North Sea Basinal Area, Europe — an Important Oil and Gas Province*

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The North Sea covers the offshore part of a major sedimentary basin which extends from Norway, Scotland, and Denmark across northern Germany and the Netherlands into eastern England. Information gained from exploration efforts over the last 10 years shows that the North Sea covers several smaller sedimentary and structural basins of different geologic ages, but for descriptive purposes these can be divided into southern and northern areas. The rocks range in age from Paleozoic to Tertiary and consist of sandstone, shale, carbonates and evaporites. The most important reservoir rocks are the Lower Permian sandstones of the Rotliegendes Formation, the Upper Permian dolomites of the Zechstein Formation, the Triassic sandstone of the Bunter Formation, the Jurassic sandstones, the Maestrichtian–Danian chalk, and the Paleocene and Eocene sandstones. Significant shows of hydrocarbons have been found in 10 formations. The main source rocks are Carboniferous coal measures, Mesozoic shale and carbonates, and Tertiary shale and carbonates. The significant traps are folds and fault blocks associated with salt movement and basement faulting.

Exploration activity received its initial impetus in 1959 from the discovery of a major gas field, Schlochteren, onshore in northern Netherlands. In the early 1960s the passing of legislation favorable for the acquisition of exploration acreage offshore added further stimulus to the exploration pace. The majority of this activity was concentrated initially in the southern area, and resulted in the discovery of the first offshore commercial gas field at West Sole in 1965. This discovery was followed rapidly by other gas discoveries in the United Kingdom and the Netherlands culminating in the Leman Bank field, a major gas field by world standards. Interest and activity lagged, however, in the northern area despite reported small oil and gas discoveries in Denmark, and the discovery in 1968 of the Cod gas-condensate field in Norway. In late 1969, oil production was established at the Ekofisk field in Norway. With this discovery and subsequent confirmation as a major field, exploratory interest has shifted to the north.

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I realize that many of you are thoroughly aware of the events leading up to the discovery of oil in the North Sea. However, I am sure that there are others present today who are not familiar with the story. Therefore, I plan first to sketch briefly the historical background, and to high-light the noteworthy events. I then plan to outline the regional geology. Next, we will examine in some detail the geological and geophysical information on the Ekofisk area in Norway, and finally, I will give you a status report on the offshore production installations at the Ekofisk Field.

* This account is an edited version of the speech given by Mr. W. W. Dunn at the Bergen Conference. It is based on a speech presented by Mr. Dunn on 18th April 1972 to the Annual Meeting of the American Association of Petroleum Geologists held in Denver, Colorado, and later published in modified form in the *Oil and Gas Journal*, January 1973 (Dunn, Eha & Heikkila – 'North Sea is a tough theater for the oil-hungry industry to explore.')

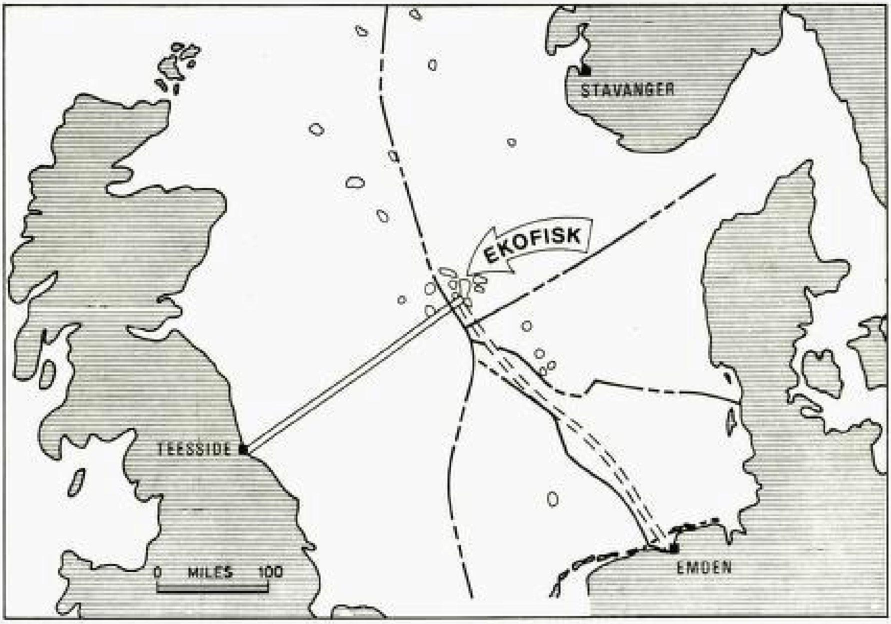


Fig. 1. Location of the Ekofisk field, North Sea, showing some of the principal oil fields. The 34″ oil pipeline to Teesside and the 36″ gas pipeline to Emden are also indicated.

With the discovery of oil at Ekofisk in Norway in 1969, the North Sea has become one of the most active new offshore exploration areas in the world. The location of the North Sea in North–Western Europe and the location of Ekofisk in the center are shown in Fig. 1. The sea covers the offshore portion of a major structural and sedimentary basin which extends from Norway, Scotland and Denmark across Northern Germany and the Netherlands and into Eastern England. The total offshore basinal area, limited northward for the purposes of this paper by latitude 62° North, is approximately 240,000 square miles (621,600 km^2) or nearly the size of France. Fig. 2 shows how the water depths gradually increase northwards, reaching a maximum depth of 2000 feet (over 700 m) in the trench bordering the Norwegian coast. Operations in the middle of the North Sea can be as far as 200 miles (320 km) from land.

In 1959, forty years of previous exploration in Northern Europe had attracted little worldwide attention to the area. Small oil fields had been found in the Carboniferous reservoirs of the East Midlands in the United Kingdom. Gas production had been established in Permian and Lower Triassic reservoirs, and oil in Upper Triassic, Jurassic and Lower Cretaceous reservoirs in Northwest Germany, and small oil and gas fields had been found in the Mesozoic of Holland (Fig. 3). In addition, a small number of wells had been drilled without success in the territorial waters of Holland and Germany.

There were two factors which dampened enthusiasm for the area, and slowed development. One was the lack of success in discovering large fields, which if found offshore would be commercial; the other was the question of

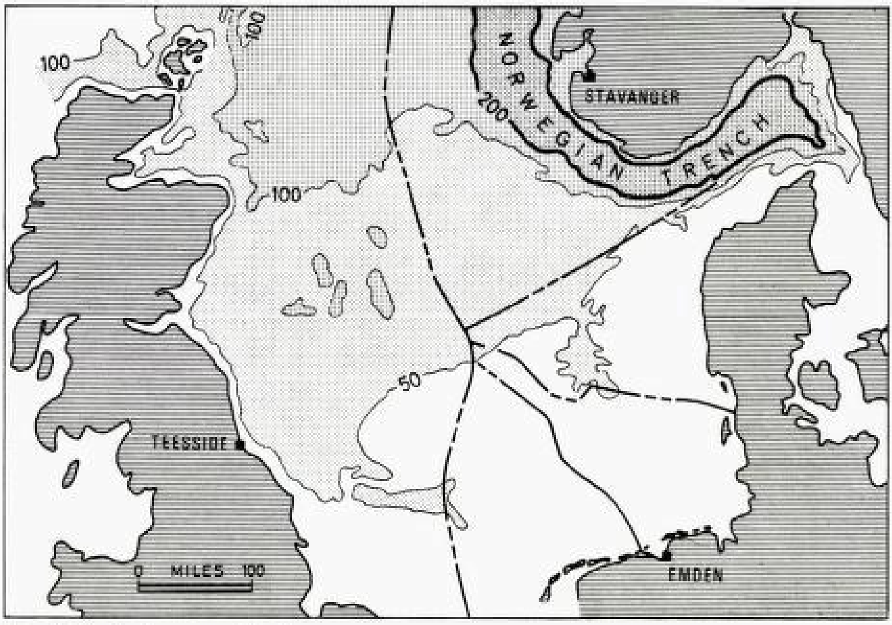


Fig. 2. North Sea water depths.

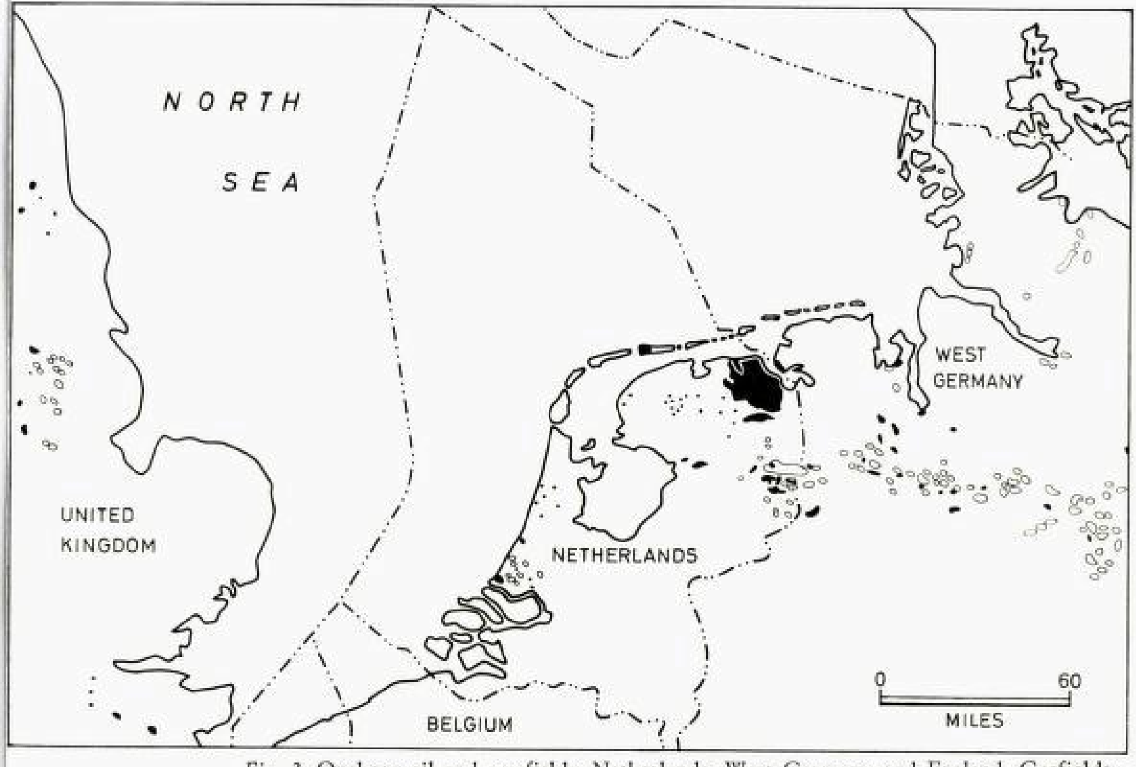


Fig. 3. Onshore oil and gas fields, Netherlands, West Germany and England. Gasfields – black areas and spots; oil fields – unornamented.

ownership of the oil and gas rights outside the territorial waters, or three-mile limit. In 1959, the gas discovery at Slochteren in Northern Holland dramatically changed all this. This discovery, combined with the increasing demand of the European energy market, and the need to diversify supplies in this market, was the catalyst which set off the offshore search.

Information became available over the next few years that this was a major gas field in the Permian Rotliegendes Sandstone. This information, combined with the fact that all the offshore areas of the world were either being actively explored or were seriously being considered for exploration in the early 1960's, focused attention on the oil and gas possibilities under the North Sea. It was not until 1963, however, that it was confirmed that the recoverable reserves at Slochteren were 58 trillion cubic feet, but by that time exploration activities in the North Sea had already started.

At the same time, the concession situation was also being legalized for the waters beyond the territorial limit. In 1958, the Geneva Convention on the continental shelf had established the ground rules for the division of these offshore areas. This convention, however, required ratification by 22 countries, and it therefore did not become effective until 1964. Treaties then had to be negotiated between the individual countries involved, in order to establish the actual boundaries. This was done with dispatch except for a disagreement between the Netherlands, Germany and Denmark which was finally resolved in 1970.

The median lines which now divide the North Sea into five sectors are indicated in Fig. 4. It is important to note that each country established its own rules and regulations for the granting of exploration and production rights. Both Denmark and Germany awarded their entire area to single consortiums, whereas the United Kingdom, the Netherlands and Norway gridded their areas, and put up their blocks for competitive application. These blocks, as illustrated, are of different sizes: a U.K. block covers about 90 square miles (57,600 acres), a Netherland block about 160 square miles (102,400 acres) and a Norwegian block about 210 square miles (134,000 acres). There are further differences in rental costs, terms, royalty, etc., but originally no bonuses were involved, only work or drilling commitments. There have been a total of eleven concession awards in the North Sea outside of Denmark and Germany, five in the U.K. in 1964, 1965, 1969, 1971 and 1972, three in Holland in 1968, 1970 and 1972, and three in Norway in 1965, 1969 and 1973. Each has had either minor or major changes in the basic requirements.

The last concession application award in the U.K. included 15 blocks which were awarded by sealed bid — an innovation for this area. Additional changes can be expected in future U.K. offers possibly similar to the carried interest requirements innovated by Norway in their 1973 acreage offers.

While the legal aspects of ownership were being resolved, exploration work was underway. The period between 1959 and 1963 was confined to a review of the published geological and geophysical data concerning the surrounding land areas. This was supplemented by geological field studies, and a minimum amount of seismic work offshore.

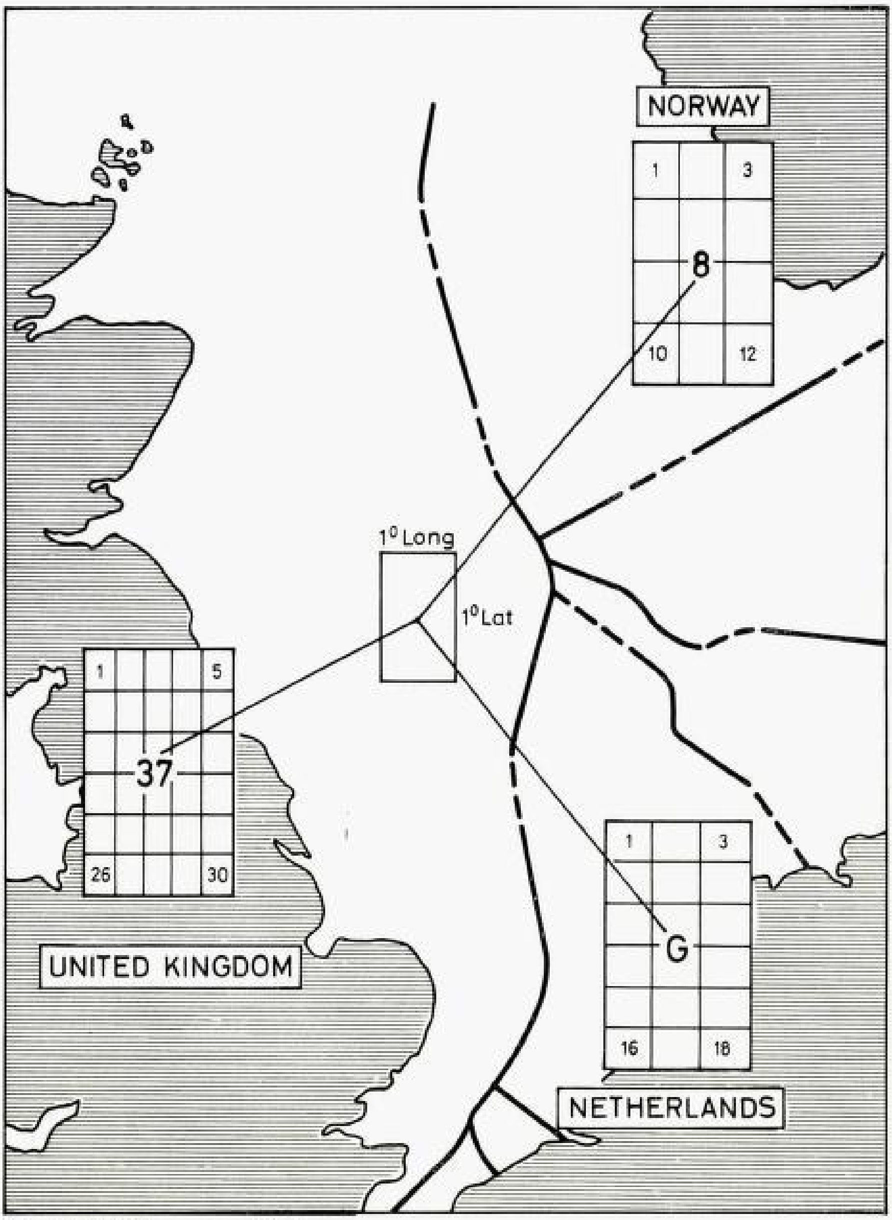


Fig. 4. North Sea average blocks.

The geological picture at that time was assessed by the industry about as follows: It was evident that there was a continuation beneath the North Sea of the Permian (the producing reservoir at Slochteren), the Mesozoic and also the Tertiary sediments which outcropped around its southern margin (Fig. 5). Published geophysical data supported this theory, and drilling in Germany and the Netherlands had revealed, beneath the Tertiary cover, a rock sequence similar to that of the Post-Carboniferous of Eastern England, but of a different facies.

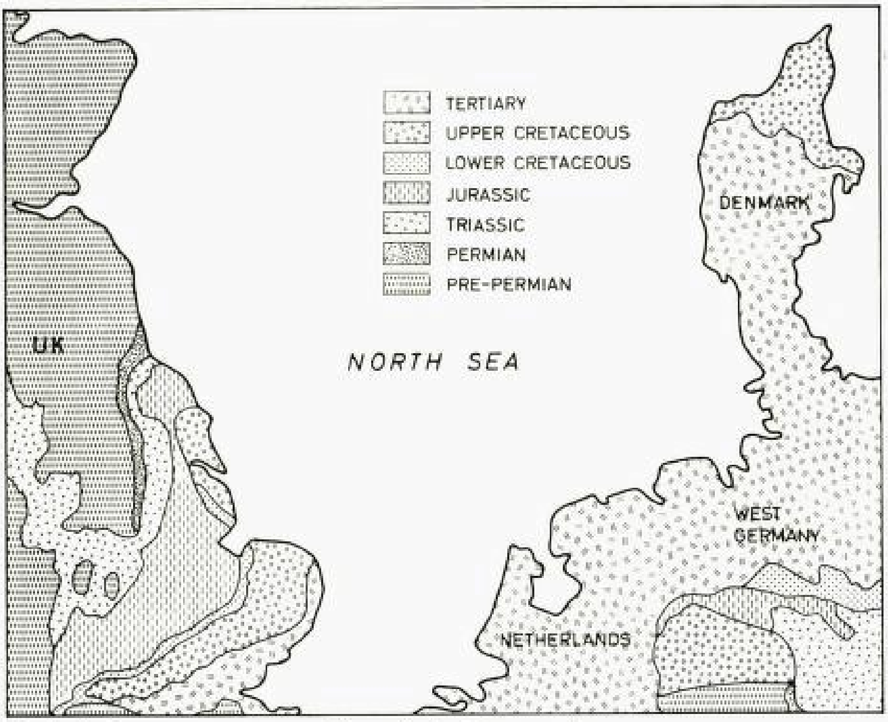


Fig. 5. Onshore outcrop pattern of post-Carboniferous rocks.

From a structural point of view, the general effects of the Hercynian, Kimmerian and Alpine orogenies were well known, and the structural and cap rock potential of the thick Permian and Triassic evaporites could be deduced from the onshore geology. The Pre-Carboniferous stratigraphy was known from the surrounding land areas, and due to the metamorphism resulting from the Caledonian orogeny, these rocks offered little incentive to the oil explorer. Of more interest were the regressive deposits of the Lower Permian, the Early Triassic, the Late Jurassic – Early Cretaceous and, possibly, the Tertiary, as likely reservoir rocks. Transgressive sediments of Carboniferous, Permian, Lower Jurassic, and again Tertiary age, offered promise of likely source rocks.

Features providing hydrocarbon entrapment were known to be of a wide variety: salt-controlled traps, fault traps, stratigraphic traps due to salt movement, anticlines, domes, etc. All the classic traps were present, and these traps could be expected offshore.

Offshore seismic work had started on a large scale in 1973, and in 1964 the first North Sea drilling began off Germany. The same year, petroleum licences were granted by the U.K. with the first exploratory drilling commencing 190 miles offshore in December.

Fig. 6 shows the location of West Sole, the first commercial offshore gas discovery, which was found the next year, 1965. Other major gas fields were quickly found: Leman Bank, Indefatigable and Hewett in 1966, and Viking in 1969. These offshore gas field were tied into two terminals in England,

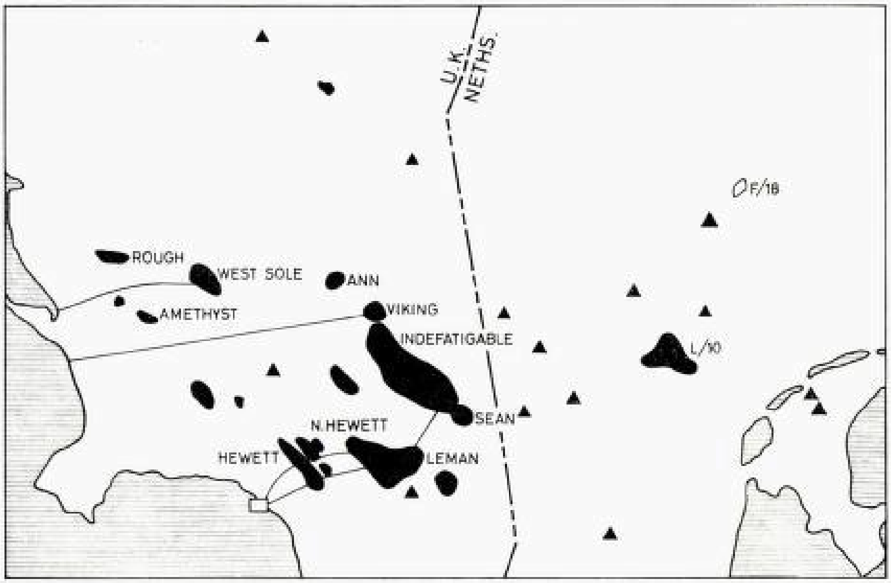


Fig. 6. Southern North Sea, oil and gas fields. Gas–black areas; Oil (F/18)–unornamented

Easington and Bacton, with a third at Maplethorpe, completed last year. Present gas productive capability in the U.K. North Sea is above 2 billion cubic feet of gas per day and it is estimated that it will reach 4 to 4½ billion by 1975.

During this period of success in the discovery of gas in the U.K., exploration operations continued without success in Germany and were discontinued there in 1968 after 17 consecutive dry holes. In the Netherlands, exploratory drilling commenced in 1968 shortly after the award of concessions, and by December gas was discovered in the Permian. Further gas discoveries were made subsequently, and development is underway in Blocks L/10 and L/11. In Denmark, drilling had started in 1966 and significant oil and gas shows had been encountered in the Danian and Upper Cretaceous. Production commenced in 1972 from the 'Dan' Field at the rate of 4000–5000 BOPD. This development was delayed by the boundary dispute with Germany.

Norway awarded concessions in 1965 and in 1969 and drilling commenced in 1966. The Cod Gas Condensate Field was discovered in 1968, but further drilling discouragements led to a decrease in drilling in 1969. About the time when enthusiasm had reached a low ebb, the Philips 2/4–1AX well, on the Ekofisk structure, had oil and gas shows at about 10,000 feet. This well indicated the first commercial oil field in the North Sea and, as it turned out, the first billion barrel or giant oil field in Western Europe. The locations of Ekofisk and other oil and gas fields discovered subsequently in the Northern area of the North Sea are shown in Fig. 7. In the Norwegion sector, Philips has a series of fields in what is referred to as the Greater Ekofisk Area, while 220 miles (350 km) to the north another group has one of the most sub-

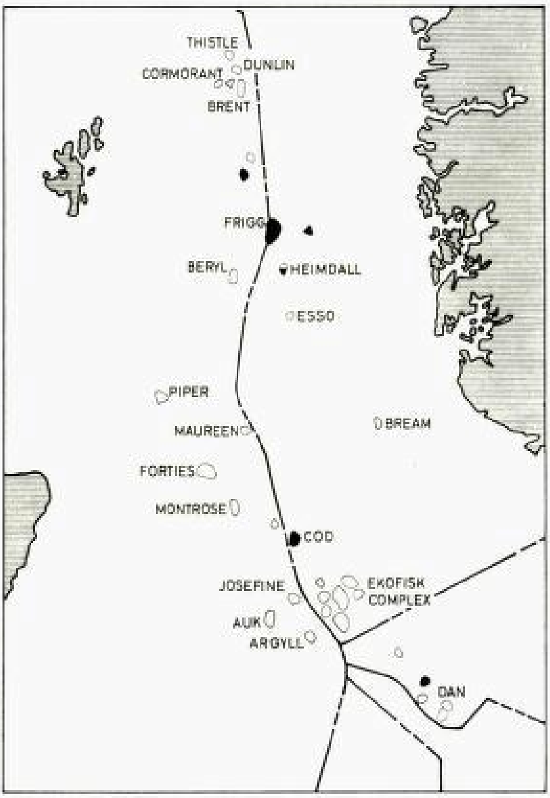


Fig. 7. Northern North Sea, oil and gas fields. Gas – black; oil – unornamented.

stantial gas discoveries to date with over 12 trillion cubic feet of recoverable reserves — the Frigg Field.

To review the oil discoveries of the Northern U.K. basin is an almost continuous task — at one stage there seemed to be a discovery per month. Now, with perhaps 15 or 16 substantial discoveries with productive capabilities varying from 40,000 BOPD at the Auk Field to 400,000 at the Forties Field, the potential production for the U.K. is bright. In all, the total oil reserves discovered to date in the North Sea could probably support a maximum production of 3½ million BOPD in 1980, which is equal to only 15% of Western Europe's predicted demand.

Later in the paper I will return to the Ekofisk area and specifically outline the geology and reservoir information in detail and discuss the present development program. But first, I would like to give you the regional geological framework for Ekofisk and other recent oil discoveries in the northern area of the North Sea.

In 1963, because of the discovery of gas at Slochteren, geological thinking was first directed towards gas and secondly towards the extent of the Permian Rotliegendes sandstone reservoir. Therefore, the primary interest of the industry was centered in the southern portion of the North Sea, where this reservoir had the best chance of being present. Other companies, however,

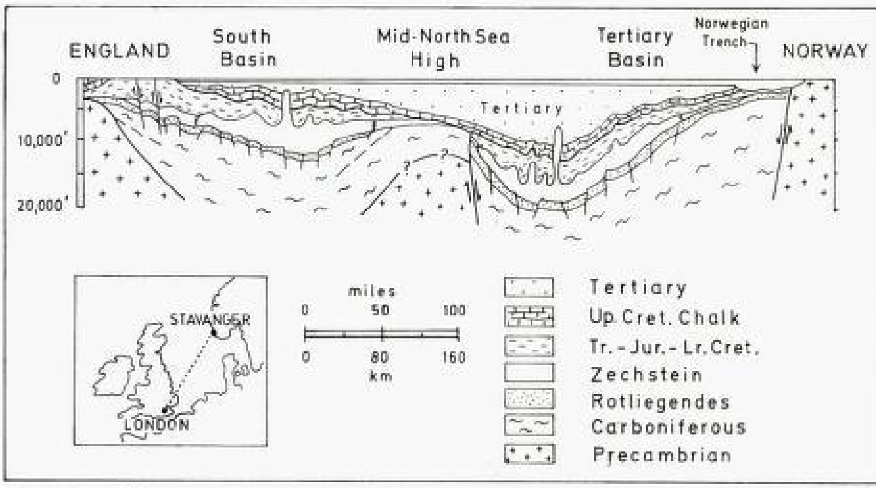


Fig. 8. Simplified geological cross-section, London – Stavanger.

became curious as to the possibilities of the northern portion of the North Sea which lay between the metamorphics and Early Paleozoic sediments of Norway and Scotland.

It was with this background that the companies began serious seismic work in the North Sea in 1961 and 1962. A simplified geological cross-section of about 550 miles from London to Stavanger illustrates some of the data revealed by the initial seismic work (Fig. 8). The main features to note are the Tertiary Basin, which contains the Ekofisk and Forties oil discoveries, the regional unconformity beneath the Upper Cretaceous, which probably plays a significant part in the more recent oil discoveries to the north, and the two Permian sub-basins, in which the original gas was discovered.

Fig. 9 is a generalized composite illustration of the structurally high areas and the intervening basins and troughs; this combines a number of structural features of different geological age.

From south to north we encounter:

1. *The Brabant Massif* of Hercynian origin limiting the North Sea basinal area to the southwest.
2. *The Mid-Netherlands Ridge*, which has been an active high during much of the Mesozoic until Upper Cretaceous.
3. The east-west trending *Mid-North Sea High* or *Northumbrian Arch* extending eastward from the U.K., which has affected Permian through Lower Cretaceous deposition and limits the so-called '*Southern U.K. Basin*' to the northwest, which in turn is an extension of the *Northwest German Basin* to the southeast, which contains huge thicknesses of Permian and Triassic deposits with their accompanying evaporites.
4. To the north the *Mid-North Sea High* is bordered by the shallow, predominantly Mid-Mesozoic Scottish Basin.
5. To the northeast the *Ringkøbing–Fyn High* is a controlling positive feature from Permian through Lower Tertiary sediments.

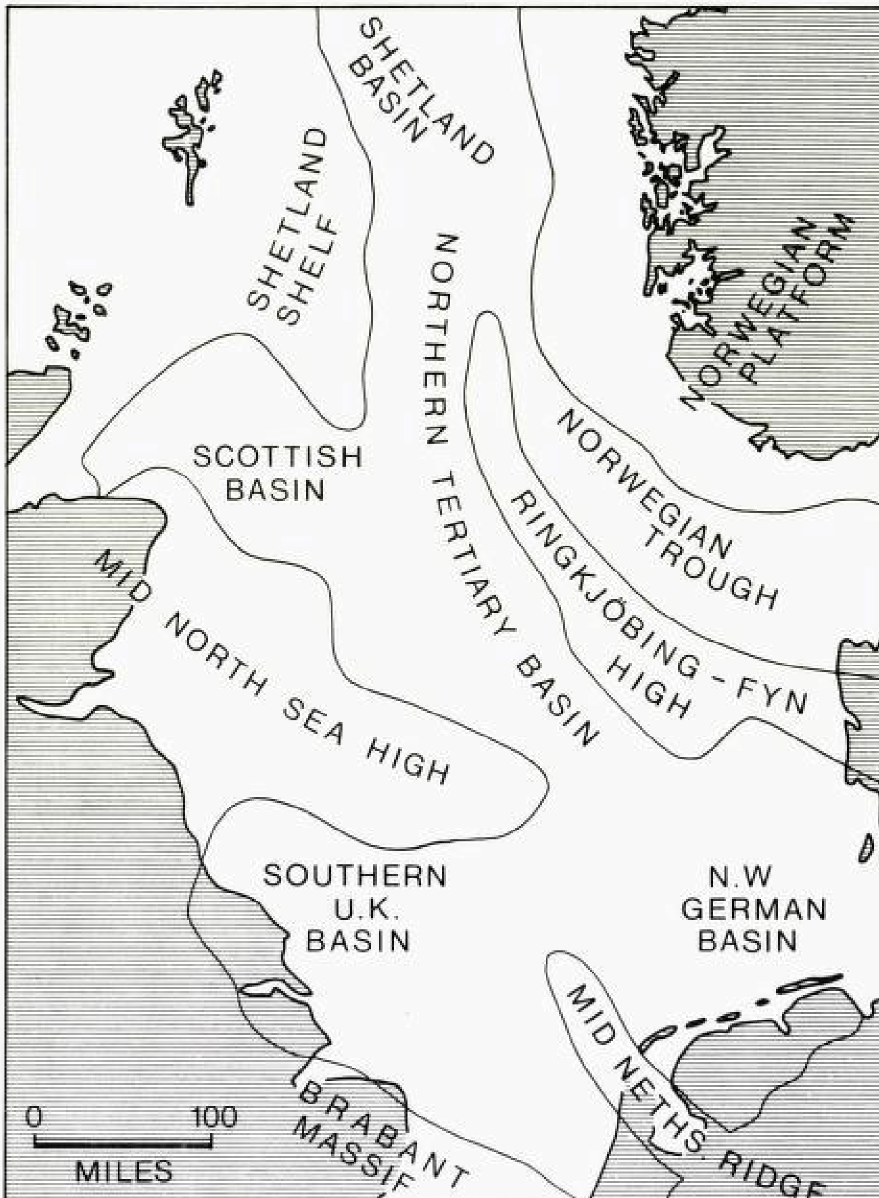


Fig. 9. Major structural features of the North Sea area.

6. To the north of 56°N latitude, the main tectonic features in the Pre–Upper Cretaceous are obscured by the increasing thickness of Tertiary sediments in the Northern Tertiary and Shetland Basins to the east of the Shetland Shelf, and to the west of the Norwegian Trench.

Figs. 10–17 show the present-day distribution of the strata which are most relevant to the oil and gas accumulations, and the relationship to the structural features discussed above.

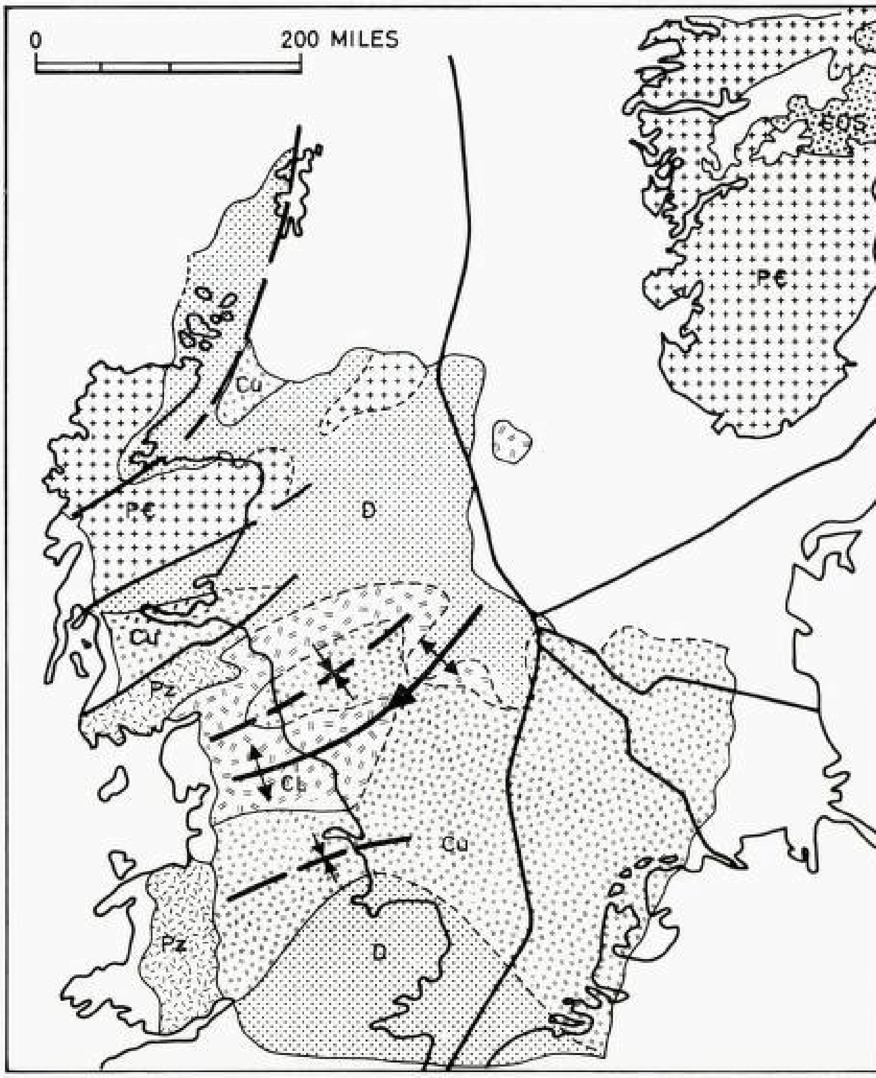


Fig. 10. Pre-Permian sub-crop, North Sea area. Cu — Upper Carboniferous; CL – Lower Carboniferous; D – Devonian; COS – Cambrian–Ordovician–Silurian; Pz – Paleozoic; PC – Precambrian.

Fig. 10 illustrates the Pre-Permian subcrop. Probably the most notable feature is the widespread deposition of the Upper Carboniferous over much of the southern portion of the North Sea. These largely estuarine and swamp deposits, with their high carbon content, play a significant part as a source rock for the gas in that area.

After the Late Carboniferous Hercynian orogeny, the Carboniferous and earlier rocks were eroded and folded, and then covered by the Lower Permian Rotliegendes Formation. This formation is essentially a product of post-Hercynian erosion. It is a continental sandstone in the Southern North Sea

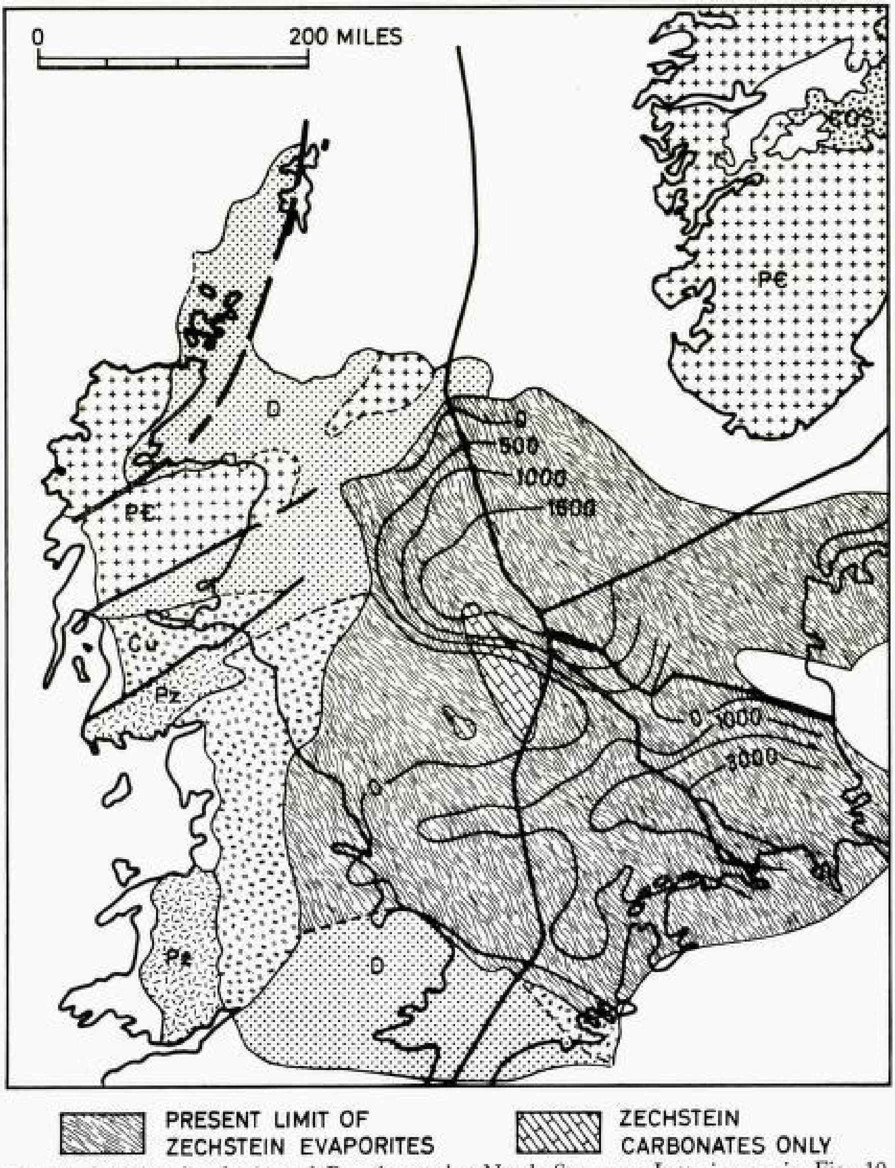


Fig. 11. Present distribution of Permian rocks, North Sea area. Lettering as in Fig. 10. Isopachs in feet.

Basin becoming shaly and marine northward. Fig. 11 shows that the important commercial gas accumulations in the Rotliegendes occupy a marginal position to the south. This is an area of greatest sand deposition where the present-day limit of the Rotliegendes coincides basically with the original southern boundary of the Early Permian deposits.

The Late Permian Zechstein transgression is the first appearance in geologic history of the present North Sea. This sea deposited thick evaporites and basin-margin carbonates. These sediments play an essential role in the subsequent

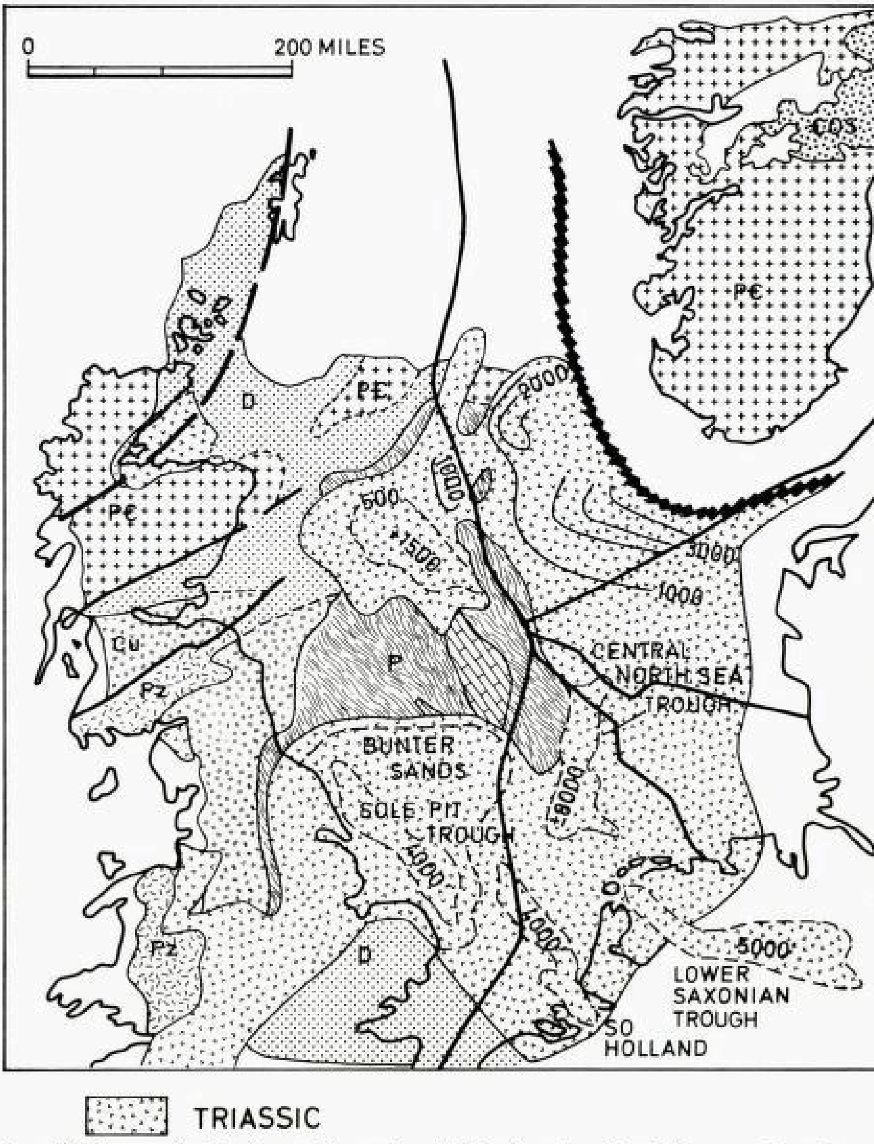


Fig. 12. Present distribution and isopachs of Triassic rocks, North Sea area. Lettering as in Fig. 10. P – Permian. Isopachs in feet.

accumulations of hydrocarbons, as cap rock for the Rotliegendes Sandstone gas reservoirs, as carbonate reservoirs for both oil and gas, and as an active agent for later structural deformation into Tertiary time. Unfortunately, the Zechstein also forms a formidable obstacle for deep seismic exploration, because of the varying salt thicknesses and evaporite composition.

Fig. 12 illustrates the extent of Triassic distribution, and shows that the more important thicknesses already reflect the main basinal areas mentioned before. Conspicuous Triassic troughs such as the Sole Pit, the Central North Sea and the Lower Saxonian troughs formed and were filled with shales and

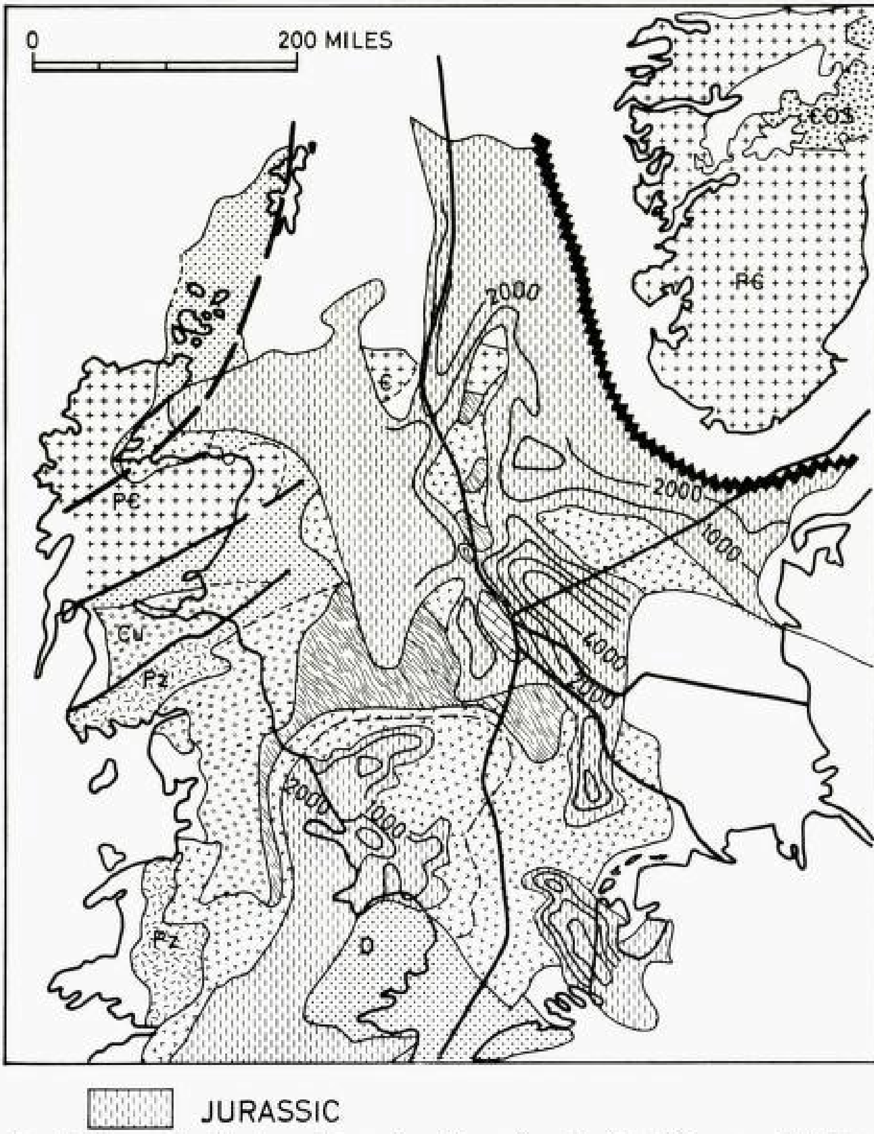


Fig. 13. Present distribution and isopachs of Jurassic rocks, North Sea area. Lettering as in Fig. 10. Isopachs in feet.

clastics. The sandstones of the Triassic serve as reservoirs in the Hewett Gas Field off England and oil shows have been encountered at Josephine in the middle of the North Sea. The sands at Hewett are red-brown and grey-green in colour, and are of continental derivation.

The Jurassic distribution is shown in Fig. 13. Both the Kimmerian movements and intensive salt tectonics show their effects on today's distribution of Jurassic and Lower Cretaceous sediments. The Jurassic and Lower Cretaceous are essential sandstone and shale units, with rapid lateral facies changes. The Jurassic shales are probably the source rocks for oil discoveries and

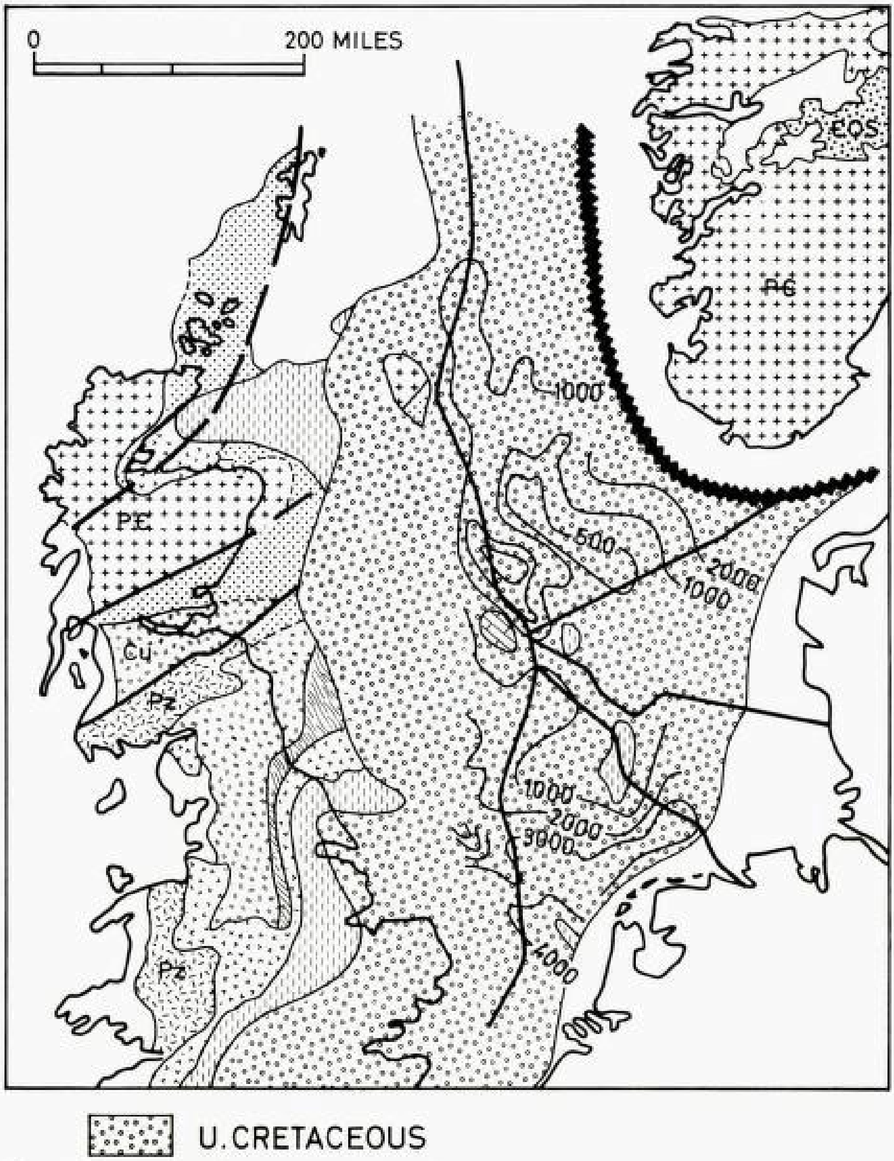


Fig. 14. Present distribution and isopachs of Upper Cretaceous rocks, North Sea area. Lettering as in Fig. 10. Isopachs in feet.

hydrocarbon shows in the Mesozoic, though in the Central and Southern areas, these accumulations occur in rather localized Mid-Jurassic sand reservoirs. To the north, the reservoirs are much more extensive as exemplified by the discoveries in the golden triangle of the Cormorant, Dunlin and Brent fields. Uplift and erosion prior to the deposition of the Upper Cretaceous Chalk caused partial to complete removal of the earlier Mesozoic beds, particularly in the central-southern parts of the basin.

As illustrated in Fig. 14, the homogeneous Upper Cretaceous Chalk is

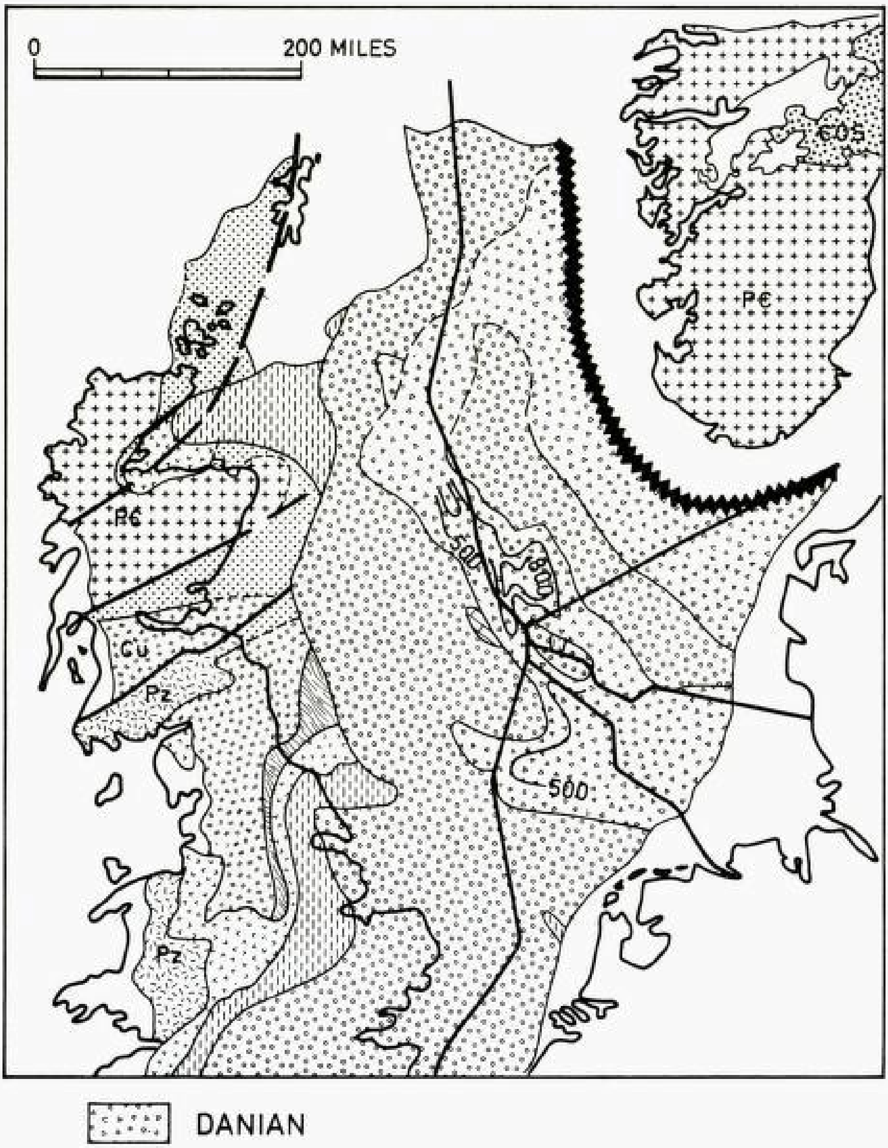


Fig. 15. Present distribution and isopachs of Danian chalk, North Sea area. Lettering as in Fig. 10. Isopachs in feet.

perhaps the most extensive formation in the North Sea. The large structural highs which were already apparent in the Jurassic, persist. While the carbonate deposition continues into the Danian, Fig. 15 shows that its extent becomes restricted to two north-south troughs in the middle of the North Sea which become more pronounced. One of these is the locale of the Ekofisk and neighboring oil fields.

With the Paleocene, another shale - silt - sand sequence begins and continues well into the Pliocene. These shales are excellent source rocks both for the

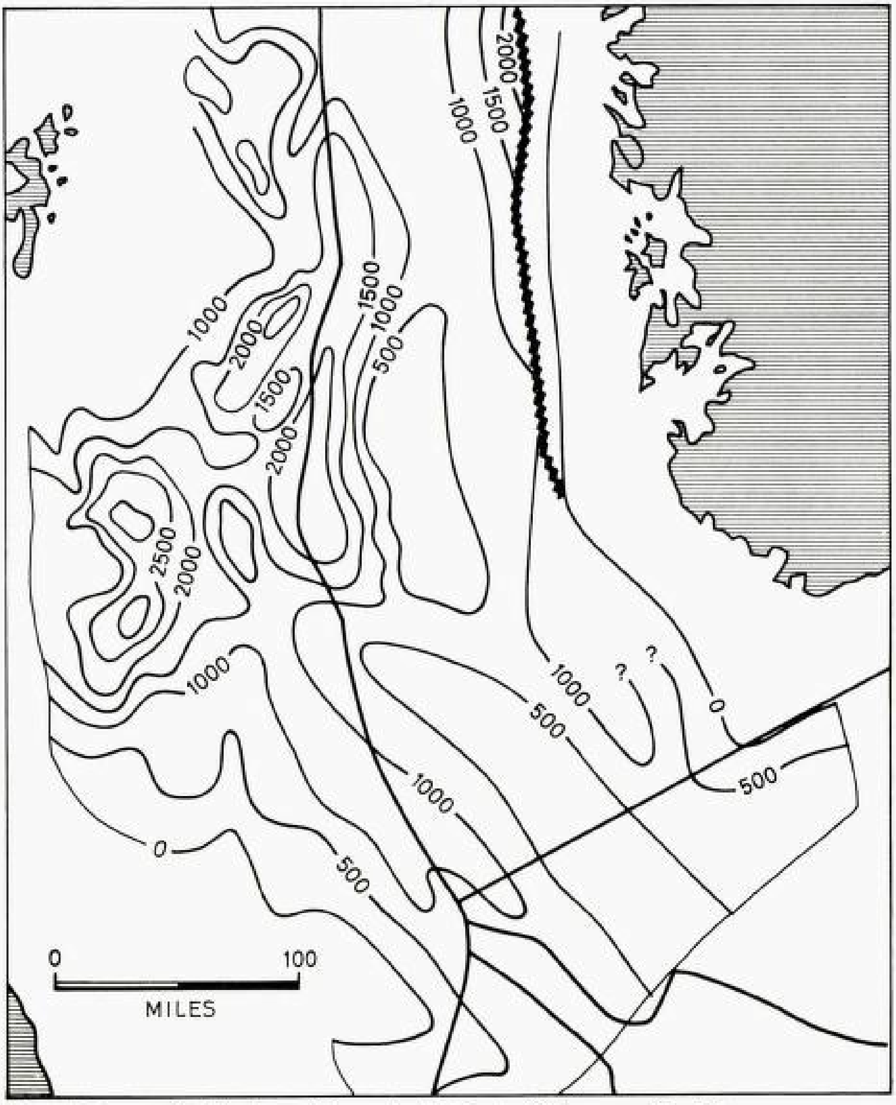


Fig. 16. Present distribution and isopachs (in feet) of Paleocene, North Sea.

underlying Danian/Upper Cretaceous reservoirs, and also for the Paleocene and Eocene hydrocarbon accumulations which occur in relatively localized sand developments such as the Cod, Frigg and Forties fields. It should also be mentioned that gas accumulations have been found as shallow as 5000 feet in localized sand lenses.

Fig. 16 is an isopach map of the Paleocene in Norwegian and northern U.K. waters. Three principal depocenters of total Paleocene (including Danian) can be distinguished. The first is in the southern part of the Northern Tertiary Basin and includes the Ekofisk and Cod fields. The second is a remnant basin flanking the Norwegian coast, west of the Norwegian Trench. This is a continuation of the onshore Danian of Denmark. The third is a possible extension of

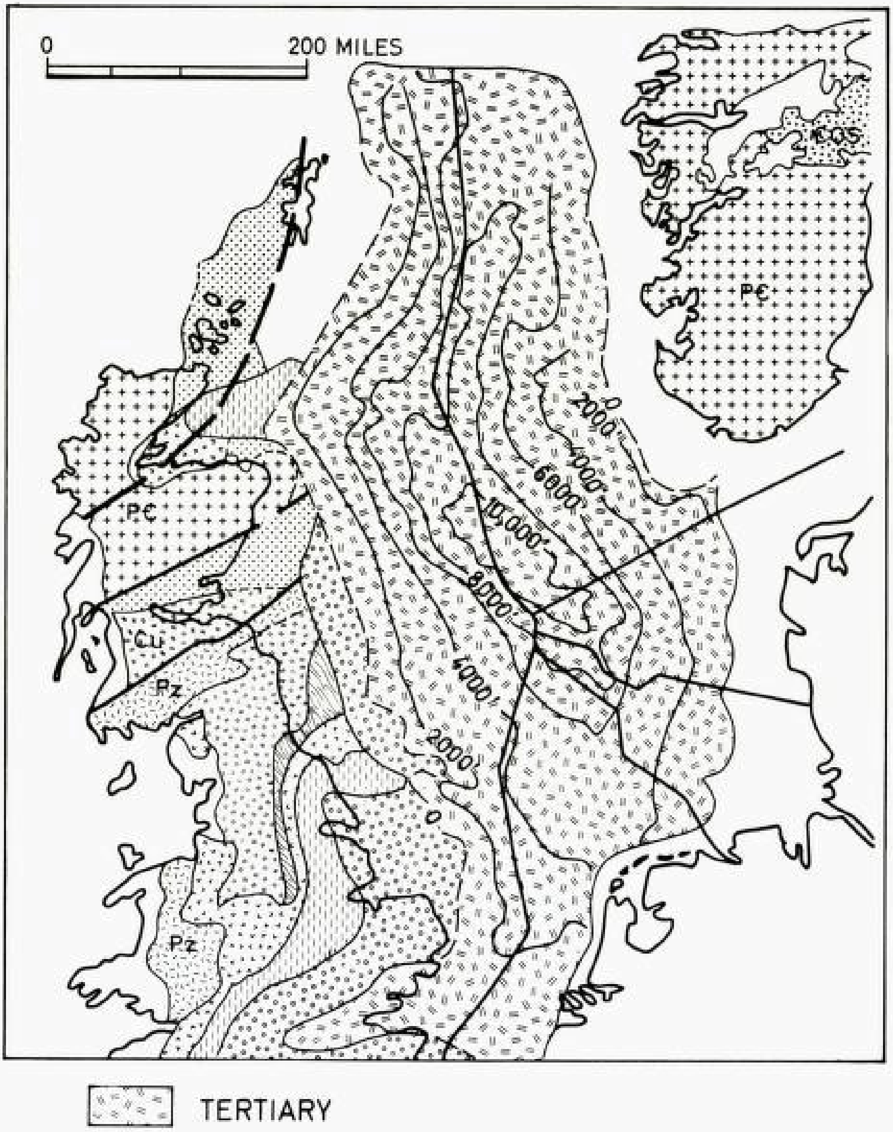


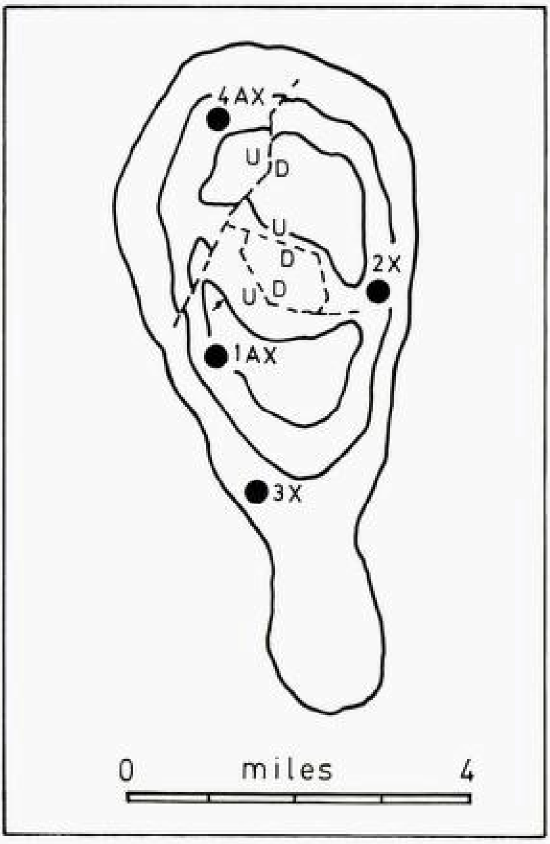
Fig. 17. Distribution and depth to the base of the Tertiary, North Sea area. Contours in feet.

the Northern Tertiary Basin north-westward, which bifurcates into a western depocenter towards the Moray Firth Basin and into a north-trending depocenter immediately east of the Shetland Shelf.

Total Tertiary thickness and its distribution are shown in Fig. 17. Only its southern margins were known at the beginning of North Sea exploration ten years ago. The Tertiary reaches a thickness of 10,000 feet in the center of the basin.

The Ekofisk and neighboring fields are located in the deepest part of the Tertiary Basin in an area containing over 1,300 feet of Danian and Paleocene

Fig. 18. Ekofisk Field, structural form-lines and positions of the 4 original wells.



sediments, approximately half of which consist of the Danian Chalk section, and the other half of Upper Paleocene clastics. The lower part of the Danian commonly contains reworked Upper Cretaceous fossils which appear also at the top of the Upper Paleocene. It can thus be assumed that at the beginning of the Danian, the Upper Cretaceous Chalk was subjected to submarine erosion wherever it may have been structurally elevated. Isopachous mapping of the Upper Cretaceous suggests the existence of elevated areas which may have been shallow relative to sea level and which were the erosional source areas for part of the Danian section. The bulk of the section, however, was deposited in deep water and consists principally of coccolith remains and lime-muds. The Danian Chalk is the primary hydrocarbon reservoir in the Ekofisk area.

The transition from Danian to Upper Paleocene sediments is usually marl, but in places may be shales and sand. The overlying Upper Paleocene section is predominantly clastic. Shale and silt are characteristic on the margins of the basin and in areas of isopach thins. Sand becomes an important component in areas of thick section, for example in the Cod Field area. Thin marl and limestone beds constitute a minor part. The Upper Paleocene section, like the Danian, is a deep water deposit. The sands in the axial part of the Northern Tertiary Basin and in the Cod Field are turbidites — a feature which is

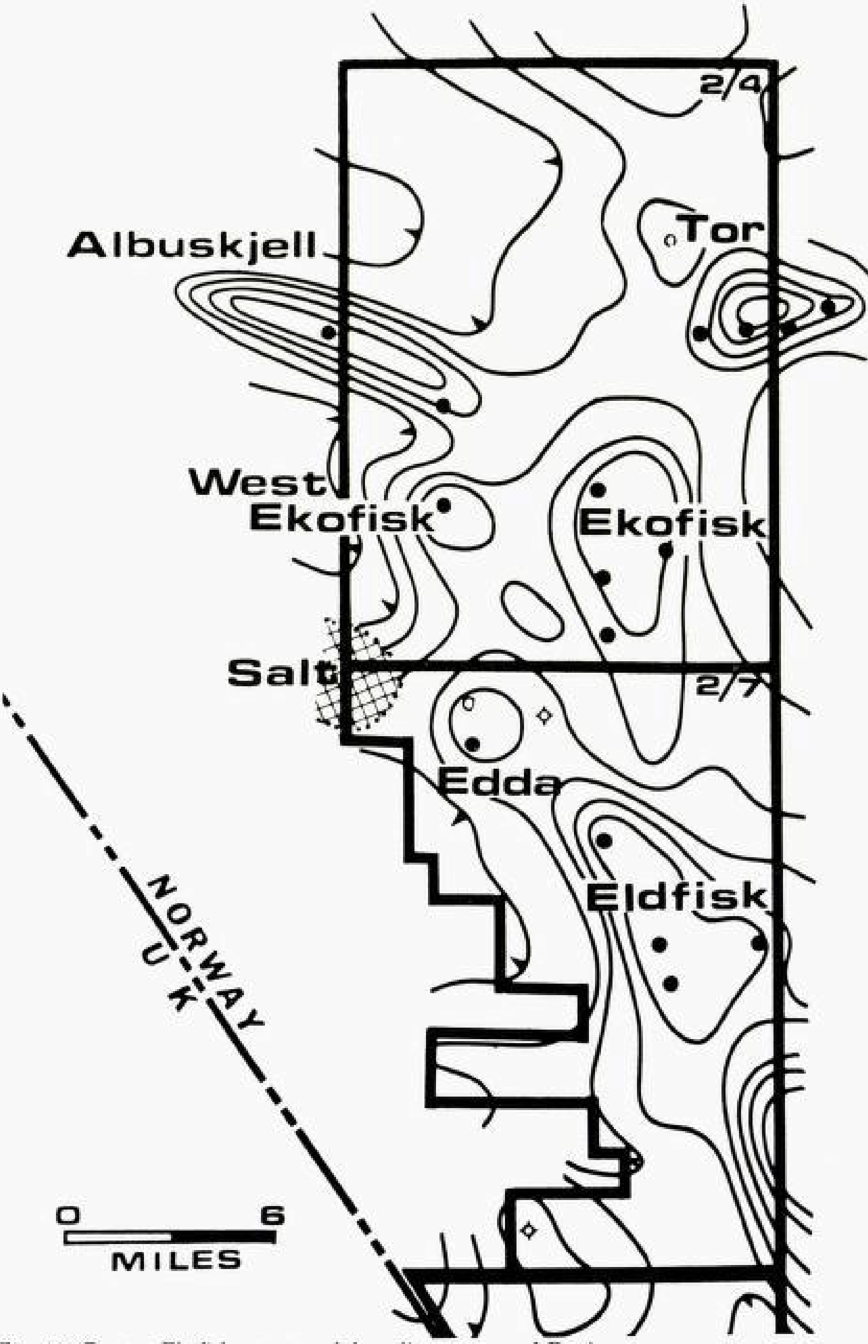


Fig. 19. Greater Ekofisk, structural form-lines to top of Danian.

consistent with the deep water origin of the total section. Sand sources may have been Mesozoic and older sediments eroded from the Mid-North Sea High. Other sources and other environments of deposition are, of course, possible and may be found outside the immediate confines of the Northern Tertiary

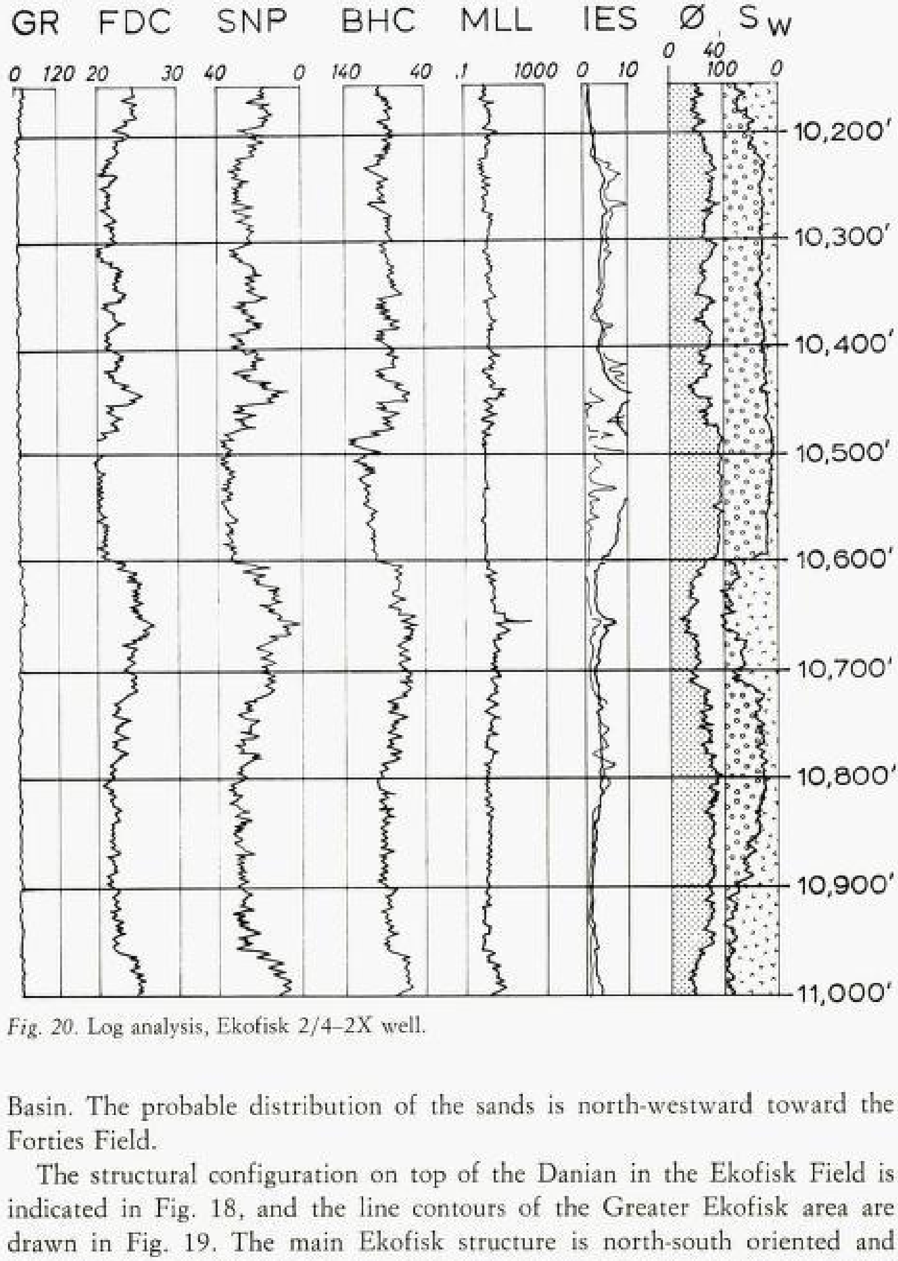


Fig. 20. Log analysis, Ekofisk 2/4–2X well.

Basin. The probable distribution of the sands is north-westward toward the Forties Field.

The structural configuration on top of the Danian in the Ekofisk Field is indicated in Fig. 18, and the line contours of the Greater Ekofisk area are drawn in Fig. 19. The main Ekofisk structure is north-south oriented and 7.5 miles long by 4.5 miles wide. An interesting aspect is that the productive limits do not appear to be entirely structurally controlled. Test information indicates:

1. that in the Ekofisk Field we are dealing with one reservoir only, and
2. that Ekofisk and West Ekofisk are separate reservoirs. Since the productive column exceeds the spill point, there should be continuity between Ekofisk and West Ekofisk. The probable explanation is that the reservoirs are controlled by porosity and permeability.

Fig. 20 shows a suite of logs over the productive interval of an Ekofisk well. Note the zone of reduced porosity from about 10,435′ to 10,510′. This interval can be recognized in all wells drilled to date and was originally thought to separate the upper and lower productive intervals into two reservoirs. Core analysis data would tend to substantiate this contention but test data do not.

The reservoir is a chalky limestone of Danian and Upper Cretaceous age with the high porosities and low permeabilities characteristic of this type of microgranular sediment. Intensive fracturing increases the low primary permeability from less than 1 millidarcy to an average of 10–12 millidarcies. Looking at the lithological characteristics of this carbonate in more detail and in particular at the distinction between 'porous' and 'tight' zones, the fine-grained, homogeneous limestones of the two zones are surprisingly similar in appearance even though their porosities are $> 30\%$ and $< 10\%$, respectively.

It was obvious that conventional thin-section examination would not give the resolution necessary to study such a fine-grained formation, and so a high-powered scanning electron microscope, SEM, was used to investigate the difference between the high and low porosity intervals. In the Fig. 21 photomicrograph, both the porous (32.7%), right, and the tight (8.2%), left, look almost alike. They both basically have the appearance of a foraminiferal micrite, with foraminifera of deep-water facies. Figs. 22 and 23 show with increasing SEM magnification two samples, one of high porosity (32.7%, right) and the other of low porosity (8.2%, left). These Figures illustrate, I believe most spectacularly, the difference between the productive and highly porous section, and the non-productive low porosity section. The highly porous section consists practically exclusively of coccolith fragments and platelets, whereas the low porosity sample clearly shows the secondary calcite growth which reduces the porosity.

In Table 1 the essential reservoir data derived from seismic, drilling and testing are presented. Values obtained from the four producing wells have been averaged. The value 10–12 millidarcies for the permeability should be understood to represent the effective permeability data obtained through testing.

To date, the Phillips Group has established oil and gas production in six fields in the Ekofisk Area (Fig. 24). These six fields plus the Cod Gas–Condensate Field, located 50 miles to the north-west, make up the seven fields currently referred to as the Ekofisk Project.

This project is being developed in four specific phases. The purpose of *Phase 1* was to get the Ekofisk Field on early production to obtain production experience, and reservoir performance information prior to committing to the tremendous investments required for the overall project. This plan was designed for temporary production with conventional equipment, but in an unusual manner. First, the four original wells drilled on the structure were completed using subsea well heads. These wells were then connected to production equipment installed on the 'Gulftide' jackup platform, a former drilling platform. This is done by means of 4½″ flow lines between the wells

Fig. 21. SEM photomicrograph of an Ekofisk Danian limestone.

Fig. 22. SEM photomicrograph magnification of the fields indicated in Fig. 21. Danian limestone, Ekofisk.

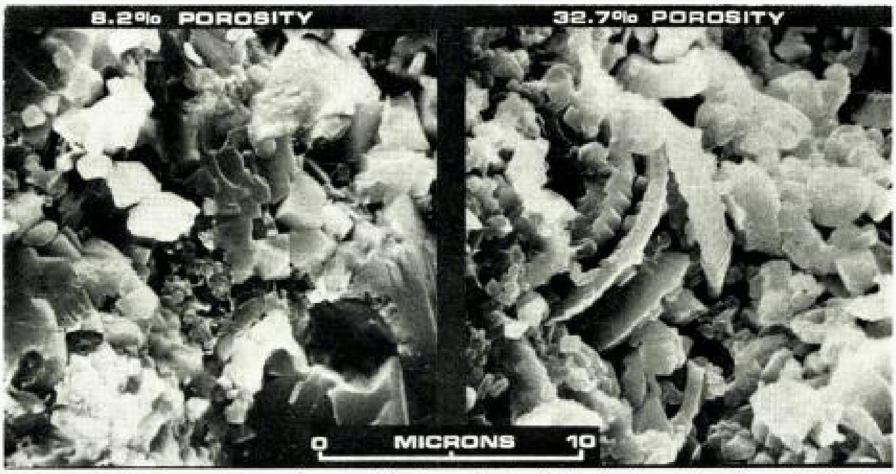


Fig. 23. SEM photomicrograph magnification of the fields indicated in Fig. 22. Danian limestone, Ekofisk. For brief explanation, see text.

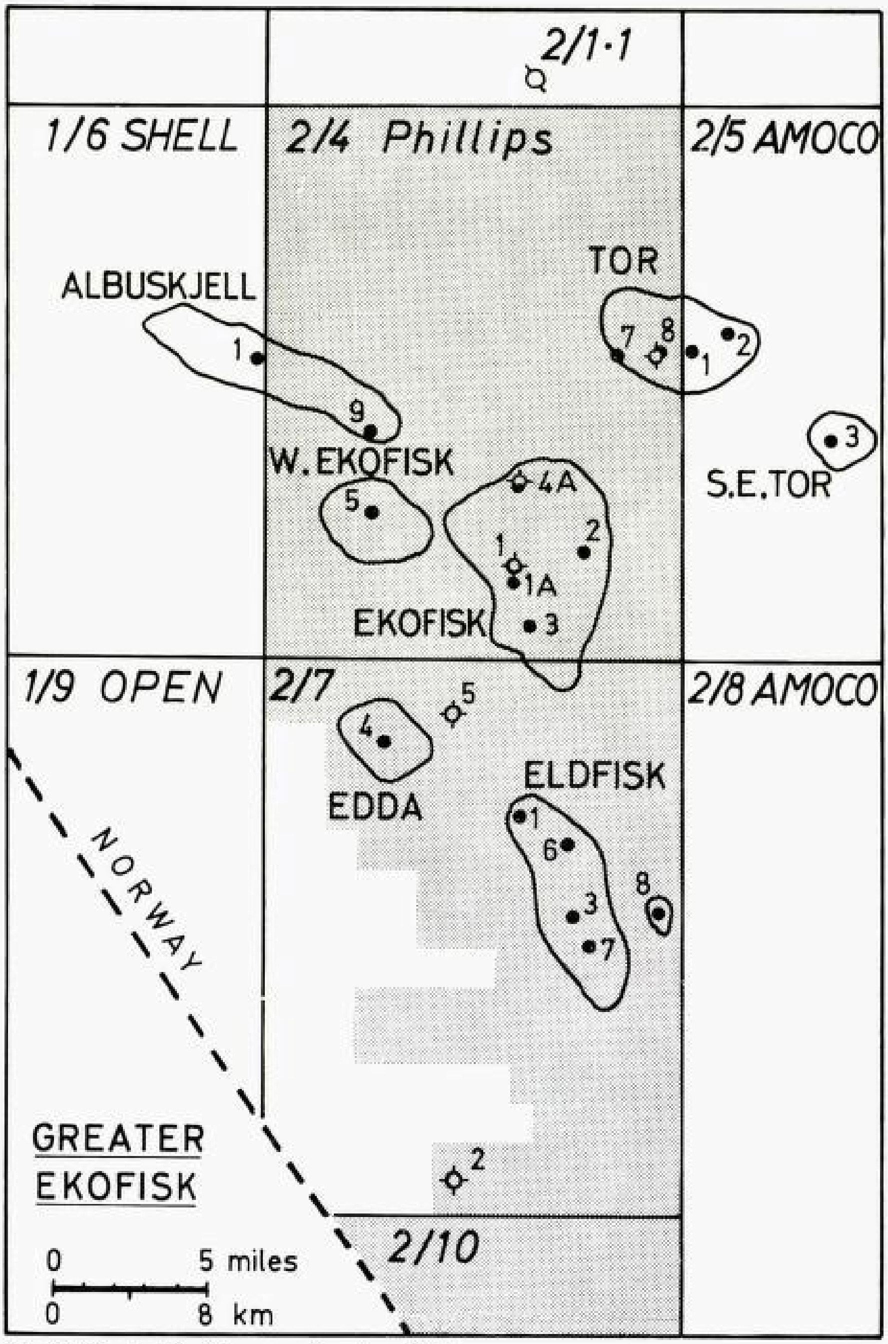


Fig. 24. Greater Ekofisk area, oil and gas fields.

and the platform, where they are then brought in a bundle up through a large caisson to the platform deck. After passing through separation and metering equipment the oil is pumped down the caisson again though one of two 10″

loading lines which go to the mooring buoys. From the buoys, the oil goes directly into a tanker for shipment.

Phase I, the total cost of which has been \$28.5 million, became operational on July 7th 1971, with a production rate of approximately 42,000 BOPD. Since that date, about 26 million barrels have been produced from the field. It has been possible to load tankers 82% of the time; the remaining 18% of the time, severe weather prevents tanker loading, and the field is shut in.

Phase II provides for full development of the Ekofisk field. This phase will require the installation of 6 major platforms, 3 bridge supports, an underwater storage tank, reconnection of the original 4 subsea wells, and the drilling of 38 wells (including 8 injection wells). By March 1974, production will increase to about 80,000 BOPD. The rate will further increase as additional wells are drilled, and by mid-1975 the Ekofisk field will be producing 300,000 BOPD.

The first platform, platform 'B', is located about 1 mile north of the Ekofisk complex (underwater storage). Two drilling rigs began operating from this platform on October 31st 1973, and 17 wells will be drilled from it. Moving south, we come to the most northerly structure in the Ekofisk complex proper, the underwater storage (UWS) tank. An idea of the size of the tank can be gained from Fig. 25. In addition to its use as a storage facility with a one million barrel capacity, the two decks will contain facilities for phase III; these facilities will be discussed later. Platform 'P', which is not installed as yet, will contain 44,000 HP capacity, initiating, crude oil pipeline pumps.

Moving south, the next structure is platform 'C'. Located on this \$23 million platform is a drilling rig with which 8 gas injection and 3 producing wells will be drilled. Drilling commenced on October 3rd 1973. Also to be located on this platform will be high pressure (88,000 HP) gas injection compressors. All gas produced with the 300,000 BOPD phase II will be re-injected back into the reservoir (the maximum volume of gas to be injected is 450 MMCFD).

An adjacent installation is the quarters, a platform which was put in service in July 1973, with services for 185 men. The next installation is the field terminal platform where all Ekofisk production will be processed. The equipment has a capacity of 1 billion CFD gas and 373,000 BOPD. A gas flare platform has also been installed: gas will be flared only in time of emergency.

Drilling platform 'A' (Fig. 26) is located about 2 miles to the south of the flare platform. One rig will drill 9 wells from this platform. Drilling operations started on September 3rd 1973.

Phase II construction is nearly complete and drilling has started on all of the drilling platforms. Concurrently with Phase II, *Phase III* has been proceeding. This consists of developing the Cod, Tor and West Ekofisk fields, completing the installation of the processing facilities on top of the UWS tank, laying oil and gas lines to shore and building shore facilities. Construction of the various platforms is under way. 195 miles (312 km) of the 34" crude line to Teesside, England, have been laid. Only 23 miles (37 km) remain. The

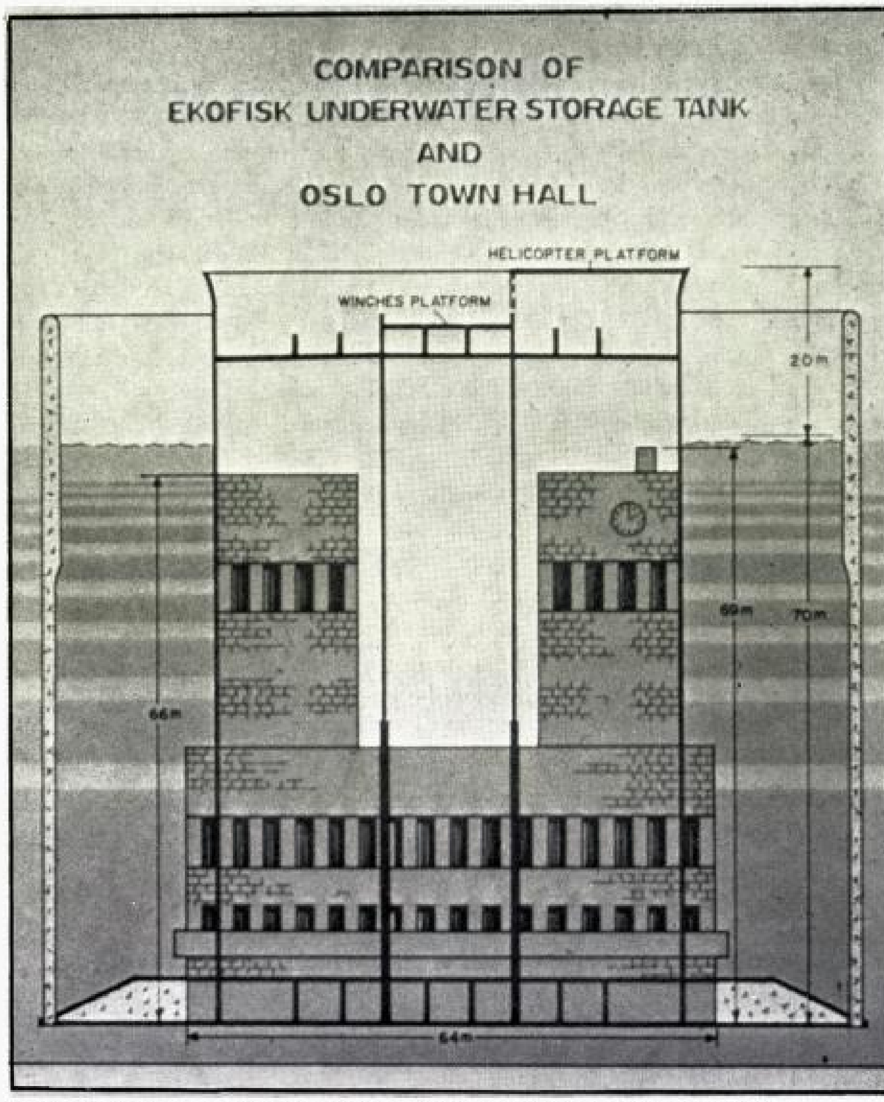


Fig. 25. Comparison of Ekofisk underwater storage tank with the Oslo town-hall.

268 mile (430 km) 36″ gas line to Emden, West Germany, will be laid in the summer of 1974 and the crude line completed. With the pipelines and shore facilities completed in October 1975, the total system will have a capacity of 1 million BOPD and 2.2 BCF gas per day. Maximum production from Phase III is estimated at about 550 thousand BOPD and about 1 BCFGD.

The nerve center of the total Ekofisk project will be the communications, and processing facilities are currently being constructed on the decks on top of the ŪWS tank. The facilities, including Ekofisk center, pipelines and shore facilities ,have been built with a capacity to handle more than Phase III production. Total development will include three additional fields — Albu-

Fig. 26. Drilling platform 'A', Ekofisk fields.

skjell, Edda and Eldfisk — as *Phase IV*. Considerable planning and design have been done and some equipment purchases have already been made in regard to Phase IV, and this is proceeding concurrently with Phase III development. It is difficult to conceive the size and scope of this project, but the investment required to fully develop the project will be more than $2 billion or more than 14 billion Norwegian kroner.

With regard to future possibilities for finding new oil and gas reserves, Fig. 27 shows a generalized stratigraphic column of the North Sea and indicates with symbols the numerous formations in which oil and gas have been encountered. With the large number of targets shown in the geologic column, and the large unexplored areas remaining, there is obviously a large potential for future significant discoveries of both oil and gas.

Also, when one fully recognizes the nearness of this new oil and gas province to one of the world's outstanding energy markets, one can understand why, despite the difficulties of the North Sea operations and the increasing limitations imposed in new concession terms, the area will continue to attract the petroleum industry in its search for new reserves.

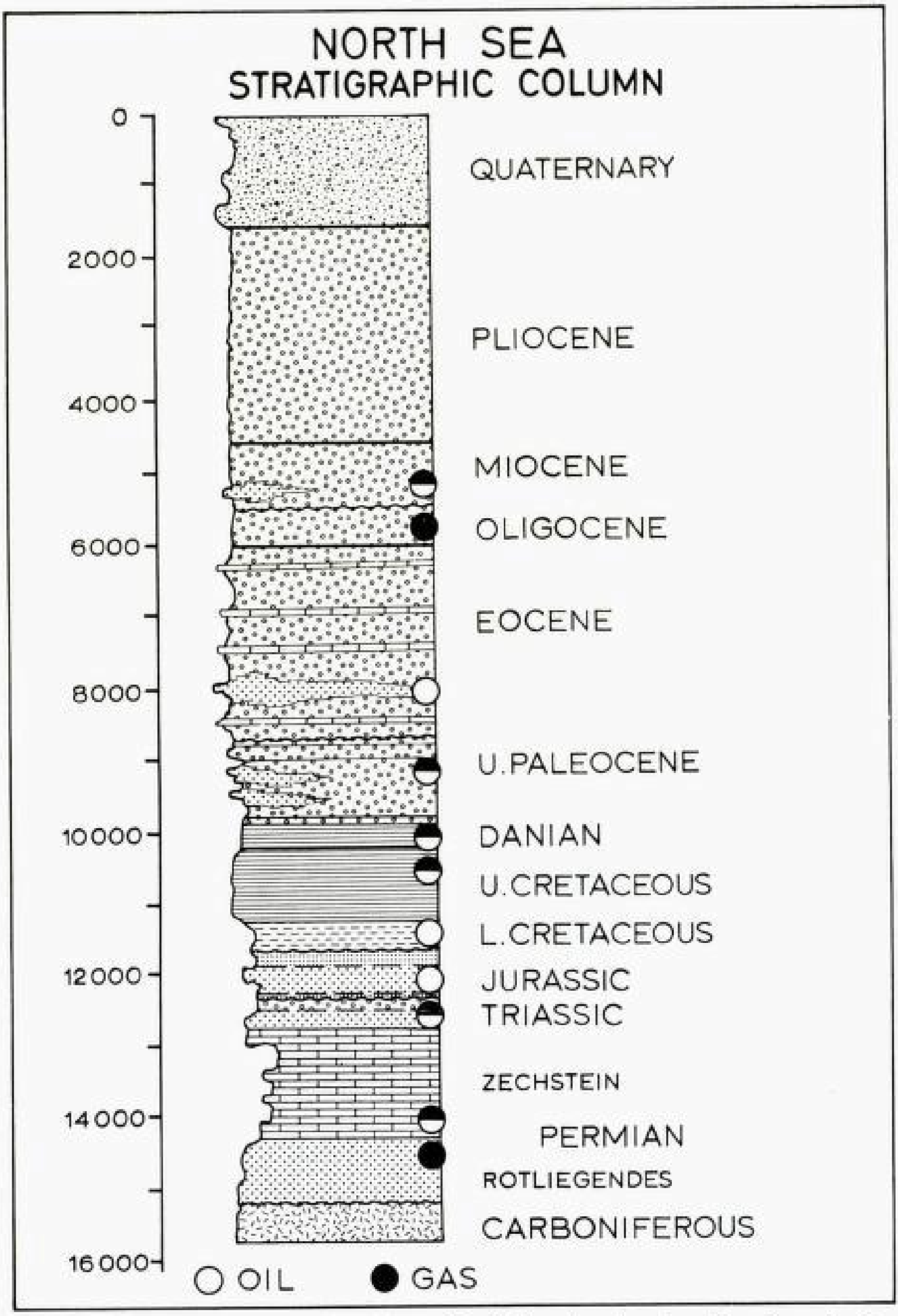


Fig. 27. Generalized stratigraphic column, North Sea, showing the oil- and gas-bearing formations. Thicknesses in feet.

Table 1. Ekofisk field, Danian reservoir data

Lithology	Limestone and chalk
Depth	– 10,400 ft. Mid point
Area	13,625 acres
Net pay	479 ft.
Gross pay	617 ft.
Net to gross ratio	0.776
Porosity	30%
Permeability	10–12 md
Reservoir pressure	7,135 psia (a – 10,400 ft.
Pressure gradient	0.685 psi/ft.
Reservoir temperature	265°F (a – 10,400 ft.
Temperature gradient	2.02°F/ft.
Interstitial water	20%
GOR	1600–1
FVF	1.78
Oil gravity	36° API
Producing mechanism	Solution gas drive