based on internal reports by Kristoffersen and Bertelsen & Michelsen.

41–164 m (257'–660')	Clay, greenish grey, partly silty. (Ler, grønliggråt, stedvis finsandet)
164–210 m (660'–810')	Sand, grey, fine-grained, at places with a little lignite. (Sand, gråt, fint, stedvis med lidt brunkul)
210–517 m (810'–1818')	Clay, greenish grey, in places occurrences of silt. From 265–292 m (990'–1080') with much lignite. (Ler, grønliggråt, stedvis forekomster af silt. Fra 265–292 m (990'–1080') med meget brunkul)
517–877 m (1818'–3000')	Clay, greyish brown, dark, micaceous. (Ler, gråbrunt, mørkt, glimmerholdigt)
877–1142 m (3000'–3870')	Clay, greenish grey and brownish grey, in the uppermost and lowest parts with some silt. (Ler, grønliggråt, og brunliggråt, øverst og nederst med en del silt)
1142–1252 m (3870'–4230')	Clay, dark greyish brown. (Ler, mørkt gråbrunt)
1252–1261 m (4230'–4260')	Clay, greenish grey. (Ler, grønliggråt)
1261–1612 m (4260'–5410')	Clay or claystone, dark greyish brown (in upper part: brownish black), slightly silty and micaceous. (Ler eller lersten, mørk gråbrun (øverst brunligsort), svagt siltet og glimmerholdigt)
1612–1920 m (5410'–6420')	Clay or claystone, greenish grey (in lower part: grey). Lowermost in the interval: brownish grey and reddish brown colours.

	(Ler eller lersten, grønliggrå (nedefter gråt). Nederst brunliggrå, grønliggrå og rødbrune farver)
1920–1935 m (6420'–6470')	Claystone, reddish brown and greenish grey. (Lersten, rødbrun og grønliggrå)
1935–1952 m (6470'–6525')	Claystone, partly laminated and with beds of volcanic tuff. (Lersten, delvis lamineret og med lag af vulkansk aske)
1952–1959 m (6525'–6549')	Claystone, reddish brown and brownish–greenish grey. (Lersten, rødbrun og brunlig–grønliggrå)
1959–2165 m (6549'–7225')	Limestone, white, possibly with occurrences of greyish, clayey parts. At places with chert and silicified limestone. (Kalksten, hvid, muligvis med forekomster af grålige, lerede partier. Stedvis med flint og forkislede partier).

Chronostratigraphy

On the basis of biostratigraphical studies by Buch, Kristoffersen, Dinesen, Bang and Stenestad the following chronostratigraphy has been proposed:

- 41– 517 m Quaternary
- 517–1976 m Tertiary
- 1976–2165 m Upper Cretaceous

Stratigraphical remarks

Upper Cretaceous: The present boring was stopped in Upper Cretaceous limestone after having penetrated Maastrichtian and Campanian deposits.

The depth figure for the Maastrichtian/Campanian boundary has not yet been fixed, but it seems to be found within the interval of 2142–2157 m (7150'–7200').

In the overlying section from 1976–2142 m (6606'–7150') Stenestad (1974) has described the presence of Lower and Upper Maastrichtian foraminiferal assemblages.

Tertiary: All known Tertiary stages are found, but further studies are needed before the depths of the boundaries between them can finally be determined. The following preliminary subdivision is proposed:

517–	621 m	Pliocene
621–	ca. 1612 m	Miocene
ca. 1612–	ca. 1746 m	Oligocene
ca. 1746–	1952 m	Eocene
1952–	1976 m	Paleocene (including Danian)

Bang (1974b) has studied the planktonic foraminifera of the cores No. 1 and 2 and of the cuttings samples. She mentions in her report that her *Globoconus daubjergensis gigantea* Zonule (Bang 1969, p. 63) is found near the top of core No. 1, where the Danian limestone has its upper limit. This shows that Upper Danian deposits are lacking in this borehole. Cfr. the table fig. 15, p. 71.

From the logs, the top of the Danian section can be placed at 1959 m (6550') and the bottom of the ash-bearing series of the Eocene at 1952 m (6525'), the total thickness of the Selandian thus being only 7 m (25').

The samples from the Eocene sequence have been inspected by Dinesen (1974), who points to the occurrence of many specimens of the agglutinating *Haplophragmoides walteri* in the cuttings below 1746 m (5850').

Oligocene beds containing amongst other species *Rotaliatina bulimoides* and *Sigmoilina tenuis* occur from 1612– ca. 1746 m (5410'–ca. 5850').

The overlying Miocene series has not yet been subdivided in detail, but the Middle Miocene/Upper Miocene boundary, as defined on gamma ray logs from the earlier Danish North Sea wells (Rasmussen 1974) was in the present boring found at 1261 m (4260').

Kristoffersen (1974) is at present of the opinion that Upper Miocene beds are present up to 621 m (2160'), covered by marine Pliocene (Scaldisian) sediments.

Quaternary: Foraminiferal investigations by Buch (1974a) are the basis for the following subdivision:

41–344 m	Undated beds
344–454 m	Icenian
454–475 m	Amstelian
475–517 m	Undated beds

Buch (l.c.) defines the Quaternary/Pliocene limit by 1) the presence of *Elphidium oregonense* above 475 m and the absence of this species in the samples below, 2) by a distinct change in the foraminiferal assemblages at 475 m and 3) by a characteristic peak on the SP and resistivity logs. Pliocene foraminifera are only observed in the samples below 484 m.

The subdivision of the Quaternary series is mainly based on 1) the pre-

sence of *Elphidium orogenense* below 454 m, 2) the dominance of *Elphidium hannai* in the section 344–454 m and 3) the SP and resistivity log features.

Occurrence of hydrocarbons

Oil and condensate were found in the Upper Cretaceous and Danian limestone.

Production tests were carried out in 6 zones:

Zone I : 2069–2076 m (6910'–6932') – 1 test

Zone III: 2019–2028 m (6745'–6775') – 1 test

Zone IV: 2007–2012 m (6708'–6723') – 4 tests

Zone V : 1987–1991 m (6640'–6655') – 2 tests

Zone VI: 1965–1968 m (6570'–6580') – 2 tests

Zones I and III yielded oil and water, while certain amounts of gas and condensate were produced from the other zones.

Dansk Nordsø F-1

Position: About 90 km WNW of Thyborøn
57°01'53'' N – 06°54'28.5'' E

Contractor: Zapata Off-Shore Company

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

Drilling: Commenced 5th October 1968
Completed 17th October 1968 at a depth of 2382 m below sea level (= 7938' below kelly bushing (KB))

Casing: 36'' to 101 m (331') below KB
13³/₈'' to 215 m (705') below KB
9⁵/₈'' to 792 m (2598') below KB

Elevations: Sea floor: – 40.8 m (134')
Kelly bushing: + 37.2 m (122')

Sampling: Cuttings samples were taken at 30' intervals or at 20' and 10' intervals.
Cores were not drilled in this well
27 sidewall cores were taken

Lithological log

The following descriptions are based mainly on an internal report written by Stenestad.

41–45 m (256'–270')	Gravel. (Grus)
45–137 m (270'–570')	Silt, brownish grey, with greenish tint, bedded, micaceous, glauconitic. (Silt, brunliggråt med grønligt skær, lagdelt, glimmerholdigt, glaukonitholdigt).
137–310 m (570'–1140')	Silt and sand, grey, occasionally brownish. In lowermost part developed as a brownish grey siltstone. In places with occurrences of lignite. (Silt og sand, gråt, stedvis brunligt. Nederst udviklet som brunliggrå siltsten. Stedvis med forekomster af brunkul).
310–621 m (1140'–2160')	Silt and clay, greyish brown, glauconitic and micaceous. (Silt og ler, gråbrunt, glaukonit- og glimmerholdigt).
621–630 m (2160'–2190')	Clay, reddish brown and greyish green, glauconitic and with a content of dark grey, fine-grained silt. (Ler, rødbrunt og grågrønt, glaukonitisk og med indhold af mørkegråt finsilt).
630–652 m (2190'–2260')	Claystone, grey, with pyrite and mica flakes. (Lersten, grå, med finfordelt pyrit og glimmer).
652–670 m (2260'–2320')	Claystone, grey, with beds of volcanic tuff. (Lersten, grå, med lag af vulkansk aske).
670–694 m (2320'–2400')	Marlstone, light grey. (Mergelsten, lysegrå).
694–738 m (2400'–2544')	Limestone, muddy, white and light grey, with occurrences of chert and silicified limestone. (Kalksten, slammet, hvid og lysegrå, med forekomster af flint og forkislet kalksten).
738–868 m (2544'–2970')	Chalk, white, with thin beds or lenses of greyish marl. (Kridt, hvidt, med tynde lag eller linser af grålig mergel).
868–1237 m (2970'–4182')	Limestone, muddy, white and greyish white, slightly hardened. In lower parts with subordinate beds of greenish grey marl and lowermost with beds of bluish red claystone.

- (Kalksten, slammet, hvid og grålighvid, let hærnet. Nedefter med underordnede lag af grønliggrå mergel og nederst med lag af blåligrød lersten).
- 1237–1264 m (4182'–4270') Lime-silt, light and dark brownish grey, irregularly bedded, glauconitic and micaceous, mainly slightly consolidated, fossiliferous (fragments of *Inoceramus*). (Kalksilt, lyst og mørkt brunliggråt, uregelmæssig lagdelt, glaukonit- og glimmerholdigt, overvejende svagt konsolideret, fossilførende (fragmenter af *Inoceramus*)).
- 1264–1283 m (4270'–4330') Siltstone, light greenish grey and brownish grey, glauconitic and micaceous. (Siltsten, lys grønliggrå og brunliggrå, glaukonit- og glimmerholdig).
- 1283–1295 m (4330'–4370') Siltstone, greyish, glauconitic, micaceous and calcareous. (Siltsten, grålig, glaukonit-, glimmer- og kalkholdig).
- 1295–1298 m (4370'–4380') Claystone, grey, with greenish and brownish tint. (Lersten, grå, med grønligt og brunligt skær).
- 1298–1299 m (4380'–4384') Limestone, whitish, soft. (Kalksten, hvidlig, blød).
- 1299–1300 m (4384'–4386') Clay, reddish brown, rather sticky, laminated. (Ler, rødbrunt, ret fedt, fint lagdelt).
- 1300–1713 m (4386'–5743') Claystone, grey, with mica flakes and glauconite, calcareous. From ca. 1542 m (5180') with laminated beds of grey siltstone, containing lignite, glauconite, mica and pyrite. From ca. 1706 m (5720') a black grey shale occurs. (Lersten, grå, med fint fordelt glimmer og glaukonit, kalkholdig. Fra ca. 1542 m (5180') med fint lagdelt grå siltsten, som indeholder lignit foruden glaukonit, glimmer og pyrit. Fra ca. 1706 m (5720') optræder sortgrå lerskifer).
- 1713–1725 m (5743'–5780') Sandstone, white grey, loose, fine-grained, at places cemented by pyrite. (Sandsten, hvidgrå, løs finkornet, stedvis cementeret af pyrit).

- 1725–1743 m (5780'–5840') Claystone, grey and dark grey, rather sticky, with content of small mica flakes and lignite. (Ler, gråt og mørkegråt, ret fedt, med indhold af små glimmerblade og lignit).
- 1743–1760 m (5840'–5896') Sandstone, white-grey, loose, mainly medium-grained to rather coarse, cemented by calcite. (Sandsten, hvidgrå, løs, overvejende mellemkornet til ret grov, cementeret af kalcit).
- 1760–2041 m (5896'–6817') Shale, grey – dark grey, with fine mica flakes, in places with siltstone of the same colour and subordinate beds of greyish brown claystone and siltstone. In the upper part of the series with subordinate beds or concretions of brown clay-ironstone. At 1883–1889 m (6300'–6320') a pyritic, grey quartzsandstone. (Lerskifer, grå-mørkegrå, med fine glimmerblade, stedvis med siltsten af samme farve og underordnede lag af grå-brun lersten og siltsten. Øverst i lagserien underordnede lag eller konkretioner af brun lerjernsten. Ved 1883–1889 m (6300'–6320') en pyritholdig, grå kvartssandsten).
- 2041–2049 m (6817'–6845') Siltstone, light grey, glauconitic and pyritic, cemented by calcite. (Siltsten, lys grå, glaukonit- og pyritholdig, cementeret af kalcit).
- 2049–2078 m (6845'–6940') Shale, black grey, with content of fine mica flakes, non-calcareous and with beds of grey or reddish violet siltstone. (Lerskifer, sortgrå, med indhold af fine glimmerblade, kalkfri og med lag af grå eller rødviolet siltsten).
- 2078–2117 m (6940'–7068') Sandstone, light grey, coarse-grained, quartzitic with subordinate beds of greyish brown claystone and siltstone. (Sandsten, lysegrå, grovkornet, kvartsitisk, med underordnede lag af gråbrun lersten og siltsten).
- 2117–2129 m (7068'–7108') Claystone, reddish brown with greenish spots, silty, micaceous, non-calcareous.

- 2129–2160 m (7108'–7210') (Lersten, rødbrun, med grønne reduktionspletter, siltholdig, glimmerholdig, kalkfri). Sandstone, light grey, with slightly reddish tint, mainly fine-grained, cemented by calcite. (Sandsten, lys grå, med svagt rødligt skær, overvejende finkornet, cementeret af kalcit).
- 2160–2307 m (7210'–7690') Claystone, reddish brown, silty, with subordinate beds of light reddish grey sandstone. (Lersten, rødbrun, siltholdig, med underordnede lag af lys rødliggrå sandsten).
- 2307–2331 m (7690'–7770') Siltstone, fine-grained sandstone, and claystone, light reddish brown. (Siltsten, finkornet sandsten og lersten, lys rødbrun).
- 2331–2382 m (7770'–7938') Claystone, very silty and siltstone, clayey, of light brownish grey colour with reddish tint. (Lersten, siltrig og siltsten, leret, af lys brunliggrå farve med rødligt skær).

Chronostratigraphy

On the basis of internal reports by Buch (1974a, 1975a), Dinesen (1974), Bang (1974c), Stenestad (1974), Christensen (1974), Bertelsen (1974a), Michelsen (1974), and publications by Michelsen (1975, 1978a), and Bertelsen (1975, 1978), the following chronostratigraphical subdivision of the drilled profile is proposed:

- 41– 63 m Quaternary
- 63– 738 m Tertiary
- 738–1299 m Upper Cretaceous
- 1299–1511 m Lower Cretaceous
- 1511–1713 m Lower Cretaceous + Upper Jurassic
- 1713–1760 m Middle Jurassic
- 1760–2041 m Lower Jurassic
- 2041–2117 m Lower Jurassic + Upper Triassic
- 2117–2382 m Upper Triassic

Stratigraphical remarks

Upper Triassic: A palynoflora, composed of *Ovalipollis* and *Triadispora*, was found by Bertelsen (1975, p. 26) in the sample 7680'–7690' (at 2307 m). Especially *Ovalipollis* points to an Upper Triassic age for the flora.

Other miospore assemblages were recovered by the same author (Bertelsen 1975, p. 25) in the sandstone from 2078–2118 m. The species include abundant *Ricciisporites tuberculatus* Lundblad and as accessories were found *Densosporites foveocingulatus* Schulz, *Aratrisporites* spp. and *Rhaetipollis germanicus* Schulz. Bertelsen (loc. cit. p. 26) correlates the beds containing this microflora with the Upper Rhaetian. For further discussions on the pre-Jurassic sequence, reference is made to Bertelsen's paper.

The sandstone from 2041–2049 m and the shale from 2049–2078 m are both referred to the Gassum Formation. The age of this formation can be either Jurassic or Triassic.

Lower Jurassic: Above the Gassum Formation a quite uniform series of dark shales or claystones, referred to the Fjerritslev Formation, is penetrated. Michelsen (1975, p. 62–64) was able to subdivide this section biostratigraphically on the basis of the ostracod fauna. This subdivision into ostracod zones is dealt with in his paper. Here only Michelsen's division into stages is recorded:

1767–1807 m Upper Pliensbachian
 1807–1871 m Lower Pliensbachian
 1871–1977 m Upper Sinemurian
 1977–2041 m Lower Sinemurian

Middle Jurassic: The sandstone and claystone from 1712–1760 m are correlated as members of the Haldager Formation, which on the basis of its position in the sections is dated in northern Danish onshore wells as of predominantly Middle Jurassic age.

Upper Jurassic: Investigations by Christensen (1974) on the ostracods in samples from the interval between 5100'–5740' have shown that Kimmeridgian and Portlandian deposits are present. Christensen found the following ostracod zones:

The *Galliaecytheridea compressa* Zone (Age: Portlandian)
 The *Galliaecytheridea spinosa* Zone (Age: Upper Kimmeridgian)
 The *Galliaecytheridea dissimilis* Zone and *G. elongata* Zone (Age: Lower Kimmeridgian)

These ostracod zones are well-known from Northwest Europe (see Christensen & Kilenyi 1970). It has not been possible to fix any depth limits

between these zones, but the thickness of the Kimmeridgian part seems to amount to about 125 m.

Lower Cretaceous: The foraminiferal content of the Lower Cretaceous sequence has been studied by Buch. Only the five uppermost samples yielded faunas which were of value for age determinations. The following preliminary subdivision into stages appears from Buch's (1975) and Christensen's (1974) internal reports:

- 1295–1313 m Albian
- 1313–1322 m Aptian
- 1322–1331 m Barremian
- 1331–1487 m Unspecified Lower Cretaceous (including Berriasian)

Upper Cretaceous: Stenestad has reported on foraminiferal investigations and log correlations in internal reports (1974 and 1975a), in which he derives the following subdivision of the Upper Cretaceous unit:

- 738– 908 m Maastrichtian
- 908– 999 m Campanian
- 999–1167 m Santonian
- 1167–1206 m Turonian
- 1206–1267 m Cenomanian

Tertiary: A preliminary subdivision of the Tertiary sequence can be summarized as follows:

- 63–118 m Upper Oligocene
- 118–652 m Middle Oligocene – Eocene
- 652–738 m Paleocene, including Danian

The uppermost boundary of the Danian unit probably lies at ca. 667 m (2310'), since Bang (1974c) found planktonic foraminifera of Danian age in the sample at 2310'. The top of the limestone is, however, found at 694 m (2400').

Superposing the Danian, some beds of Paleocene age occur containing, amongst other species, many specimens of *Spiroplectamina spectabilis*. A boundary to the Eocene volcanic tuff beds is visible on the gamma ray log at 652 m, while other Tertiary units can hardly be recognized from the Schlumberger logs.

The Eocene sequence contains strata whose characteristics are well known from Danish onshore sections. However, it has still not been possible to find a distinct boundary between the Eocene and Oligocene beds in this well.

Dinesen (1974) mentions that the Oligocene sequence probably consists of Middle Oligocene beds. The foraminiferal species *Turrilina alsatica* is very common here and is reminiscent of the fauna in the Middle Oligocene Viborg Formation known from the Danish onshore. Other characteristic faunal elements are *Ceratobulimina contraria* and numerous "*Dentalina*".

The upper part of the brownish micaceous and glauconitic silt from 63–137 m may be of Upper Oligocene age. It contains *Asterigerina guerichi*, and it seems most likely that no Miocene or younger Tertiary beds are present in this boring.

Quaternary: Only 3 samples (from 256'–330') can be considered of Quaternary age. They contain a few Quaternary foraminifera (Buch 1974a). In the sample 300'–330' Upper Oligocene species such as *Sphaeroidina variabilis* and *Nonion affine* are also present. They are probably derived from the underlying layers.

Occurrence of hydrocarbons

No oil or gas was demonstrated in this well.

Dansk Nordsø G-1

- Position*: About 205 km W of Esbjerg
55°35'04.9" N – 05°09'46.3" E
- Contractor*: Zapata Off-Shore Company
- Equipment*: Drilling platform "Mærsk Explorer" with rig type Oil-well E-3000
- Drilling*: Commenced 26th October 1968
Completed 2nd December 1968 at a depth of 3775 m below sea level (= 12.508' below kelly bushing (KB))
- Casing*: 36" to 109 m (358') below KB
20" to 221 m (726') below KB
13³/₈" to 1068 m (3503') below KB
9⁵/₈" to 2223 m (7294') below KB
- Elevations*: Sea floor: – 48.8 m (160')
Kelly bushing: + 37.2 m (122')
- Sampling*: Cuttings samples were taken at 30' intervals from 370'–6700',

at 20' intervals from 6700'–7210', and at 10' intervals from 7210'–7390' and from 10300'–12508'.

Cores were drilled in the following intervals:

No. 1: 6615'–6645' (Recovery: 30')

No. 2: 6645'–6688' (Recovery: 43')

No. 3: 6688'–6703' (Recovery: 15')

Sidewall cores were taken at scattered depths from 9354' to 10488' (24 samples in all).

Lithological log

The following descriptions are based on reports by Michelsen and Bertelsen & Michelsen.

- | | |
|---------------------------|---|
| 49–188 m (282'–740') | Clay, grey, dark grey or brownish grey, sticky or silty, calcareous. Beds of coarse-grained sand or gravel. In places with many mollusc shells. (Ler, gråt, mørkegråt eller brunliggråt, fedt eller finsandet, kalkholdigt. Lag af grovkornet sand eller grus. Stedvis mange molluskskaller). |
| 188–415 m (740'–1484') | Clay, sticky or silty, grey, in upper part dark grey, in lower part more brownish grey, mainly non-calcareous, micaceous. Shell fragments. (Ler, fedt eller finsandet, gråt, øverst mørkegråt, nedadtil mere brunliggråt, overvejende kalkfrit, glimmerholdigt. Stedvis en del skalfragmenter). |
| 415–423 m (1484'–1510') | Gravel and coarse-grained sand. (Grus og grovkornet sand). |
| 423–1147 m (1510'–3884') | Clay, rather sticky, grey or brownish grey, non-calcareous, micaceous. (Ler, ret fedt, gråt eller brunliggråt, kalkfrit, glimmerholdigt). |
| 1147–1575 m (3884'–5290') | Clay, rather sticky, dark and greyish brown – brownish black (lighter in lower part), non-calcareous, micaceous, in lowermost part with occurrences of silt. A bed of greenish grey clay at 4150'–4180'. (Ler, ret |

- fedt, mørkt og gråligbrunt-brunsort (lysere nedefter), kalkfrit, glimmerholdigt, nederst med forekomster af finsand. Et lag grønlig-gråt ler ved 1228–1237 m (4150'–4180').
- 1575–1639 m (5290'–5500') Clay, dark brownish grey, non-calcareous, with occurrences of greenish clay and limestone. (Ler, mørkt brungråt, kalkfrit, med forekomster af grønligt ler og kalksten).
- 1639–1913 m (5500'–6400') Claystone, tight, olive grey and greenish grey, in lower part often brownish. In places beds of marl or limestone. (Lersten, fed, olivengrå og grønliggrå, nederst ofte brunlig. Stedvis lag af mergel og kalksten).
- 1913–1938 m (6400'–6460') Claystone, reddish brown and greenish grey. (Lersten, rødbrun og grønliggrå).
- 1938–1947 m (6460'–6510') Claystone, partly laminated, and with beds of volcanic tuff. (Lersten, stedvis lamineret, og med lag af vulkansk aske).
- 1947–1950 m (6510'–6520') Claystone, greenish grey and reddish brown. (Lersten, grøngrå og rødbrun).
- 1950–1978 m (6520'–6610') Claystone, brownish grey and dark grey. (Lersten, brunliggrå og mørkegrå).
- 1978–2020 m (6610'–6750') Limestone, compact, rather hard, whitish, with light grey chert and many mm-thin beds of rather sticky, greenish grey – dark grey, very calcareous clay. (Kalksten, tæt, ret hård, hvidlig, med lysegrå flint og mange mm-tynde lag af ret fedt, grønliggråt-mørkegråt, stærkt kalkholdigt ler).
- 2020–2032 m (6750'–6790') Limestone, compact, rather hard to soft, whitish, with light grey chert. (Kalksten, tæt, ret hård eller blød, hvidlig, med lysegrå flint).
- 2032–2182 m (6790'–7280') Limestone, whitish, with light grey chert. At 6830'–6870' a compact, very hard, yellowish white limestone. (Kalksten, hvidlig, med lysegrå flint. Ved 2045–2057 m tæt, meget hård, gullighvid kalksten).
- 2182–2221 m (7280'–7410') Limestone, light grey or white, and claystone, grey. (Kalksten, lysegrå eller hvid og grå lersten).

Dansk Nordø G-1

Dansk Nordø H-1

Dansk Nordø I-1

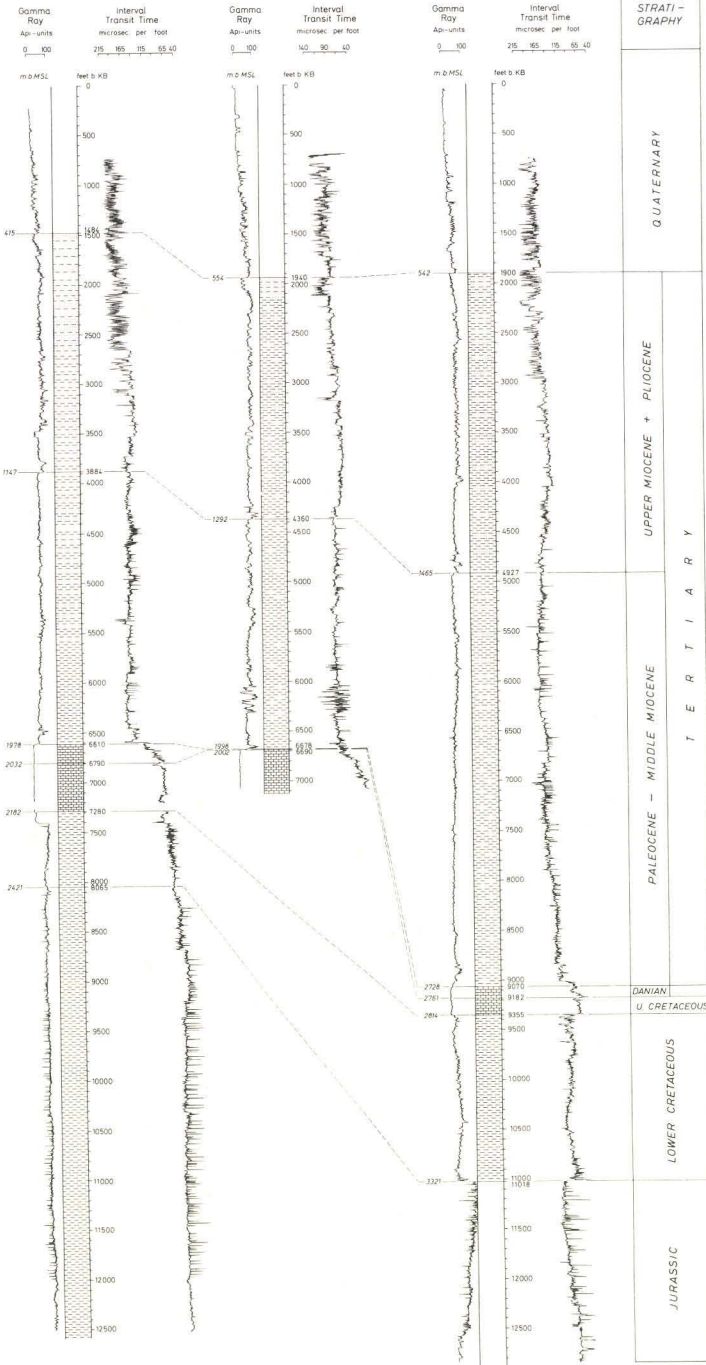


Fig. 13.

- 2221–2307 m (7410'–7690') Claystone, brownish red, brownish grey and grey – dark grey. (Lersten, brunliggrød, brunliggrå og grå- mørkegrå).
- 2307–2421 m (7690'–8065') Claystone, partly hard, partly sticky, dark grey, slightly calcareous. (Lersten, ret hård, ret fed, mørkegrå, svagt kalkholdig).
- 2421–2462 m (8065'–8200') Claystone, soft, rather sticky, dark brownish grey, micaceous, non-calcareous. (Lersten, blød, ret fed, mørk brunliggrå, glimmerholdig, kalkfri).
- 2462–3775 m (8200'–12508') Claystone, dark brownish grey in upper parts, dark grey in lower parts; often shaly. Below 2611 m (8690') with mm-thin beds of glauconitic siltstone and limestone. Marine fossils of bivalves and ammonites. (Lersten, i de øvre dele mørk brunliggrå, i de nedre dele mørkegrå, ofte skifret. Under 2611 m med mm-tynde lag af glaukonitholdig finsandsten og kalksten. Marine fossiler af muslinger og ammonitter).

Chronostratigraphy

The following subdivision is based on internal reports by Buch, Dinesen, Bang, and Christensen:

- 49– 415 m Quaternary
 415–2032 – Tertiary
 2032–2182 – Upper Cretaceous
 2182–2362 – Lower Cretaceous
 2362–3775 – Upper (and Middle?) Jurassic

Stratigraphical remarks

Jurassic: The lowermost 1300 m of the boring penetrated a series of dark coloured claystones and beds of siltstone and limestone. The main part of this series, more than 1000 m in thickness, is referred to the Kimmeridgian on the basis of preliminary investigations of the ostracods by Christensen (1974).

In the lowermost samples a find of a single shell of *Progonocytheridea* ?sp. may indicate the presence of Middle Jurassic beds in the bottom part of the borehole. Otherwise only Upper Jurassic strata are present in the drilled section.

The Kimmeridgian is mainly represented by the *Galliaecytheridea spinosa* Zone, which seems to be of considerable thickness. Above the Upper Kim-

meridian there occurs a less than 100 m thick series of Portlandian comprising the *Galliaecytheridea compressa* Zone. (Christensen 1974).

A detailed biostratigraphical subdivision of the Upper Jurassic in this boring must wait until more thorough investigations have been carried out.

Lower Cretaceous: A subdivision of the Lower Cretaceous section and determination of the limit to the Upper Jurassic was made by Buch (1974) on the basis of the foraminiferal content. He concludes the following chronostratigraphy:

- 2182–2191 m Albian
- 2191–2234 m Barremian
- 2234–2307 m Hauterivian-Valanginian
- 2307–2362 m Berriasian

Upper Cretaceous: Unfortunately the foraminifera in the samples from the Upper Cretaceous series are badly preserved. The preliminary investigations by Stenestad (1974) have therefore been very difficult, and have hitherto only proved the existence of beds of Maastrichtian, Campanian and Santonian age.

Tertiary: Resting on the Upper Cretaceous limestone a white limestone of Danian age occurs. Bang (1974d) has succeeded in finding in the cores most of the zones or zonules proved by her to occur in the Danian of the Danish North Sea area (cf. the table fig. 15, page 71).

The top of core no. 1 includes the *Globorotalia* 5/6 zonule, while the boundary between the *Globigerina daubjergensis* Zone and the *Subbottina triloculinoides* Zone is situated at 1986 m (6638'). The *Tuborotalia* sp. 4 Zonule is found at 1992 m (6656'), the *Globigerina gigantea* Zonule at 1994 m (6665') and the »Sandby assemblage« at 2002 m (6691'). The uppermost zonule, »The Nordsøeina-assemblage« Zonule, has not been found in the samples.

The section between the bottom of the beds with volcanic tuff at 1947 m and the top of the white limestone of Danian age at 1977 m is referred to the remaining part of the Paleocene.

In cuttings samples from 6520', 6550' and 6580' Bang (1974 d) has found agglutinating foraminifera, characteristic of the non-calcareous Paleocene clay (*Spiroplectammina spectabilis* Assemblage).

The Eocene-Oligocene boundary in this boring is not well defined. Dinesen (1974) has inspected some of the samples and found specimens of the foraminifera *Haplophragmoides walteri* in the sample 5860'–5890', but single specimens of the same species occurred already in sample 5290'–5320', and it is not obvious that the species is restricted to the Eocene.

Beds of probable Middle Oligocene age with, amongst other species, *Sigmoilina tenuis*, *Glomospira charoides* and *Rotaliatina bulimoides* are present in the samples below 1603 m (5380'), according to preliminary investigations by Dinesen (1974).

It is not precluded that beds of Upper Oligocene age are present, but as a whole the section from 1603 m (5380') to 415 m (1484') is of Neogene age. The base of the Upper Miocene sequence as defined on the gamma ray log is found in this well at 1147 m (3884'). The deposits below this depth and down to 1603 m (5380') are mainly of Middle Miocene age, probably including Lower Miocene beds.

The Pliocene/Upper Miocene boundary is placed at 481 m (1700') according to Kristoffersen (1974).

A. Buch (1974 a) found foraminifera in sample 1360'–1390' and the Pleistocene species *Elphidium oregonense* in sample 1330'–1360'. It seems probable, therefore, that the Pleistocene/Pliocene boundary is found at about 377 m (1360'). Kristoffersen (1974) suggests this limit at 415 m (1484').

Our present knowledge of the chronostratigraphical subdivision of the Tertiary sequence in this borehole can finally be summarized as follows:

- 415– 481 m Pliocene
- 481–1603 m Miocene
- 1603–1749 m Oligocene and Eocene
- 1749–2032 m Paleocene (including Danian from 1977–2032 m).

Quaternary: The younger sediments in the boring and their foraminiferal content were studied by Buch (1974 a), who dates them to be Quaternary and gives the following subdivision:

- 76–167 m Pleistocene. Stage unknown
- 167–185 m Unknown stage. Samples missing
- 185–259 m Icenian, probably reworked
- 259–377 m Icenian. Marine beds with dominance of *Elphidiella hannai*.

Occurrence of hydrocarbons

Small amounts of gas and a very little condensate was obtained, especially from testing of the interval 1978–1984 m (6612'–6632'), which forms part of the Danian limestone.

Dansk Nordsø H-1

- Position:* About 240 km W of Esbjerg
55°46'26.87'' N – 04°38'48.44'' E
- Contractor:* Zapata Off-Shore Company
- Equipment:* Drilling platform »Mærsk Explorer« with rig type Oilwell E-3000
- Drilling:* Commenced 13th December 1968
Completed 30th December 1968 at a depth of 2127 m below sea level (= 7100' below kelly bushing (KB))
- Casing:* 36'' to 108 m (355') below KB
13³/₈'' to 213 m (698') below KB
9⁵/₈'' to 1065 m (3495') below KB
7'' to 2154 m (7068') below KB
- Elevations:* Sea floor: –46.3 m (152')
Kelly bushing: + 37.2 m (122')
- Sampling:* Cuttings samples were taken at 30' intervals throughout the well.
Cores were drilled in the following intervals:

- No. 1: 6682'–6685' (Recovery: 4,5')
No. 2: 6708'–6715' (Recovery: 2')
No. 3: 6715'–6738' (Recovery: 23')
No. 4: 6738'–6768' (Recovery: 30')
No. 5: 6768'–6796' (Recovery: 28')
No. 6: 6796'–6825' (Recovery: 30')
No. 7: 6825'–6855' (Recovery: 30')

Lithological log

The descriptions are based on studies by Bertelsen (internal report) of the cuttings and of many sidewall cores taken in the intervals 1942'–3500'(27) and 6052'–6656'(24).

- 46–146 m (274'–600') Clay, brownish grey and grey, calcareous, with beds of sand and gravel. Occurrences of lignite. Many shells of molluscs throughout the series. (Ler, brunliggråt og gråt, kalkholdigt, med lag af brunkul. Lagene indeholder mange molluskskaller).
- 146–210 m (600'–810') Sand, grey, fine-grained, glauconitic. In places with lignite. (Sand, gråt, finkornet, glaukonitholdigt. Stedvis med brunkul).

- 210–292 m (810'–1080') Silt, grey or light grey, with occurrences of clay and gravel. Lowermost in the interval occurrences of lignite. (Silt, gråt eller lysegråt, med forekomster af ler og grus. Nederst i afsnittet forekomster af brunkul).
- 292–554 m (1080'–1940') Clay, bluishgrey – grey, rather sticky, faintly micaceous. Subordinate beds of silt. Shell fragments down to about 1560'. At 1740' rusty clay and traces of greenish black – dark olive brown clay. (Ler, blåliggråt-gråt, ret fedt, svagt glimmerholdigt. Underordnede lag af finsand. Skalstumper ned til ca. 438 m (1560'). Ved 493 m (1740') rustfarvede partier og spor af grønligsort-mørk olivenbrunt ler).
- 554–676 m (1940'–2340') Sand, fine-grained, greyish, downwards with growing content of clay and mica. (Sand, finkornet, gråligt, nedefter med stigende lerindhold og voksende glimmerindhold).
- 676–926 m (2340'–3160') Clay, grey, micaceous, partly calcareous. Traces of yellowish grey limestone, grey marl and beds of light greenish silt. (Ler gråt, glimmerholdigt, stedvis kalkholdigt. Spor af gulgrå kalksten og mergel samt lag af lyst grønligt finsand).
- 926–931 m (3160'–3178') Silt, micaceous, medium – coarse-grained, grey, clayey, glauconitic, with subordinate beds of grey or brownish grey, micaceous clay. (Glimmerfinsand, mellem-grovkornet, gråt, leret, glaukonitholdigt, med underordnede grå eller brunliggrå, glimmerholdige lerlag).
- 931–1030 m (3178'–3500') Clay, greyish brown, rather sticky, micaceous, partly with glauconite and pyrite («Mica Clay»), with beds of fine to medium-grained grey silt. (Ler, gråbrunt, ret fedt, glimmerholdigt, stedvis glaukonit- og pyritholdigt («Glimmerler») med lag af fint-mellemkornet, gråt finsand).
- 1030–1234 m (3500'–4170') Clay, brownish grey, downwards grey, sticky, micaceous and pyritic, non-calcare-

- ous, with beds of greyish brown, clayey, glauconitic siltstone. (Ler, brungråt, nederst gråt, fedt, glimmerholdigt og pyritholdigt, kalkfrit, med lag af gråbrun, leret, glaukonitholdigt finsandsten).
- 1234–1270 m (4170'–4290') Claystone, faintly shaly, grey, more or less calcareous. At about 1255 m (4240') and 1267 m (4280') a grey, hard, clayey limestone. (Lersten, let skifret, grå, svagt kalkholdig til kalkholdig. Ved ca. 1255 m (4240') og 1267 m (4280') grå, hård, leret kalksten).
- 1270–1292 m (4290'–4360') Shale, light grey – grey, faintly calcareous or non-calcareous. From 1270–1280 m (4290'–4320') with translucent needle-shaped spicules of sponges (?). (Lerskifer, lysegråt-gråt, svagt kalkholdigt til kalkfri. Fra 1270–1280 m (4290'–4320') med glasklare, nåleformede spongie (?)-spikler).
- 1292–1581 m (4360'–5310') Clay or claystone, greyish brown, alternating with black – brown layers, non-calcareous and micaceous. (Ler eller lersten, gråbrun, vekslende med sorte-brune lag, kalkfri, glimmerholdig).
- 1581–1746 m (5310'–5850') Claystone, greenish grey – grey, downwards darker, rather soft and sticky, with pyrite. From 5340'–5370' and from 5610'–5640' a white grey marl occurs. At about 5840' a greyish yellow clayey, soft limestone. (Lersten, grønliggrå-grå, nedefter mørkere, ret blød og fed, med indhold af pyrit. Fra 1590–1600 m (5340'–5370') og fra 1673–1682 m (5610'–5640') lidt hvidgrå mergel. Ved ca. 1743 m (5840') grågul leret, blød kalksten).
- 1746–1807 m (5850'–6050') Claystone, dark grey, brownish or greenish and greyish brown, hard or white grey, soft limestone. From 1801 m (6030') a light greyish blue, whitish grey or yellow limestone predominates. (Lersten, mørkegrå, brunlig eller grønlig og gråbrun, hård eller

- 1807–1883 m (6050'–6300') Hvidgrå, blød kalksten. Fra 1801 m (6030') dominerer kalksten af lys gråblå, hvidgrå eller gullig farve). Limestone, brown and grey, often clastic, interchanging with predominantly dark and greyish claystone or shale. The limestone probably occurs in bands. (Kalksten, brunlig og grå, ofte klastisk, vekslende med overvejende mørke og grålige lersten eller lerskifre. Kalkstenen forekommer muligvis i bænke).
- 1883–1971 m (6300'–6590') Shale, grey, with greenish, bluish grey or brownish tint. (Lerskifer, grå i grønlig, blågrå eller brunlige nuancer). Shale, grey – greybrown, often finely laminated, hard, with beds of volcanic ash or tuff. From abt. 1993 m (6630') a yellowish white hard limestone with pyrite and fish remains occurs (Lerskifer, grå – gråbrun, ofte fint lamineret, hård, med lag af vulkansk aske. Fra ca. 1993 m forekommer en gullighvid, kornet, hård kalksten med pyritkrystaller og fiskerester).
- 1971–1994 m (6590'–6665') Shale, light grey, partly grey or greenish grey. (Lerskifer, lysegrå, med partier af grå og grønliggrå farve).
- 1994–1998 m (6665'–6678') Limestone, white – yellow, with chert and silicified parts. Scattered occurrences of thin beds of clay. The uppermost beds impregnated with crude oil. (Kalksten, hvid-gullig, slammet, med flint og forkislede partier. Spredte forekomster af fine, tynde lerlag. De øverste lag er imprægneret med olie).
- 1998–2127 m (6678'–7100')

Chronostratigraphy

The chronostratigraphical subdivision of the drilled section of this borehole is based on investigations by Buch (1974 *a*), Kristoffersen (1974) Dinesen (1974), Bang (1974 *e*), and Stenestad (1974). Their results can be summarized as follows:

46– 554 m Quaternary

554–2002 m Tertiary
2002–2127 m Upper Cretaceous

Stratigraphical remarks

Upper Cretaceous. The Upper Cretaceous series in this borehole seems to be rather reduced in relation to onshore Danish Cretaceous series.

It has not been possible to determine the limit between the Danian and the Maastrichtian because of the lack of samples from the interval 6683'–6708', within which the limit must be found.

A preliminary stratigraphical subdivision of the Upper Cretaceous section by Stenestad (1974), based on the foraminiferal remains, shows the following reduced series:

- ca. 2000–2007 m ?Upper Cretaceous
- 2007–2066 m Lower Maastrichtian
- 2066–2075 m ?Lower Maastrichtian
(samples not present)
- 2075–2093 m Upper Campanian
- 2093–2127 m Lower Campanian

Tertiary. The top of the Danian can probably be placed at 1998 m (6678') on the basis of the logs. The Danian series is thus very reduced. Preliminary investigations by Bang (1974 e) on the foraminiferal content in samples from core no. 1 (6682'–6685') and in limestone cuttings obtained from a sample at 6670' show the occurrence of a subzone of the *Globoconusa daubjergensis* Zone (see fig. 15, p. 71) and probably also of a zonule from the same zone. Strata of Upper Danian age do not seem to be present in this boring.

According to the same author, the Selandian is represented by a grey shale containing agglutinating foraminifera (*Ammodiscus*, *Haplophragmium*, *Rzehakina* etc.). The top of the shale can probably be placed at 1994 m (6665'), which depth, according to our view, is identical with the base of the tuff-bearing Eocene series.

Eocene agglutinating foraminifera are found in the interval 1807–1994 m (6050'–6665') and Oligocene forms such as *Sigmoilina tenuis* and *Rotaliatina bulimoides* have been proved by Dinesen (1974) to occur scattered in the samples from the interval 1581–1807 m (5310'–6050'), pointing to a predominantly Middle Oligocene age for this interval.

Kristoffersen (1974) subdivides the Neogene in this borehole on the basis of Schlumberger logs and foraminifera. His chronostratigraphical proposals are included in the following summary of the whole Tertiary in the boring:

554– 640 m Pliocene (Scaldisian)

640–1292 m Upper Miocene
 1292–1581 m Middle and Lower Miocene
 1581–1618 m Miocene and Oligocene
 1618–1807 m Oligocene
 1807–1994 m Eocene
 1994–1998 m Selandian
 1998–2002 m Danian

Quaternary. The preliminary investigations by Buch (1974 a) on the samples from 290' – ca. 1830' are based on the foraminiferal content. An interval of Icenian age with *Elphidiella hannai* as the dominating species occurs from 301–493 m (1110'–1740'), but the samples from the beds above this interval have still not been included in the investigations. The upper limit of the Icenian has therefore not been determined. Occurrences of *Elphidium oregonense* in the interval 493–521 m (1740'–1830') indicate an Amstelian age, and finds of *Pseudoeponides pseudotepidus* in the samples farther below point to a Pliocene age for these beds.

Occurrence of hydrocarbons

Condensate and traces of oil were found in the Upper Cretaceous-Eocene part of the section. Six zones in the section 1811–2034 m (6064'–6794') were tested for hydrocarbons.

Dansk Nordsø I-1

Position: About 270 km WNW of Esbjerg
 56°03'10'' N – 04°14'59.5'' E

Contractor: Zapata Off-Shore Company

Equipment: Drilling platform »Mærsk Explorer« with rig type Oil-well E-3000

Drilling: Commenced 5th February 1969
 Completed 1st April 1969 at a depth of 3872 m below sea level (12823' below kelly bushing (KB))

Casing: 42'' to 113 m (371') below KB
 20'' to 225 m (737') below KB
 13³/₈'' to 1228 m (4029') below KB
 9⁵/₈'' to 3314 m (10874') below KB

Elevations: Sea floor: – 57.3 m (188')
 Kelly bushing: + 37.2 m (122')

Sampling: Cuttings samples were taken at 30' intervals from 450'–8960' and at 10' or 20' intervals from 8980'–12820'

Cores were drilled in the following intervals:

No. 1: 9091'–9121' (Recovery: 17')

No. 2: 9121'–9153' (Recovery: 32')

No. 3: 9188'–9218' (Recovery: 30')

No. 4: 9218'–9276' (Recovery: 58')

No. 5: 9276'–9541' (Recovery: 48')

Lithological log

57–155 m (310'–630')	Sand, occasionally with beds of clay. (Sand, stedvis med lag af ler).
155–542 m (630'–1900')	Clay, more or less silty, brownish grey to grey. (Ler, mere eller mindre siltholdigt, brunliggråt til gråt).
542–731 m (1900'–2520')	Clay, partly very silty, brownish grey to grey. (Ler, stedvis meget siltholdigt, brunliggråt til gråt).
731–868 m (2520'–2970')	Clay, slightly silty, micaceous, brownish grey. (Ler, svagt siltholdigt, glimmerholdigt, brunliggråt).
868–1078 m (2970'–3660')	Clay, rather sticky, micaceous, dark brownish grey or grey. (Ler, ret fedt, glimmerholdigt, mørkt brunliggråt eller gråt).
1078–1465 m (3660'–4927')	Clay, more or less silty, micaceous, partly glauconitic, with beds of silt. (Ler, mere eller mindre siltholdigt, glimmerholdigt, stedvis glaukonitholdigt, med lag af silt).
1465–1773 m (4927'–5940')	Clay, rather sticky, greyish brown, black or grey. (Ler, ret fedt, gråbrunt, sort eller gråt).
1773–2633 m (5940'–8760')	Clay, rather sticky, mainly greenish grey or grey, in places chocolate brown. Occurrences of silt, partly coarse-grained, darker in colour than the clay, throughout the interval. (Ler, ret fedt, hovedsagelig grønliggråt til gråt, stedvis chokoladebrunt. Forekomster af silt, mere eller mindre grovkornet og mørkere af farve end leret, findes i hele intervallet).
2633–2660 m (8760'–8850')	Claystone, shaly, reddish brown, partly greyish green. (Lersten, skifret, rødbrun, delvis grågrøn).
2660–2688 m (8850'–8940')	Clay (stone), dark brownish grey, with beds

- of volcanic tuff. (Ler (sten), mørk brunlig-grå, med lag af vulkansk aske).
- 2688–2728 m (8940'–9070') Claystone, grey, greyish green, brownish, in lower part with beds of light coloured marl. (Lersten, grå, grågrøn, brunlig, nederst med lag af lys mergel).
- 2728–2810 m (9070'–9355') Limestone, white, partly grey, hard, partly silicified. (Kalksten, hvid, delvis grå, hård med forkislede partier).
- 2810–2814 m (9340'–9355') Limestone, reddbrown. (Kalksten, rødbrun).
- 2814–2855 m (9355'–9490') Shale, silty, calcareous, greygreen, interbedded with clay (or claystone), non-calcareous, grey-green, with pyrite. (Skifer, siltholdigt, kalkholdig, grågrøn, med lag af ler (eller lersten), fedt, kalkfrit, grågrønt, med pyrit).
- 2855–2950 m (9490'–9800') Limestone, grey or greyish white, with beds of clay or marl, greyish green. (Kalksten, grå eller gråhvid, med lag af grågrønt ler eller mergel).
- 2950–3102 m (9800'–10300') Marl(stone), grey, gradually passing into shale. (Mergel(sten) grå, gradvis gående over i skifer).
- 3102–3321 m (10300'–11018') Shale, grey to dark grey, partly brownish, silty, calcareous. (Skifer, grå til mørkegrå, delvis brun, finsandet, kalkholdig).
- 3321–3872 m (11018'–12823') Claystone, silty, dark greyish brown to brownish black, gradually becoming harder downwards, with beds of limestone and sandstone. (Lersten, finsandet, mørk grå-brun til brunsort, gradvis hårdere nedadtil, med lag af kalksten og sandsten).

Chronostratigraphy

On the basis of the various internal reports from Buch, Dinesen, Bang, Stenestad, Christensen, and Bertelsen, the following preliminary chronostratigraphical subdivision of the boring has been proposed. Studies of Schlumberger logs have, however, been taken into consideration to correct the depth figures.

57– 542 m Quaternary
542–2761 m Tertiary

2761–2814 m Upper Cretaceous
 2814–3321 m Lower Cretaceous
 3321–3872 m Upper Jurassic

Stratigraphical remarks

Upper Jurassic: No biostratigraphical subdivision of the section 3321–3872 m has hitherto been made. Some few ostracods were found, indicating an Upper Jurassic (Kimmeridgian) age for at least some of the beds (Christensen 1975).

Lower Cretaceous: A preliminary investigation by Buch (1975 a) of the foraminiferal content of the section 2814–3313 m gives rise of the following subdivision:

2814–2831 m Albian
 2831–2858 m Aptian
 2858–2910 m Barremian
 2910–3256 m Hauterivian
 3256–3313 m Berriasian

Upper Cretaceous: This section is very reduced in thickness and the samples are highly contaminated by caving. The preliminary examinations of the foraminifera by Stenestad (1975 a) point to a possible absence of the Upper Maastrichtian. If so, only the Lower Maastrichtian and the Upper Campanian seem to be present in the boring. Stenestad suggests the following zonation:

2770–2800 m (Upper?) and Lower Maastrichtian
 2800–2810 m Upper Campanian

Tertiary: Bang (1975 a) states that a typical Upper Danian foraminiferal assemblage is present in a core sample from 2734 m (9091'). The top of the Danian beds may be found at approximately 2709 m (9010'), where a young Upper Danian assemblage occurs.

The preliminary investigations by Bang show the following chronostratigraphy:

2688–2721 m Selandian + ? Upper Danian
 2721–2734 m no samples
 2734 m Upper Danian (the lower part)
 2734–2750 m Danian
 2750–2765 m Danian + Senonian
 2765 m Senonian

The remaining Paleocene has not been further subdivided into chronostratigraphical units. A few specimens of *Spiroplectamina* sp. and other agglutinating foraminifera characterizing the Selandian have been shown to occur in the samples below 2688 m (8940') (Bang 1975 a).

The Eocene sequence is introduced by the base of the tuff-bearing beds at 2688 m (8940'), and in the Lower Eocene strata in this boring a planktonic foraminiferal fauna is present, containing amongst other species *Globigerina patagonica*, known from the Lower Eocene Røsnæs Clay of Denmark (Dinnesen 1974). The first occurrence of *G. patagonica* was recorded at 2642 m (8790').

The uppermost occurrence of the agglutinating species *Haplophragmoides walteri* is found at 1746 m (5850'), this depth presumably being close to the top of the Eocene.

Typical Middle Oligocene forms such as *Turrilina alsatica* and *Rotaliatina bulimoides* are recognised above 1746 m (5850'), and the topmost specimens of *Sigmoilina tenuis* have been recorded at 1691 m (5670'). According to Schlumberger correlation the top of the Middle Oligocene section is indicated as lying at 1654 m (5550').

It is a question whether Upper Oligocene beds are present or not in this boring. The sequence above 1654 m (5550') and up to 1462 m (4920') is mainly of Middle Miocene age, but the faunas from this section have not yet been studied in detail. An important boundary at 1465 m (4927') is, however, indicated on the Schlumberger logs. This is the Middle Miocene – Upper Miocene limit or, more exactly, the boundary between the Hodde Formation and the Gram Formation.

The Miocene – Pliocene boundary is found at about 603 m (2100'). The samples from 511–530 m (1800'–1860') contain specimens of *Pseudoeponides pseudotepidus*, which may indicate that beds of Pliocene age are present in the boring.

Quaternary: The 450 m thick Quaternary sequence is divided by Buch (1975 b) into the following units:

- 57–237 m Quaternary, undated
- 237–329 m »marine post–Eemian«
- 329–475 m Icenian
- 475–508 m Amstelian

Most of the samples in the interval 57–237 m are devoid of foraminifera, and the section 237–329 m is characterised by low frequencies of foraminifera. *Elphidium clavatum* and *Protelphidium orbiculare* predominate.

The Icenian section is dominated by *Elphidiella hannai*, and the interval

329–475 m contains *Elphidium oregonense* in its upper part, suggesting an Amstelian age.

Occurrence of hydrocarbons

Gas and oil were tested from the Upper Cretaceous limestone. Drill stem tests were made in the interval 9185'–9204'. The oil gravity is about 0,83 (= 41°API).

Dansk Nordsø J-1

- Position:* About 35 km W of Hanstholm
57°25'57.4'' N – 08°33'05.6'' E
- Contractor:* Zapata Off-Shore Company
- Equipment:* Drilling platform »Mærsk Explorer« with rig type Oil-well E-3000
- Drilling:* Commenced 23. December 1969
Completed 14th January 1970 at a depth of 1950 m (= 6519' below kelly bushing KB))
- Casing:* 36'' to 105 m (345') below KB
20'' to 227 m (744') below KB
13³/₈'' to 1061 m (3418') below KB
- Elevations:* Sea floor: – 44.2 m (145')
Kelly bushing: + 37.2 m (122')
- Sampling:* Cuttings samples were taken at 30' intervals from 330'–3500', at 20' intervals from 3500'–4900', and at 10' intervals from 4900'–6519'. No cores were cut in this well.
28 sidewall cores were taken in the interval 4658'–6505'.

Lithological log

The log is based on descriptions of the dried samples (cuttings) by Bertelsen, Kristoffersen, Jacobsen, and Michelsen.

- 44–80 m (267'–385') Clay, sand and gravel, probably with beds of clay in the upper part of the section, and with silty clay in the lower part. (Ler, sand og grus, muligvis med lerlag i den øvre del og siltholdigt ler i den nedre del).
- 80–187 m (385'–735') Chalk, white, with chert. In the lower part beds of limestone, greyish brown. (Kridt, hvidt, med flint. Nedadtil lag af gråbrun kalksten).

- 187–194 m (735'–758') Marlstone, greyish green to light grey. (Mergelsten, gråliggrå til lysegrå).
- 194–214 m (758'–825') Limestone, tight, light grey, clayish. (Kalksten, tæt, lysegrå, lerholdig).
- 214–284 m (825'–1055') Clay, more or less sticky, dark grey in upper part, brownish grey in lower part, pyritic. (Ler, mere eller mindre fedt, mørkegrå opadtil, brunliggrå nedadtil, pyritholdigt).
- 284–300 m (1055'–1105') Marlstone, light grey. (Mergelsten, lysegrå).
- 300–353 m (1105'–1280') Clay, grey to brownish grey or greyish brown, downwards with sand or silt. (Ler, grå til brunliggrå eller gråbrunt, nedadtil sand- og siltholdigt).
- 353–676 m (1280'–2340') Clay, silty, grey, with shaly sections, especially from 1850'–1958'. (Ler, siltholdigt, grå, med skifrede partier, især fra 527–560 m).
- 676–1055 m (2340'–3582') Claystone, silty, grey, greyish green, calcareous. Hard claystones occur subordinately from 3520' downwards. Beds of lignite especially occurring in the interval 3540'–3560'. (Lersten, siltholdigt, grå, grønliggrå, kalkholdig. Hårde lerstenslag optræder underordnet nedadtil fra 1036 m. Lag af brunkul forekommer specielt i afsnittet 1042–1048 m).
- 1055–1074 m (3582'–3647') Siltstone, light grey, micaceous, alternating with claystone, silty, dark grey, shaly, non-calcareous. (Siltsten, lys grå, glimmerholdig, vekslende med lersten, siltholdig, mørkegrå, skifret, kalkfri).
- 1074–1158 m (3647'–3920') Claystone, silty, grey, non-calcareous. (Lersten, siltholdig, grå, kalkfri).
- 1158–1697 m (3920'–5690') Claystone, dark grey and grey, partly shaly, with pyrite. In places many fossils: ammonites, gastropods, crinoids etc. Many intercalations of siltstone. (Lersten, mørkegrå og grå, delvis skifret, pyritholdig. Her og der mange fossilrester af bl.a. ammonitter, gastropoder og krinoider. Mange tynde lag af siltsten).

- 1697–1722 m (5690'–5773') Sandstone, fine – to medium-grained, yellowish white. Occurrences of grey siltstone and subordinate beds of grey to dark grey claystone. (Sandsten, fin- til mellemkornet, gullighvid. Forekomster af grå siltsten og underordnede lag af grå til mørkegrå lersten).
- 1722–1735 m (5773'–5815') Claystone and siltstone, grey – dark grey. (Lersten og siltsten, grå–mørkegrå).
- 1735–1769 m (5815'–5925') Sand, light grey, in upper part coarse-grained, in lower part mainly fine-grained. Lignite and claystone with lignite-particles occur in some intervals (5850'–5900', especially 5890'–5900'). (Sand, lysegrå, øverst grovkornet, nederst finkornet. Brunkul og lersten med kulpartikler forekommer i visse intervaller (1746–1761 m, især 1756–1761 m)).
- 1769–1787 m (5925'–5985') Siltstone, mainly coarse-grained, and claystone variegated (tints of red, yellow and grey). (Siltsten, hovedsagelig grovkornet, og lersten, broget farvet (nuancer af rødt, gult og gråt)).
- 1787–1799 m (5985'–6025') Sandstone, whitish grey, with subordinate beds of siltstone, grey – dark grey, and clay, light brown or grey. (Sandsten, hvidliggrå, med underordnede lag af siltsten, grå–mørkegrå, og ler, lysebrunt og gråt).
- 1799–1848 m (6025'–6185') Clay or claystone, variegated, with subordinate sandstone or siltstone. (Ler eller lersten, broget farvet, med underordnede lag af sandsten eller siltsten).
- 1848–1950 m (6185'–6519') Sandstone, light grey, and beds of clay, claystone and siltstone, reddish brown, with occurrences of anhydrite. (Sandsten, lysegrå, og lag af ler, lersten og siltsten, rødlig-brun, med forekomster af anhydrit).

Chronostratigraphy

The following chronostratigraphical subdivision is based partly upon publications by Michelsen (1975, 1978a), Bertelsen (1978a), and internal reports by Buch, Stenestad and Christensen.

- 44– 80 m Quaternary
- 80– 214 m Upper Cretaceous
- 214– 772 m Lower Cretaceous
- 772– 954 m Lower Cretaceous + Upper Jurassic
- 954–1055 m Upper Jurassic
- 1055–1074 m Middle Jurassic
- 1074–1697 m Lower Jurassic
- 1697–1769 m Lower Jurassic + Upper Triassic
- 1769–1950 m Triassic

Stratigraphical remarks

Triassic: A subdivision of the Triassic sequence has not been possible due to the absence of characteristic fossils.

The well-defined Gassum Formation is, however, clearly present to judge from the gamma ray and the I.T.T. logs. This formation is partly Upper Triassic and partly Lower Jurassic of age (see Bertelsen 1978a and Michelsen 1975).

Lower Jurassic: The sequence above 1697 m has been investigated by Michelsen (1975), who subdivides the marine claystone from 1074–1697 m biostratigraphically into 3 ostracod zones (Michelsen, 1.c. pp. 56–59) and refers the whole interval to the Fjerritslev Formation (Michelsen 1978a). His investigations conclude in the following chronostratigraphical units:

- 1074–1158 m Toarcian–Aalenian
- 1158–1310 m Upper Pliensbachian
- 1310–1520 m Lower Pliensbachian + Sinemurian
- 1520–1697 m Sinemurian + Hettangian

Middle Jurassic: It is evident from the wireline logs that the middle Jurassic Haldager Formation is present from 1055–1074 m. Only very few non-characteristic fossils have been recorded from the samples. It has therefore only been possible to date the sandy deposits in the interval on the basis of the log-correlations (Michelsen 1978a).

Upper Jurassic: The interval between the Lower Jurassic and the Lower

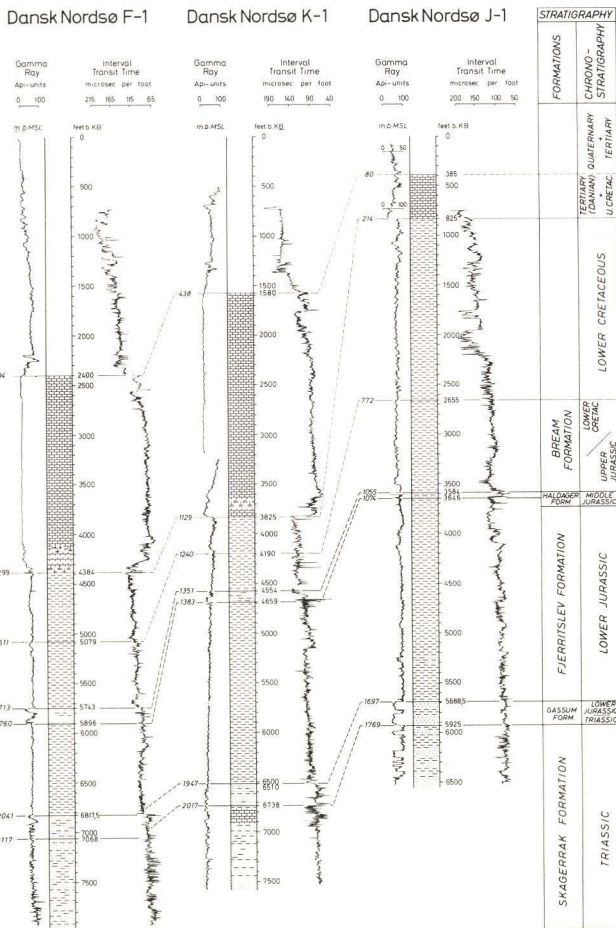


Fig. 14.

Cretaceous has been inspected for ostracods by Christensen, who gives the following comments in his internal report (1975) :

640– 902 m Berriasian – Portlandian.

Only few fossils. Contains amongst other species *Mandelstamia sexti* Neale and *Galliaecytheridea teres* (Neale).

902– 993 m Portlandian – Upper Kimmeridgian.

The fauna includes *Galliaecytheridea compressa* Bruun Chr. & Kilenyi, *G. spinosa* Kilenyi, *Mandelstamia* spp., *Aalenella gracilis* Bruun Chr. & Kilenyi, *Macrodentina* spp., *Dicrorygma maior* Bruun Chr, and *D. reticulata* Bruun Chr.

993–1072 m Lower Kimmeridgian and (probably) Upper Oxfordian.

Galliaecytheridea dissimilis Oertli, *G. postrotunda* Oertli,
and *Macrodentina gallica* Malz, *Mandelstamia* spp.

1072–1174 m Oxfordian and Middle Jurassic. *Praeschuleridea* sp.

The depth figures given by Christensen all originate from the labels of the cuttings samples. They do not correspond to log depth figures and therefore need to be corrected. However, they give an impression of the succession of important ostracod species in this particular well, and they furthermore indicate the presence of the chronostratigraphical units mentioned.

Lower Cretaceous: A preliminary subdivision based on the foraminiferal fauna is given by Buch (1975b):

214–249 m Albian

249–316 m Aptian

316–356 m Barremian

356–551 m Hauterivian

551–640 m Valanginian

640–676 m Berriasian

Upper Cretaceous: The reduced Upper Cretaceous sequence seems to lack beds of Maastrichtian age. Stenestad has studied the foraminiferal content in the samples from this interval and derives the following subdivision (internal report 1975a):

80–161 m Upper + Lower Campanian

161–179 m Santonian

179–197 m Turonian

197–214 m Cenomanian

Quaternary: No Tertiary beds have been identified in this borehole. Above the chalk only two samples were available (from 60–79 m). They contained 7 and 11 specimens respectively of Quaternary foraminifera, together with a few Upper Cretaceous forms. Buch (1975b) considers this combination to have originated from glaciogene sediments.

Occurrence of hydrocarbons

No oil or gas was found in this boring.

Dansk Nordsø K-1

- Position:* About 90 km W of Hanstholm
57°07'37.7" N – 07°09'43" E
- Contractor:* Zapata Off-Shore Company
- Equipment:* Drilling platform "Mærsk Explorer" with rig type Oilwell E-3000
- Drilling:* Commenced 21st January 1970
Completed 5th February 1970 at a depth of 2254 m below sea level (= 7518' below kelly bushing)
- Casing:* 36" to 113 m (372') below KB
20" to 217 m (711') below KB
13³/₈" to 574 m (1882') below KB
- Elevations:* Sea floor: – 56.4 m (185')
Kelly bushing: + 37.2 m (122')
- Sampling:* Cuttings samples were taken at 30' intervals from 300'–2250', at 20' or 10' intervals from 2250'–4370' and at 30' intervals from 4430'–7490'.
No cores were cut in this well.
18 sidewall cores were taken in the interval 1560'–7018'.

Lithological log

The following description is based on the preliminary investigations of the cuttings, carried out in the laboratory by Bertelsen, Jacobsen, Kristoffersen and Michelsen (internal report, dated August 1970).

57–109 m (310'–480')	Clay, partly very silty, light grey. (Ler, stedvis meget siltholdigt, lysegråt).
109–348 m (480'–1265')	Clay, very silty, brownish, micaceous, calcareous. (Ler, meget siltholdigt, brunligt, glimmerholdigt, kalkholdigt).
348–382 m (1265'–1375')	Clay, greenish and greyish, occasionally with beds of weathered volcanic ash (tuff). (Ler, grønligt eller gråligt, stedvis med lag af forvitret vulkansk aske).
382–438 m (1375'–1560')	Clay, silty, grey, changing into greyish to light grey marl. (Ler, siltet, gråt, gående over i grålig til lysegrå mergel).
438–501 m (1560'–1765')	Limestone, white. (Kalksten, hvid).
501–926 m (1765'–3160')	Chalk, white. From about 676 m (2340') more hardened and with higher clay content.

- Downwards with occurrences of greyish-greenish marl. (Kridt, hvidt. Fra 676 m mere hærddet og større lerindhold. Nedadtil med forekomster af grålig-grønlig mergel).
- 926–1057 m (3160'–3590') Limestone, rather hard, whitish – greyish white. Small occurrences of greyish marl. (Kalksten, ret hård, hvidlig-grålighvid. Små forekomster af grålig mergel).
- 1057–1069 m (3590'–3630') Limestone, rather hard, white. (Kalksten, ret hård, hvid).
- 1069–1129 m (3630'–3825') Marl, silty, greyish, dominating in the upper part of the section, intercalated with lime-siltstone, white – greyish white, micaceous (dominating from 3730'–3825'). (Mergel, siltholdig, grålig, dominerende i afsnittets øvre del, vekslende med kalksiltsten, hvid-grålighvid, glimmerholdig (dominerende fra 1100–1129 m)).
- 1129–1142 m (3825'–3860') Claystone, reddish brown, non-calcareous, and claystone, greyish brown, calcareous. (Lersten, rødbrun, kalkfri og lersten, gråbrun, kalkholdig).
- 1142–1276 m (3860'–4310') Claystone, silty, brownish grey (below 4000' of grey colour), with pyrite and subordinate occurrence of siltstone, clayey, grey or greenish, partly glauconitic. (Lersten, siltholdigt, brunliggrå (under 1182 m gråt), med pyrit og underordnede forekomster af siltsten, leret, grå eller grønlig, stedvis glaukonitholdig).
- 1276–1351 m (4310'–4554') Claystone, silty, downwards shaly, dark grey, with pyrite, mica flakes and lignite. In the lower part of the interval siltstone, laminated, grey, or brownish. Fossils of molluscs. (Lersten, siltholdig, nedadtil skifret, mørkegrå, med pyrit, glimmerblade og lignit. I afsnittets nedre del siltsten, lagdelt, grå og brunlig. Molluskskaller).
- 1351–1383 m (4554'–4659') Sand (stone), fine-grained in the upper part and coarse-grained in the lower part. Subordinate siltstone with pyrite and lignite. (Sand

- (sten), øverst finkornet, nederst grovkornet. Underordnet siltsten, imprægneret med pyrit; forekomster af lignit).
- 1383–1391 m (4659'–4685') Claystone, dark grey. (Lersten, mørkegrå).
- 1391–1392 m (4685'–4690') Sandstone, yellowish, with oolites in a matrix of greyish brown siderite. (Sandsten, gullig, med ooliter i en matrix af gråbrun siderit).
- 1392–1546 m (4690'–5195') Claystone, shaly, silty, dark grey, pyritic, micaceous and with lignite. Beds of siltstone, clayey, greyish-brown. (Lersten, skifret, siltholdig, mørkegrå, pyritisk, glimmerholdig og med lignit. Lag af siltsten, leret, gråbrun).
- 1546–1761 m (5195'–5900') Shale, silty, dark grey – grey, pyritic, micaceous and lignitic. Subordinate beds of siltstone, clayey, brownish. Occurrence of coarse-grained, glauconitic siltstone. Pyritized fossils of pelecypods, cephalopods and crinoids. (Lerskifer, siltet, mørkegrå–grå, pyritisk, glimmerholdig og med lignit. Underordnede lag af siltsten, leret, brunlig. Forekomster af grovkornet, glaukonitisk siltsten. Pyritiserede fossiler af pelecypoder, cephalopoder og crinoider).
- 1761–1947 m (5900'–6510') Shale, silty, dark grey, pyritic. (Skifer, siltholdig, mørkegrå pyritisk).
- 1947–2017 m (6510'–6738') Sandstone, more or less coarse-grained, colourless, yellow or grey, with beds of more fine-grained or medium-grained sandstone. At 6660' one or more coal beds. (Sandsten, mere eller mindre grovkornet, farveløs, gul eller grå, med lag af mere finkornet eller mellemkornet sandsten. Ved 1993 m et eller flere kullag).
- 2017–2042 m (6738'–6822') Claystone, silty, slightly calcareous to non-calcareous, dark grey, slightly darker than above, with subordinate beds of greyish – brownish sandstone and coal. (Lersten, siltholdig, svagt kalkholdig til kalkfri, mørkegrå, svagt mørkere end ovenfor, med underordnede lag af gråbrun sandsten og kul).

- 2042–2056 m (6822'–6866') Limestone, marly, greyish–brown, with beds of claystone and sandstone. (Kalksten, mergelholdig, gråbrun–brun, med lag af lersten og sandsten).
- 2056–2133 m (6866'–7120') Claystone, with varying content of silt, reddish brown, calcareous, interchanging with sandstone, unconsolidated, medium – coarse-grained, colourless or yellowish. (Lersten, med varierende indhold af silt, rødbrun, kalkholdig, vekslende med sandsten, ukonsolideret, mellem–grovkornet, farveløs eller gullig).
- 2133–2141 m (7120'–7148') Shale, silty, greyish green. (Lerskifer, silt–holdig, gråliggrøn).
- 2141–2256 m (7148'–7525') Sandstone, unconsolidated, medium – coarse-grained, colourless, yellowish or rusty, interchanging with claystone, silty, reddish brown, in the upper part of the section, and with siltstone, reddish brown in the lower part. (Sandsten, ukonsolideret, mellem–grovkornet, farveløs, gullig eller rustfarvet, vekslende med lersten, siltholdig, rødbrun i den øvre del af afsnittet, og med siltsten, rødbrun, i den nedre del).

Chronostratigraphy

The following chronostratigraphical subdivision has been prepared on the basis of internal reports by Bertelsen, Christensen, Michelsen, Buch, Stenestad, Bang and Dinesen and, for the lower part of the boring, from publications by Bertelsen (1975, 1978a) and Michelsen (1975, 1978a).

- 57– 133 m Quaternary
- 133– 501 m Tertiary
- 501–1129 m Upper Cretaceous
- 1129–1240 m Lower Cretaceous
- 1240–1351 m Lower Cretaceous + Upper Jurassic
- 1351–1383 m Middle Jurassic
- 1383–1947 m Lower Jurassic
- 1947–2017 m Lower Jurassic + Upper Triassic
- 2017–2256 m Triassic

Stratigraphical remarks

Triassic: The lowermost beds in this borehole consist of sandy red beds of the type well known from Lower Triassic sections elsewhere in the region (Bertelsen 1978a). They are presumed to be of Upper Triassic age, by comparison with the F-1 well, though no fossil evidence has been obtained from the samples. The strata from 1947–2042 m contain a microflora which was studied by Bertelsen (1975, pp. 27–28, text-fig. 2), who found a predominance of the mainly Rhaetian miospore *Ricciisporites tuberculatus* Lundblad in some samples from the section 1993–2042 m. Other finds, such as the dinoflagellate *Rhaetogonyaulax rhaetica* (Sarjeant) Loeblich & Loeblich, seem to confirm the Rhaetic age of this section.

A single specimen of an ostracod *Darwinula* sp. was found by Christensen (1975) in the sample 6830'. This particular find is worth mentioning, since the *Darwinula* concerned is present in a limestone which can be correlated with an oolitic limestone found in the Upper Triassic in Jylland, e.g. in the Nøvling No. 1 boring (see Christensen in Rasmussen et. al. 1973, p. 134), where it contains a characteristic ostracod fauna chronostratigraphically placed at the transition between Middle Keuper and Lower Rhaetic (*sensu germanico*). The formation in the Nordsø K-1 well, including the limestone, is referred by Bertelsen (1975, pp. 27–28 and text-fig. 2) to the Vinding Formation (defined by Larsen 1966). Cfr. Bertelsen 1978a.

The beds above 2017 m and up to 1947 m have yielded no Triassic spores, but according to Bertelsen (1975) are lithostratigraphically referable to the Gassum Formation of Denmark (defined by Larsen 1966), their age probably being Upper Triassic and, partly, Lower Jurassic.

Lower Jurassic: The interval from 1383–1947 m, mostly consisting of shale or claystone, has been divided biostratigraphically and chronostratigraphically by Michelsen (1975 pp. 64–65 text-fig. 14) on the basis of ostracods. Rich faunas occur in certain intervals. The four biozones that are present are described in Michelsen's paper, and form the basis for the following chronostratigraphical subdivision:

- 1395–1487 m Upper Pliesbachian
- 1487–?1618 m Lower Pliesbachian
- ?1618–1761 m Upper Sinemurian
- 1761–1947 m Lower Sinemurian and Hettangian

Middle and Upper Jurassic: Middle Jurassic faunas or floras have not yet been found in this boring, but the sand or sandstone from 1367–1383 m and the overlying claystone from 1351–1367 m are both correlated by Michelsen

(1975, 1978a) with the Haldager Formation of Denmark (defined by Larsen 1966) and in consequence are probably of Middle Jurassic age.

The beds above 1383 m contain ostracods, which were preliminarily studied by Christensen (1975). The foraminifera in the samples from around the limit between Jurassic and Lower Cretaceous were furthermore investigated by Buch (1975b). A combination of the views of these two geologists results in the following preliminary chronostratigraphical subdivision:

- 1255–1276 m Berriasian and Portlandian
- 1276–1340 m Lower Kimmeridgian
- 1340–1383 m Oxfordian and Middle Jurassic

Christensen notes in his report that it is hardly possible to separate the Berriasian and the Portlandian in the section 1240–1276 m (4190'–4310') on the basis of the recovered forms of the ostracods *Mandelstamia sexti* Neale and species of *Galliaecytheridea*. The occurrence of Upper Kimmeridgian ostracods can not be claimed with certainty, but a find of the species *Aalenella gracilis* Chr. & Kilenyi probably derives from beds of Upper Kimmeridgian age.

In the samples from 4310'–4620' (1276–1340 m) the ostracod zones with *Galliaecytheridea dissimilis* and *G. elongata* contain many *Macrodentina* spp.

Lower Cretaceous: Buch (1975b) subdivides the Lower Cretaceous section on the basis of the foraminifera content as follows:

- 1129–1139 m Albian
- 1139–1150 m Aptian
- 1150–1158 m Barremian
- 1158–1191 m Hauterivian
- 1191–1240 m Valanginian
- 1240–1255 m Berriasian

Upper Cretaceous: The samples from the Upper Cretaceous section are highly contaminated by foraminifera from the beds above and are thus difficult to use as a safe basis for a stratigraphical subdivision. Nevertheless, Stenestad (1975a) has succeeded in establishing a preliminary chronostratigraphy for these beds:

- 501–ca. 688 m Upper and Lower Maastrichtian
- ca. 688–ca. 853 m Upper and Lower Campanian
- ca. 853–ca. 1017 m Santonian

- ca. 1017–ca. 1066 m Coniacian
- ca. 1066–ca. 1102 m Turonian
- ca. 1102–ca. 1129 m Cenomanian

Tertiary: On the basis of foraminiferal investigations by Bang and Dinesen it is possible to give the following preliminary view of the subdivision of the Tertiary:

- 133–365 m Middle Oligocene and possibly Eocene
- 365–374 m Probably Eocene
- 374–438 m Paleocene (Selandian and ?Danian)
- 438–501 m Paleocene (Danian)

Resting on the Maastrichtian chalk occurs a white limestone with a valuable foraminiferal content. Bang (1975b) has been able to find evidence for the two foraminiferal zones into which she subdivides the North Sea Danian biostratigraphically (see fig. 15, p. 71):

The *Globoconusa daubjergensis* Zone (top to be found in the sample interval 1620'–1650' (457–466 m)) and the *Subbotina triloculinoides* Zone. The top of the Danian is probably to be found in the sample interval 1380'–1410' (383–393 m), where an assemblage used to define the top of the Danian occurs together with an assemblage characterizing the Selandian marl (Ker-teminde Marl) found in eastern onshore Denmark. The lithology in this boring is thus an example, among others, that the Danian sedimentation is not only restricted to the white limestone.

The top of the Selandian can be placed either at 382 m, just below the volcanic tuff beds (age: probably Eocene), or a little higher, at 374 m, because Paleocene foraminifera seem to occur in the sample 1350'–1380' (374–383 m) (Dinesen 1974). The only trace of a possible Eocene foraminiferal fauna is the dominant occurrence of *Glomospira charoides* in the sample 1320'–1350' (365–374 m).

Above 365 m micaceous clays with *Turrilina alsatica* are present, pointing to a Middle Oligocene age. It can not be precluded, however, that the lower part of the section is represented by Eocene sediments which lack microfossils of Eocene age, but are filled with Oligocene foraminifera deriving from the overlying beds due to caving.

Upper Oligocene, Miocene, and Pliocene sediments do not seem to be present in this boring.

Quaternary: Buch (1975b) has succeeded in subdividing the Quaternary sequence into two units:

Danian zonation

57– 91 m marine Weichsel (Skærumhede Interstadial)
91–133 m ? Saale

The section 57–91 m contains numerous foraminifera with a high content of *Elphidium clavatum* and *Cassidula crassa*. The occurrence of *Elphidium subarcticum*, *Nonion labradoricum* and *Elphidium asklundi* make a correlation to the so-called “Older Yoldia Clay” of Vendsyssel, Denmark, probable.

Below this marine series the sediments contain a contamination of Upper Cretaceous, Tertiary, and Quaternary foraminifera, as is often the case in boulder clay.

Occurrence of hydrocarbons

No oil or gas was found in this boring.

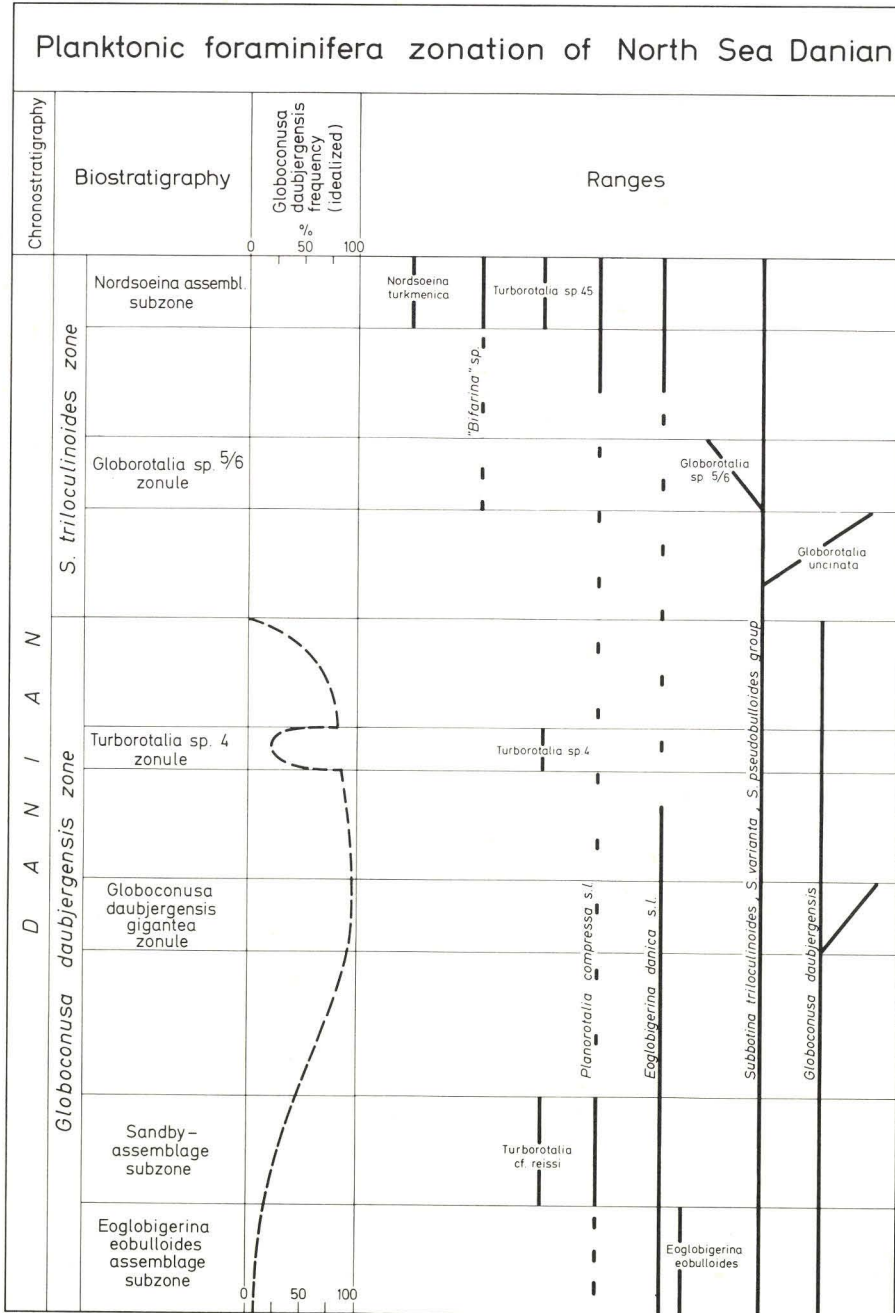
Appendix

Some comments on the planktonic foraminifera-zonation of the North Sea Danian by Inger Bang

A long series of biostratigraphical studies on the Danian of Denmark, based upon the planktonic foraminiferal faunas, have been carried out by Inger Bang. Her preliminary results are briefly presented in the following 8 figures.

Though Bang’s important work is still in progress, it is considered appropriate to publish here some of the results from her internal report of 1974, in order to give the reader an opportunity of becoming familiar with the succession of the biozones in the Danian of the Danish North Sea Sector.

The single zones have been given preliminary working-names by Bang. These names and the succession of the zones appear in the table fig. 15. The most important species are depicted by Bang in figs. 16–22 and some comments are given to each figure. The only zone which has not been depicted is the so-called “Nordsoeina assemblage subzone”. This subzone will be dealt with by Bang in another paper.



D GU 1974 INGER BANG

Fig. 15.

Fig. 16. Dansk Nordsø E-2. 6604.2'–6604.6'

Specimens from the *Eoglobigerina eobulloides* Subzone within the *Globoconusa daubjergensis* Zone. The picture gives a selection of the rich variety of species forming the assemblage. The lowermost Danian, e.g. as described by Bang in 1971, was not stated to be present in the Danish North Sea sector at the time when the report by Bang was finished (1974).

Fig. 17. Dansk Nordsø A-2. Ca. 6093'

Specimens from an assemblage zone (preliminarily named the "Sandby-assemblage") within the *Globoconusa daubjergensis* Zone. Among the species pictured are *Turborotalia* sp. 3 (= cf. *reissi*, Bang 1962) in the lower right corner and *Planorotalia compressa* in the upper right corner. Specimens of *Globoconusa daubjergensis* are seen in the upper left part of the picture, showing a great variation of types, morphological as well as in relation to size.

Fig. 18. Dansk Nordsø A-2. 6020'8''–6023'

Specimens of the *Globoconusa daubjergensis* Zone, a typical "Middle Danian" fauna containing "*Globorotalia*" *trinidadensis* of which only a few specimens have been found, but which provides a correlation to the biostratigraphy of Bolli (1957, see references in Bang 1969).

Fig. 19. Dansk Nordsø G-1. 6665'

Specimens of the *Globoconusa daubjergensis gigantea* Zonule of the *G. daubjergensis* Zone. Reference is made to Bang 1969.

Fig. 20. Dansk Nordsø G-1. 6656'.

Specimens of the *Turborotalia* sp. 4 Zonule of the *Globoconusa daubjergensis* Zone. The *Turborotalia* sp. 4 itself is seen in the right upper part and in the middle of the picture.

Fig. 21. Dansk Nordsø G-1. 6615'.

Varying specimens of *Globorotalia uncinata* from the *Subbotina triloculinoides* Zone, in a typical so-called "Klintholm-assemblage" of Denmark.

Fig. 22. Dansk Nordsø M-1. 5902'.

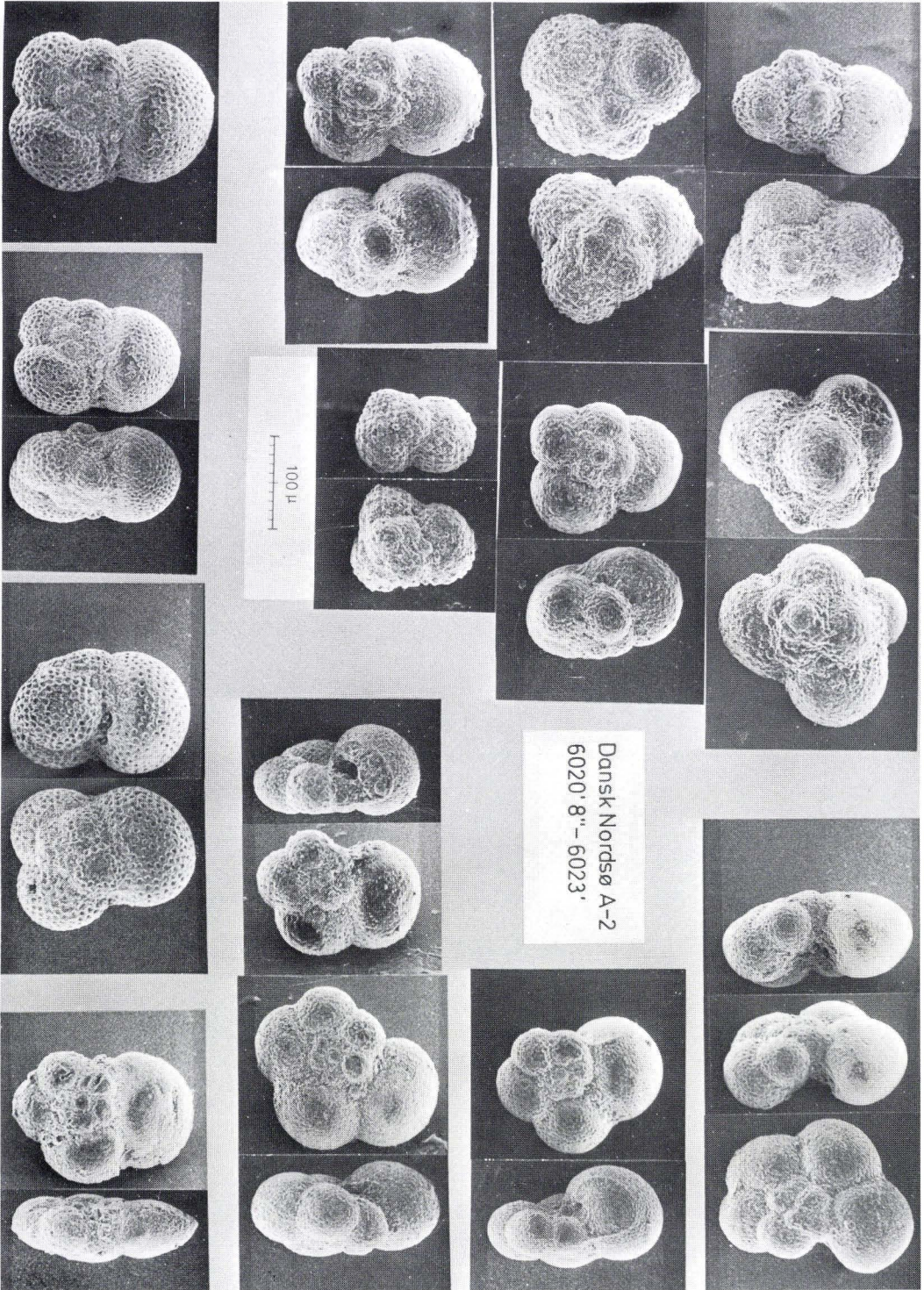
Specimens from the *Globorotalia* sp. 5/6 Zonule of the *Subbotina triloculinoides* Zone. Reference is made to Bang 1969. In the right-hand column of specimens the species *Planorotalia compressa* s. 1. is seen.



Fig. 16.



Fig. 17.



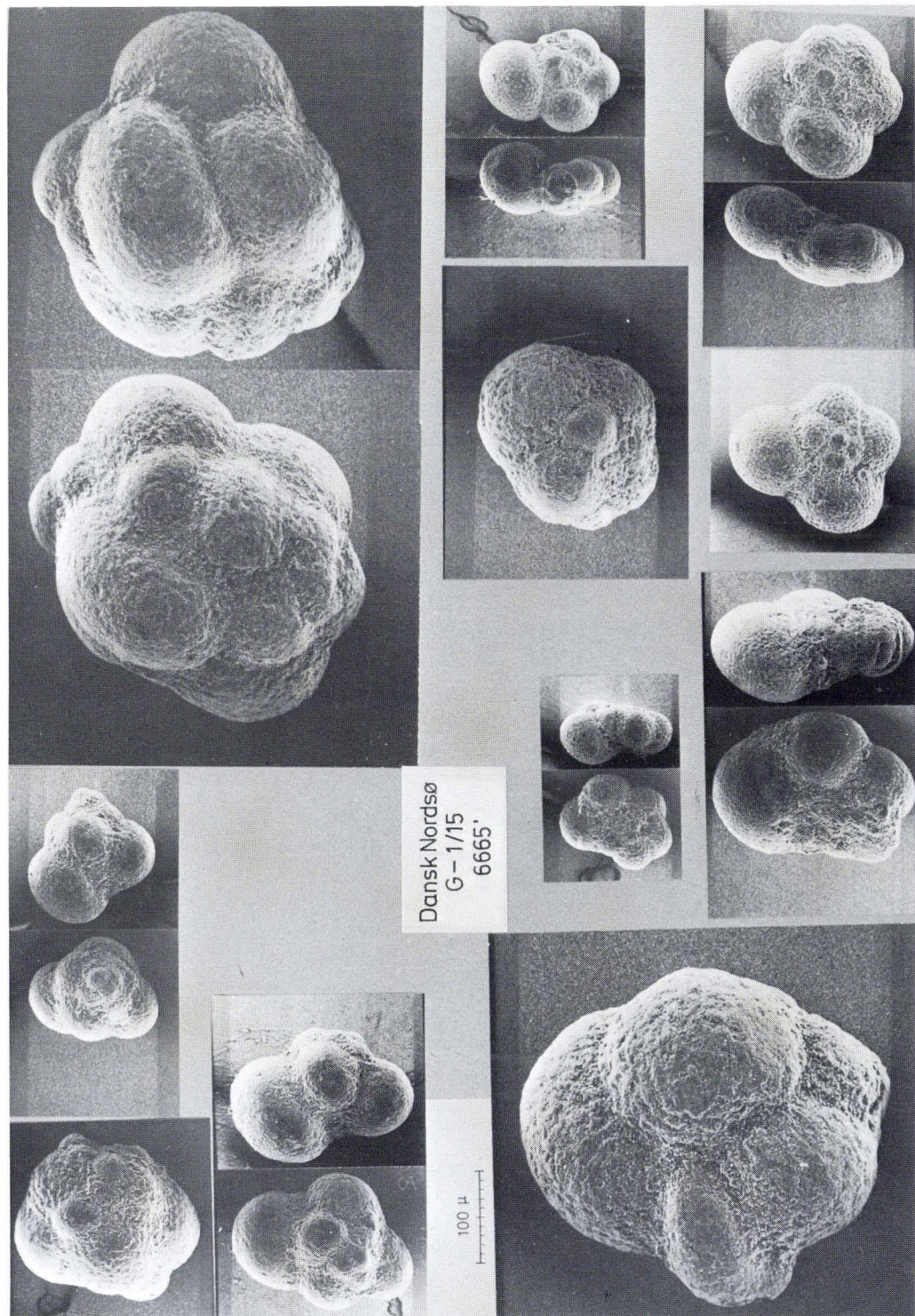


Fig. 19.



Fig. 20.

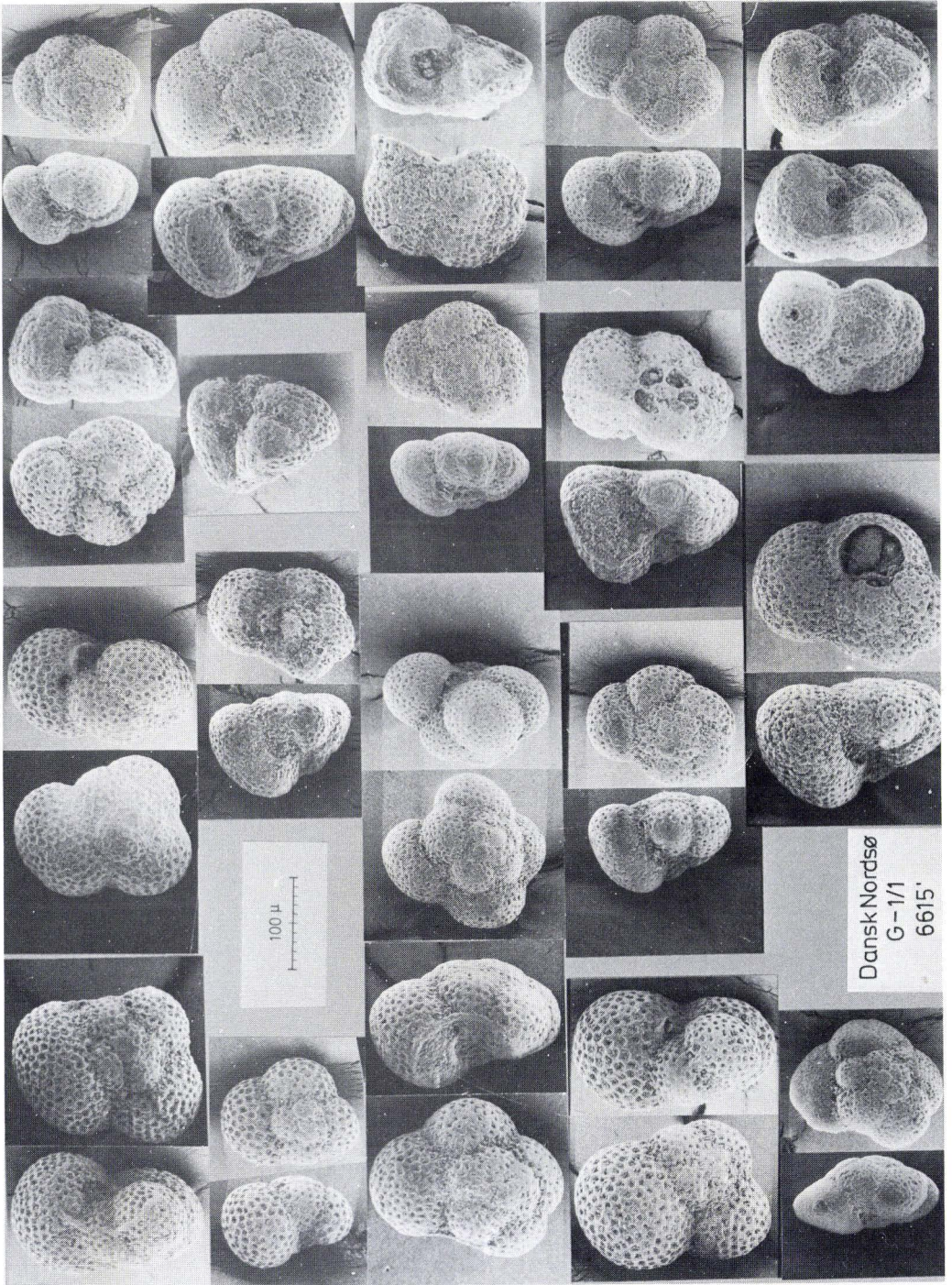


Fig. 21.

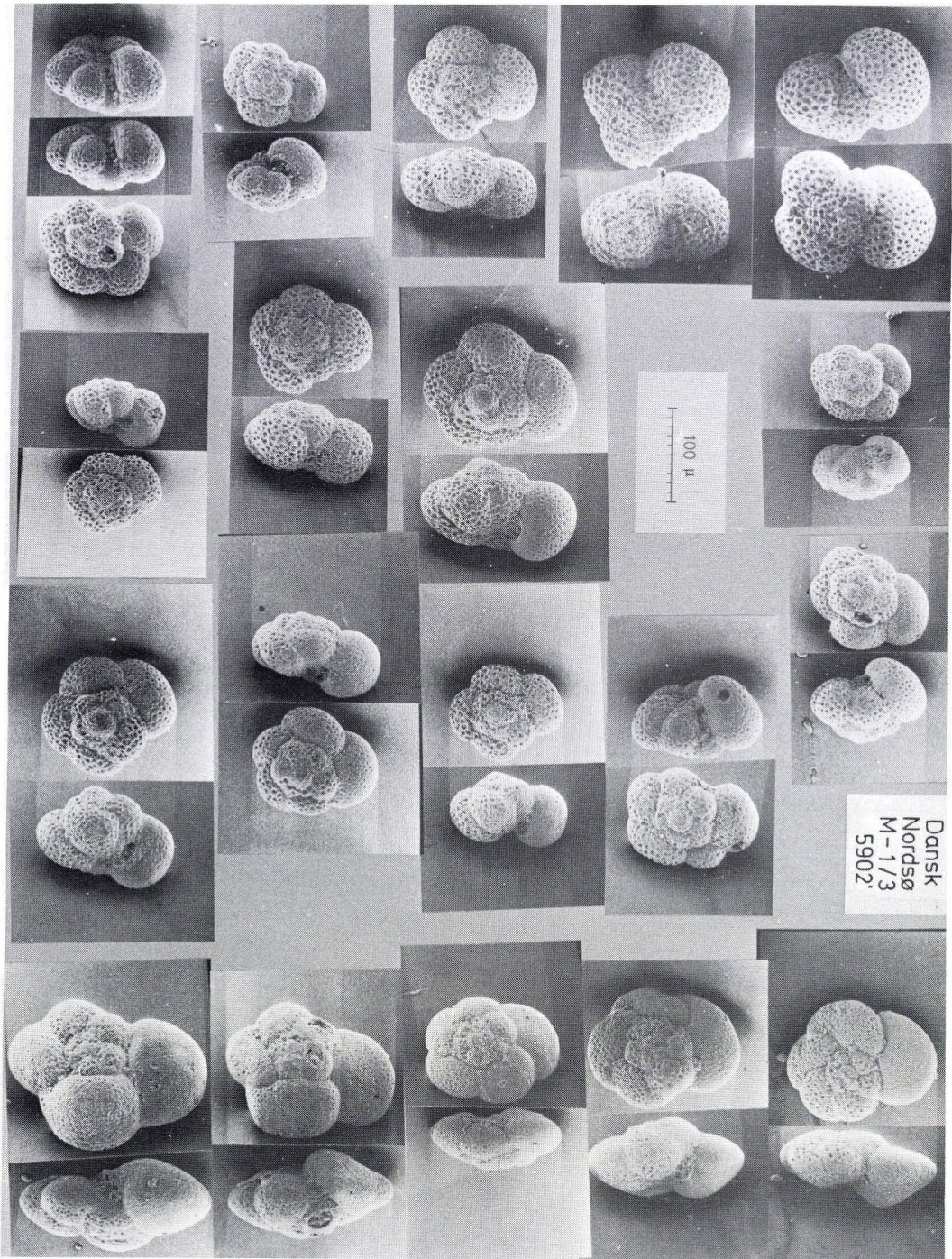


Fig. 22.

Acknowledgements. The author wishes to express his thanks to his colleagues in the Department of Subsurface Geology at the DGU for having provided him with the results of their investigations and for having critically read and correlated his compilations.

Special thanks are due to Mrs. *Inger Bang*, M.Sc., for permission to publish and picture some of the preliminary biostratigraphical results from her investigations of the planktonic foraminifera of the Danish Danian deposits.

J. C. Baartman, geophysicist, has constructed the structural map fig. 1, and both he and *Lars Madsen*, M.Sc., have carried out the geophysical interpretations for the cross-sections figs. 4–11.

The drafting of the structural map was done by *Inge Martin-Legène*, while the cross-sections, the well logs figs. 12–14, and the table fig. 15 were drawn by *Kirsten Andersen*.

The English manuscript was corrected by *M. Robson*, B.A. The manuscript was typed by *Lene Kristensen* and the photos were prepared by *O. Neergaard Rasmussen*.

All the above-named persons are thanked for their careful work.

Dansk sammendrag

Geologiske træk fra den danske Nordsø sektor, med rapport over borerne E-1, E-2, F-1, G-1, H-1, I-1, J-1 og K-1

Den her foreliggende oversigt over otte danske dybdeboringer i Nordsøen fortsætter publiceringen af de foreløbige geologiske resultater af olie- og gasboringerne. Rapporterne over de enkelte borer følger samme inddeling i afsnit som i den tidligere publikation (Rasmussen 1974), hvortil der henvises.

De otte borer er udført i årene 1968 til 1970. Forskellige forhold har medført, at publikationen fremkommer et par år forsinket, idet det oprindelig var hensigten at udsendelsen skulle have fundet sted i 1976. De til grund for oversigten liggende interne rapporter er derfor afsluttede i 1975, medens nyere undersøgelser kun i meget begrænset omfang er indføjede i teksten. Af nyere resultater er næsten kun taget hensyn til trykte afhandlinger. Disse fremgår af litteraturfortegnelsen, hvor der i to grupper er skelnet mellem trykte arbejder og utrykte, interne rapporter.

Endnu i 1974–76 var studier og vurderinger af Schlumberger diagrammer (petrofysiske logs) fra borehullerne kun i sin vorden på DGU, men siden er erfaringerne på dette område skredet betydeligt frem blandt de geologer, som beskæftiger sig med de dybe borer, og nu ville man vurdere de lithologiske forhold i borerne ved hjælp af petrofysiske logs i langt højere grad, end det var tilfældet for et par år siden.

Det er ydermere planen i fremtiden at publicere borerne på en anden måde, end det er sket i 1974 og i nærværende afhandling. Det vil f.eks. kunne foregå i sammenhæng med en analyse af et aflejringsbassin eller en del af et sådant, eller det kan ske som led i en undersøgelse af et bestemt tidsafsnits aflejringer, eller som en del af en helt anden art af regionale undersøgelser.

Kendskabet til Nordsøens geologi er iøvrigt skredet meget frem siden 1974. Især blev der på en større international konference i London i 1975 (se Woodland 1975) givet talrige bidrag, som betød en betydelig udvidelse af kendskabet til geologien i denne del af Europa. Af oversigter, som behandler hele Nordsøen, må især fremhæves P. A. Zieglers afhandlinger (1975, 1977), som på en instruktiv måde tillige med mange gode oversigtskort giver en

udmærket indføring i emnet. Da Ziegler har et grundigt kendskab til bl.a. det danske område fra sin tilknytning til Shell firmaet og dets aktiviteter indenfor Dansk Undergrunds Consortium, udgør hans oversigter en god baggrund for en regional opfattelse af geologien i den danske Nordsøsektor.

En oversigt over alle boreriger indtil 1975 med forkortede boreprofiler (udarbejdet af Michelsen) blev offentliggjort i sammenhæng med en rapport om eneretsbevillingen, afgivet af handelsministeriets tilsyn med koncessionshaveren, og senere trykt i DGU's årbog for 1975 (Michelsen 1976b). Denne oversigt giver et indtryk af de enkelte perioders lagmægtigheder.

Dybere gående enkeltundersøgelser er siden 1974 fra dansk side udført af Michelsen på juraaflejringerne og af Bertelsen på triasaflejringerne i det Dansk-Norske Bassin (se litteraturlisten). Sidstnævnte har tillige i 1978 publiceret en undersøgelse af karbonaflejringerne i boringen P-1, hvor man nåede ned i metamorfe, siluriske grønsten, der viser, at den kaledoniske bjergkædefoldning har ramt området. På grundlag af dette fund, og enkelte andre udenfor det danske område, tegner Ziegler den kaledoniske front ind over dansk område.

De regionale strukturelle forhold på den danske del af Nordsøen var i hovedsagen kendt allerede i 1967, da Heybroek et al. publicerede et strukturkort, som også inkluderede den danske sektor. I nærværende sammenhæng gengives i fig. 1 et nyt strukturkort udarbejdet af J. C. Baartmann, omfattende Danmark og omliggende shelfområder. De strukturelle forhold, især som de fremtræder på kortet, vil blive beskrevet nærmere (på Dansk og Engelsk) i en særskilt publikation, hvor kortet medfølger som farvetrykt tavle i større format (Rasmussen, under forberedelse).

De otte dybdeboringer, som beskrives detaljeret i nærværende publikation, giver ikke oplysninger om tilstedeværelsen af aflejringer fra geologiske perioder, som ikke allerede var påvist i det danske Nordsø område tidligere. De ældste aflejringer tilhører triasperioden, hvis lag blev nået i borerigerne F-1, K-1 og J-1 i det Dansk-Norske Bassin. En stor mægtighed af juraperiodens aflejringer (mere end 1400 m) blev konstateret i G-1 boringen i Central Graben, men de blev ikke gennemboret i denne boring. Endvidere blev den store lagtykkelse af de tertiære lag i Central Graben, som der kort blev redegjort for i rapporten om de fem første boreriger, atter bekræftet.

Der er ikke i nærværende sammenhæng fremlagt regionale stratigrafiske korrelationsresultater, da sådanne publiceres i anden sammenhæng (se f.eks. Michelsen 1978a og Bertelsen 1978b) på basis af et større antal boreriger. Derimod finder man her beskrivelser af hver enkelt af de otte boreriger og en fremlæggelse af de hidtil (indtil 1975) opnåede resultater af de biostratigrafiske undersøgelser, som er foretaget af geologer i prækvartærafdelingen ved DGU.

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