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A standard lithostratigraphic nomenclature for the Central and Northern North Sea

Compiled by C. E. Deegan and B. J. Scull

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FOREWORD

This joint report is a unique venture in international cooperation. It is a compilation of the work of the committees of Norway and the United Kingdom to erect a lithostratigraphic nomenclature for a major part of the North Sea. The contributions are more than bi-national. Nationals of six countries participated in the Norwegian committees and those of five countries in the UK committees.

The compilers of this report, Dr Deegan of the Institute of Geological Sciences and Dr Scull of the Norwegian Petroleum Directorate, have been responsible for coordinating the efforts of the various sub-committees set up to consider the nomenclature on either side of the common median line in the Central and Northern North Sea. They have collaborated throughout the project, have been personally responsible for writing much of the text, synthesising text and figures and approaching the operators for permission to publish the well logs and seismic sections that illustrate it.

Dr Deegan was responsible for the compilation of the preliminary drafts that were submitted to the committees for comment and revision and for the compilation of the final version of the report. Typing of all the compiled drafts and the drawing of all the text figures and plates were done in the Edinburgh Office of the Institute of Geological Sciences.

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A proposed standard lithostratigraphic nomenclature for the Central and Northern North Sea

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COMPILERS' STATEMENT

Our objective, in accordance with the wishes of the sponsoring organisations, has been to compile the work of the sub-committees into a practical framework for the lithostratigraphic nomenclature of the Central and Northern North Sea. These areas are immature with respect to subsurface control from wells and seismic data, which tend to be unevenly distributed. Therefore there is inevitably some variation in the reliability of the correlations presented here. Future data releases will allow additional clarification but none the less we believe that the overall framework erected in this report is sound and that subsequent efforts should be concentrated on improving the correlations, distribution patterns and nomenclature of smaller stratigraphic intervals in more restricted areas than those included in this report

Although we have had the responsibility of compiling this report, we must emphasise that the selection and interpretation of the data was mostly done by the various subcommittees. (The memberships of these sub-committees are given in the introduction.) Their knowledge and cooperation furnished the definitions and relationships of the components of the framework. The diversities in experience and philosophy of the members of the sub-committees assured a careful evaluation of the available data. That these diversities, together with the unevenness in the distribution of data, resulted in significant disagreement in only a few instances reinforces our opinion that the nomenclature proposed in this report is a practical one. Nevertheless it should be noted that the results presented here are not necessarily the unanimous opinion of all committee members and some compromises have had to be negotiated.

On behalf of the sponsors and ourselves we wish to thank all the committee members for contributing to this effort.

Bibliographical references

Deegan, C. E. and Scull, B. J. (compilers) 1977. A proposed standard lithostratigraphic nomenclature for the Central and Northern North Sea. *Rep. Inst. Geol. Sci.*, No. 77/25; *Bull. Norw. Petrol. Direct.*, No. 1.

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INTRODUCTION

HISTORY

In late 1972, following collaboration between the United Kingdom Offshore Operators Association (UKOOA), the Petroleum Exploration Society of Great Britain (PESGB) and the Institute of Geological Sciences (IGS), a committee was formed to consider the precise nomenclature of lithostratigraphic and structural units in the North Sea. The committee was composed of representatives from petroleum companies and members of IGS. The committee adopted the following terms of reference:

1. To define with precision the subsurface lithostratigraphic units of the North Sea and to name them in accordance with the international rules of scientific nomenclature.
2. To name the structural units in the North Sea taking due account of the names already in use.
3. To effect liaison with similar committees in other countries bordering the North Sea.
4. To report on these subjects in a form suitable for publication.

The committee determined that the detailed work involved in erecting a standard lithostratigraphic nomenclature should be entrusted to a number of sub-committees which would take instruction from and be answerable to the main committee.

It was agreed that the first phase of the committee's study should concentrate on the Southern North Sea, this being defined as the area lying south of 56°N. The results of this phase of the work have been published by the IGS (Rhys, 1974).

In accordance with the terms of reference of the committee, communication was established with those national organisations in Norway, Denmark, West Germany and the Netherlands, which are concerned with exploration for hydrocarbons in the North Sea. At the time they all expressed interest in the British initiative but had no plans of their own to undertake similar projects.

In 1974 the Norwegian Petroleum Directorate (NPD) and the Stavanger Exploration Branch of the Norwegian Petroleum Society decided to sponsor a lithostratigraphic nomenclature committee for offshore Norway in order to establish a practical nomenclature and help prevent a proliferation of local names. An organising committee was selected by the sponsors from nominees submitted by Norwegian companies and institutions and on the recommendation of the sponsors the members of the organising committee became the members of the main committee.

During the initial meeting the main committee decided that the main committee and sub-committee system used in the UK for the lithostratigraphic nomenclature of the Southern North Sea (Rhys, 1974) was effective and adopted it with the provision that the Main

Committee members would serve on the appropriate subcommittees.

Late in 1974 the Norwegian Main Committee contacted Dr A. W. Woodland (IGS) to discuss the possibility of cooperating with the UK to erect a mutually acceptable lithostratigraphic nomenclature for the Northern North Sea. In response to the Norwegian initiative Woodland convened the UK Main Committee in February 1975 and it was decided to commence this second phase of their work, in which the IGS involvement was supported by the Department of Energy. It was decided to follow similar procedures and terms of reference as those adopted for the first phase of the work. Consequently a number of subcommittees were set up to carry out the detailed work involved in achieving the objectives.

After his experience in the first phase of the work G. H. Rhys (IGS) took the chair at the initial meetings of the UK subcommittees to initiate their work and to provide continuity of approach. After the early stages Dr C. E. Deegan (IGS) replaced Rhys.

It was convenient and possible to establish subcommittees on a chronostratigraphic basis since progress in the Northern North Sea had achieved a general appreciation of the position of the major system boundaries. However this did not impose any constraints on lithostratigraphic nomenclature and the results of the work have indicated that a number of lithostratigraphic units must transgress system boundaries. During the course of the work there have been a number of meetings between the two countries at both main and sub-committee level and at an early stage it was decided that the results of the work would be published in a joint UK-Norwegian report. In accordance with this Deegan collated the results of the UK sub-committees and B. J. Scull collated those of the Norwegian sub-committees. The collated results were then compiled into the present report by Deegan.

In 1975 the Norwegian Main Committee contacted the Danes who subsequently formed a lithostratigraphic nomenclature committee to coordinate with the Norwegian committee on studies of strata of mutual interest.

COMMITTEE MEMBERSHIPS

Norway

Main Committee: Dr B. J. Scull (NPD, chairman), R. Myrland (NPD, secretary), C. Arcilise (Phillips), M. C. Berthon (Elf), Dr K. Bjørlykke (University of Bergen), Dr E. F. Jones (Mobil), W. V. Naylor, Jr (Esso), B. E. Shaw (Amoco) and B. Yonge (Conoco).

Early in 1975 transfers resulted in Jones and Shaw being replaced by R. F. P. Hardman (Amoco) and H. L. Taylor (Mobil). Later on Berthon was transferred and Yonge assumed different duties and they were replaced by K. Havard (Elf) and Dr W. J. van den Bosch (Conoco). In the latter part of 1976 Arcilise and Taylor were transferred from Norway and their committee posts were taken by R. H. Kirk (Mobil) and K. G. Finstad (Saga).

Sub-committees: The sub-committee members are listed with the chairman named first and past members listed after the dash. An asterisk * denotes members with some responsibility for the authorship of the report of that sub-committee.

1 For the pre-Jurassic systems: *K. Havard (Elf), W. V. Naylor Jr (Esso), *B. J. Scull (NPD), W. J. van den Bosch (Conoco) — B. Yonge (Conoco), M. C. Berthon (Elf, past chairman).

2 For the Jurassic system: *W. J. van den Bosch (Conoco), R. H. Kirk (Mobil), R. Myrland (NPD), I. Norbury (Amoco) — C. L. Ruble (Amoco), H. L. Taylor (Mobil), B. Yonge (Conoco, past chairman).

3 For the Cretaceous system: *B. J. Scull (NPD), R. H. Kirk (Mobil), R. Myrland (NPD), I. Norbury (Amoco) — *C. Arcilise (Phillips, past chairman), C. L. Ruble (Amoco), H. L. Taylor (Mobil).

4 For the Tertiary system: *W. V. Naylor Jr. (Esso), *K. Havard (Elf), *B. J. Scull (NPD) — M. C. Berthon (Elf), C. Arcilise (Phillips).

5 For structural nomenclature: H. C. Rønnevik (NPD), E. Bandlien (Saga), K. Lien (Statoil), W. J. van den Bosch (Conoco). (Lien replaced F. Linder (Statoil) who resigned.)

6 Onshore/offshore coordination: K. Bjørlykke (University of Bergen), B. J. Scull and R. Myrland (both NPD).

United Kingdom

Main Committee: Dr A. W. Woodland (IGS, chairman), G. H. Rhys (IGS, secretary), Dr C. E. Deegan and D. A. Ardus (all IGS), R. J. Johnson (Burmah), D. Kelland (Occidental), B. T. Lee (BNOC), A. Masters (Total), Dr J. R. Parker (Shell), Dr M. F. Ridd (BP), A. A. Slanis (Phillips), J. B. Thomas (Amoco), D. Warwick (Hamilton).

Sub-committees:

1 For the pre-Jurassic systems: G. H. Rhys/*C. E. Deegan and G. Warrington (all IGS), *I. A. G. Willis (Shell), *B. Blanche (BNOC), J. J. Pennington (Hamilton), *C. J. Banks (Phillips), *D. Warwick (Hamilton).

2 For the Jurassic system: G. H. Rhys/*C. E. Deegan, *J. A. Chesher and R. J. Davey (all IGS), J. A. Coleman (Burmah), A. Gabanyi (Amoco), *D. G. Kelland (Occidental), *D. C. Kennedy (BP), B. T. Lee (BNOC), A. Masters (Total), *W. G. Townson (Shell), C. J. Banks and J. Davis (both Phillips).

3 For the Cretaceous system: G. H. Rhys/*C. E. Deegan, *J. A. Chesher and *S. M. Paterson (all IGS), G. Williams (BP), R. J. Johnson (Burmah), *C. J. Banks (Phillips).

4 For the Tertiary system: G. H. Rhys/C. E. Deegan, *O. S. Petrie, and *K. Rochow (all IGS), *J. R. Parker (Shell), *G. Williams (BP), A. A. Slanis (Phillips), A. Masters, J. Gerard and G. Sambet (all Total).

STRUCTURAL NOMENCLATURE

Unlike the Norwegians the UK did not set up a separate sub-committee to consider structural nomenclature. The preliminary results of the Norwegian structural nomenclature sub-committee have been published (Rønnevik and others, 1975) and this terminology is in use in the Norwegian sector of the North Sea.

The present report uses both the structural terminology published by Rhys (1974, fig. 8) for the UK sector, and that of Rønnevik and others (1975) for the Norwegian sector. The main point of conflict between these two nomenclatures lies in the usage of the term Viking Graben. The Norwegians prefer the term Viking Trough, which they would limit to the narrowest part of the northerly sedimentary basin between the East Shetland Platform and the Vestland Arch. Where the basin opens out to the north they use the term East Shetland Basin.

For the purposes of the present report the term Viking Graben is used in the sense illustrated by Rhys (1974) (see Figure 1), and includes both the Viking Trough and the East Shetland Basin of the Norwegian usage.

As the work progressed it became apparent that in broad terms the Northern North Sea included two major sedimentary provinces and that different lithostratigraphic nomenclatures would be required for each. Palaeontological dating will eventually establish the chronostratigraphic relationship between the two. These two provinces are separated by an area of structural complexity at the southern end of the Viking Graben, which approximately coincides with the 59°N latitude line. The two provinces are referred to as the Central North Sea and the Northern North Sea. The Central North Sea includes the Central Graben (or Central Trough in the Norwegian terminology), the Forth Approaches Basin, the Moray Firth Basin, including the Halibut Horst and Fladen Ground Spur, and the Norwegian part of the Norwegian-Danish Basin. It is essentially the area between 56°N and 59°N. The Northern North Sea includes the Viking Graben (Viking Trough and East Shetland Basin in the Norwegian terminology) and the bounding platform areas, namely the East Shetland Platform and the northern part of the Vestland Arch. It is essentially the area between 59°N and 62°N. An outline map of the main structural elements of the Central and Northern North Sea is included on Figure 1.

LITHOSTRATIGRAPHIC NOMENCLATURE

As in the first phase of the work the establishment of a lithostratigraphic nomenclature has entailed consideration of the geological succession illustrated in composite well logs. The results are presented in accordance with the recommendations of the International Subcommission on Stratigraphic Nomenclature (Hedberg, 1976). Where lithostratigraphic subdivisions can be recognised they have been formally defined under the following headings: *name, well type section, well reference section, thickness, lithology, boundaries, distribution, age* and *depositional environment* (if known). It is felt that this approach is helpful to the user since with a reference document it is essential to be able to locate definitions as quickly as possible. The text definition is linked to a diagram of the relevant well or wells which gives a graphic representation of the lithology flanked by the relevant gamma ray and sonic logs.

The criteria influencing the selection of type and reference wells included completeness of section, quality of petrophysical logs and availability of good core or samples. However, it should be appreciated that choices were made from a very limited number of wells available, and in some cases the most suitable well could not be used and a less satisfactory one had to be substituted. Figure 1 is a location map of all the wells figured in this report.

According to Hedberg (1976) the name of a lithostratigraphic unit should be formed from the name of an appropriate local geographic feature combined with the designation of its rank. However in offshore areas the availability of geographic and bathymetric designations is usually limited and recourse must be made to some other source of nomenclature. In the present report new names are derived from the following sources:

1 Geographic/bathymetric features.
2 Oil fields where the unit is well developed but not necessarily where the well type section is located.
3 Names of famous British and Norwegian explorers and voyagers, particularly those with a marine association.
4 Names of geographic features on immediately adjacent coasts such as headlands and fjords.
5 Names of regions, towns, lochs etc. in adjacent countries where it is felt that no geographic confusion is likely to arise.
6 Names of fish.

The above sources may appear to be unnecessarily varied but it should be noted that one of the objects of this project has been to produce a practical nomenclature which will be used by oil companies and academics alike. When work began there was already a widely used heterogeneous informal nomenclature in use in the Northern North Sea, and it was decided to retain as much of this as possible in order to avoid the introduction of too many unfamiliar names. The proposed nomenclature may therefore appear heterogeneous but it should also prove to be practical.

It should be noted that chronostratigraphic definition is still rather broad in the North Sea. Determinations are normally based on the analyses of cuttings and will almost certainly be refined in the future. The ages quoted in the definitions of the lithostratigraphic units and those appearing on the diagrams should therefore be regarded as a guide rather than a definitive identification.

STRATIGRAPHIC SEQUENCES

The post-Carboniferous sediments of the North Sea Basin were deposited in four major sequences. The oldest sequence consists of red beds and evaporites which are essentially of Permo-Triassic age. This is overlain by a dominantly marine sand-shale sequence with rather thick and extensive fluvial and deltaic intercalations culminating in a widespread calcareous shale and mudstone unit. These sediments were deposited during Jurassic and Early Cretaceous times. The third sequence consists essentially of carbonates and its principal expression is the thick section of Late Cretaceous Chalk. The youngest sequence, which extends up to the sea floor, is dominantly marine shale and clay of Tertiary to Recent age. In the Palaeocene and Early Eocene thick wedges of deltaic and fan sands were deposited, particularly along the basin margins but extending towards the basin centre at times. From Early Eocene to Recent time the basin was mainly a site of argillaceous deposition with only local minor sand accumulations.

PRE-PERMIAN

A number of widely scattered boreholes have penetrated pre-Permian rocks but the thicknesses drilled have generally been minimal and on the basis of the well information currently available it is not possible to erect a lithostratigraphic nomenclature for these rocks. Representative well sections of the Carboniferous and Devonian in the UK Sector are presented to illustrate the lithofacies on an informal basis. In the Viking Graben serpentinites and mica schists of probable Early Palaeozoic or Precambrian age are known from several wells, but no sedimentary sequences of unquestionable pre-Devonian age have been encountered. In Norwegian waters the pre-Permian rocks normally encountered are metasediments and granitic gneiss of probable Early Palaeozoic to Precambrian age, but red clastics of probable Devonian age are preserved locally

(NPD Paper No. 2). In the southern part of the Central North Sea Carboniferous rocks have been penetrated but the details are not yet available.

In the UK sector the Devonian is divisible into two main lithofacies, continental clastics of Old Red Sandstone aspect, and marine limestones. The former comprise conglomerates, sandstones, siltstones and shales, typically with red colouration, and occur in wells on the Shetland Platform, the western margins of the Viking and Central Grabens and in the Forth Approaches and Moray Firth Basins. The marine limestone facies is considered to have a rather limited geographical distribution in the southern part of the Central North Sea. Hamilton well 30/24–3 has been chosen as the illustrative section for both these facies (Figure 2). In this well, the overlying red clastics are separated from the marine limestones by a succession of red dolomites, anhydritic shales and siltstones.

The Carboniferous rocks proved so far in the Central and Northern North Sea extend from the Moray Firth Basin into the northern end of the Forth Approaches Basin and are bounded to the north by the East Shetland Platform. Generally, they comprise interbedded sandstones, shales and coals with subordinate carbonates, and are rather similar to the Limestone Coal Group of Central Scotland. The presence of diagnostic floral assemblages in these rocks has resulted in good time stratigraphic control. It is apparent that the sedimentary sequences proved to date are Early Carboniferous in age, ranging from Viséan to questionable Namurian.

In the Moray Firth (Total well 12/23–1) a sequence of tuffs, basalts and dolerites has been encountered which may be at least partly Carboniferous in age. A comparison of this sequence with that of the Orkneys suggests that the volcanics may be of Middle Devonian age overlain by Upper Devonian rather than Rotliegendes red beds. Radiometric dating of the Hoy volcanics gives a Middle- to Late-Devonian age but the spread of dates extends into the Carboniferous, although the overlying Hoy sandstone contains Late-Devonian fish material (Halliday and others, in press).

The Carboniferous section of Occidental well 14/19–1 (Figure 3) has been released as an illustration of the sedimentary sequence encountered in the Moray Firth area. Regionally the upper boundary of the Carboniferous is a major unconformity, most commonly overlain by Lower Permian (Rotliegendes) sandstone, although in well 14/19–1 the overlying rock is Zechstein dolomite. The lower boundary of the Carboniferous has rarely been reached and nothing can be said about it at this stage.

PERMIAN

At the end of the Variscan orogeny there was a major change in the tectonic pattern in north-west Europe. A long period of basically compressive forces was replaced by an extensional stress regime. The Variscan foreland was initially subjected to uplift, tilting and erosion, followed by differential subsidence resulting in the formation of post-orogenic, intracratonic basins and a set of narrow rifts and grabens. The Southern and Central North Sea Basins were initiated at this time, separated by the Mid North Sea—Ringkøbing-Fyn High, and the formation of the Viking Graben may have begun (P. A. Ziegler, 1975).

Lithostratigraphy

Permian sediments in Northwest Europe can generally be subdivided into a lower (Rotliegendes) unit and an

Table 1 Permian and Triassic lithostratigraphic nomenclature

System	Series	Northern North Sea	Central North Sea (U.K.)	Central North Sea (Norway)	Group
Jurassic		Statfjord Formation	Volcanics or paralic sediments	Paralic sediments	Fladen Gp
Triassic	Upper	Cormorant Formation ?	Josephine Member; Smith Bank Formation	Skagerrak Formation	"Triassic Group"
Triassic	Middle	?	Smith Bank Formation	Smith Bank Formation ?	"Triassic Group"
Triassic	Lower	?	Smith Bank Formation	Smith Bank Formation	"Triassic Group"
Permian	Upper	Local occurrences of dune sandstone overlain by Zechstein mudstones, salts and carbonates. (Brennand and Siri, 1975)	Marginal facies: Halibut Bank, Turbot Bank and Argyll Formations; Basinal facies: Z_1 - Z_4 evaporite cycles; Kupferschiefer Fm.	Basinal facies: Z_1 - Z_4 evaporite cycles; Kupferschiefer Fm.	Zechstein Group
Permian	Middle	Local occurrences of dune sandstone overlain by Zechstein mudstones, salts and carbonates. (Brennand and Siri, 1975)	Auk Formation / Fraserburgh Fm	Red, fine-grained clastics and conglomerates (see Figures 7 and 11)	Rotliegendes Group
Permian	Lower		Auk Formation / Fraserburgh Fm	Red, fine-grained clastics and conglomerates (see Figures 7 and 11)	Rotliegendes Group

upper (Zechstein) unit. In the Central North Sea these subdivisions can normally be recognised, the lower unit comprising primarily subaerial sediments and the upper consisting of a restricted marine evaporite sequence. The Permian has not often been encountered in the Northern North Sea and no recommendations are made for that area at present.

The terms Rotliegendes and Zechstein were originally used in a lithostratigraphic sense without being formally defined. In the present report the Rotliegendes and Zechstein units are given group status since some formations can be defined within them. Further subdivisions at formation level are also apparent but are not defined here because of the lack of data available to the sub-committee. The suggested nomenclature is shown in Table 1.

Rotliegendes Group

The Rotliegendes Group consists of a sequence of clays, shales, sandstones and minor conglomerates deposited in continental environments. The sediments are frequently red and diagnostic floras are rare resulting in poor chronostratigraphic control.

In the UK sector of the Central North Sea the Rotliegendes Group is subdivided into two interdigitating formations, the Fraserburgh Formation and the Auk Formation. In places one or other of these formations may make up the whole of the group as shown in the cross-section (Figure 4). This twofold subdivision compares with that in the Southern North Sea Basin (Rhys, 1974).

In the Norwegian sector no subdivision of the group is made because of lack of data but a reference section for the group is discussed below, and it is thought that division into formations similar to those in the UK sector will be possible.

The distribution of Rotliegendes sediments in the Northern North Sea is poorly known and no lithostratigraphic divisions can be proposed at present. The Rotliegendes of the Moray Firth Basin has not been considered because of lack of data.

Auk Formation

Name: The formation is named after the Auk Field where it is well developed.

Well type section: UK well 30/16–1 (Shell/Esso) (Figure 5). The formation occurs from 2375 m (7792 ft) to 2859 m (9380 ft) below KB.

Well reference section: None.

Thickness: 484 m (1588 ft) in the type well but decreasing to the north-west where it interfingers with the Fraserburgh Formation.

Lithology: The formation is characterised by reddish brown to grey, very fine to coarse grained, subangular to well rounded, moderately to well sorted, friable sandstones. They normally appear massive but occasionally contain laminated and cross-bedded units. The sandstones are normally cemented with haematite and authigenic clay, but dolomite and anhydrite are locally important cements. The main sandstone body is 470 m (1542 ft) thick and there is a basal conglomerate which is 14 m (46 ft) thick. This conglomerate is reddish brown and contains angular to subangular clasts of quartz and schist. It may well be only a local phenomenon and could be given member status in the future.

Boundaries: In the type well and a number of others the junction between the Auk Formation and the overlying Zechstein Group is marked by a distinctive increase in the gamma ray response caused by the overlying Kupferschiefer (Figure 5). The lower boundary could be problematical, particularly where the Auk Formation rests on Devonian strata, which may be of a similar red-bed facies. In the case of the type well however, the contact is an unconformity.

Distribution: The formation is best developed in UK quadrants 29 and 30. It can be traced for at least 100 km away from the Mid North Sea High and is recognisable over a distance of 150 km in an NW–SE direction.

Age: Precise dating has not been possible because of lack of fossils.

Depositional environment: Dipmeter and petrological studies indicate that the sandstones were deposited as aeolian dunes. The dune sandstones are identified by regular foreset cross-bedding of constant dip (20–28°) usually underlain by sediments showing decreasing dip with depth, interpreted as bottomset deposits. Dipmeter analysis suggests that the dunes migrated westwards under the influence of the prevailing winds.

Fraserburgh Formation

Name: The formation is named after the town of Fraserburgh in north-east Scotland.

Well type section: UK well 21/11–1 (Shell/Esso) (Figure 6). The formation occurs from 3165 m (10 384 ft) to 3295 m (10 809 ft) below KB.

Well reference section: None.

Thickness: 130 m (425 ft) in the type well. It thins to the north-west and thickens to the south-east where it passes into the Auk Formation.

Lithology: The formation comprises a sequence of dark grey to reddish brown, dense, hard, dolomitic shales. The shales are interbedded with thin dolomitic and micaceous sandstone stringers (2–3 cm thick) which are very argillaceous and anhydritic with irregular wavy bedding and anhydritic nodules (0.5–2 cm in diameter). These sandstones are dark brown to grey and vary from fine to coarse grained.

Boundaries: The Fraserburgh Formation is normally overlain by the basal Kupferschiefer shale of the Zechstein Group, the boundary being marked by an upward increase in gamma log response. The lower boundary of the Fraserburgh Formation is normally an unconformity and in the case of the type well (Figure 6) the underlying rocks are of Early Carboniferous (Viséan) age and have a lower gamma log response.

Distribution: To the south and south-east the formation interdigitates with the Auk Formation and eventually passes laterally into it.

Age: Palynological studies have dated the formation as Permian but have been unable to refine the age further.

Depositional environment: Dipmeter and core data indicate that the formation was deposited in a dune-bordered sabkha environment. The sediments show low dip angles (2–5°) and the sandstone stringers contain wavy lamination which may be interpreted as adhesion ripples. The presence of anhydrite nodules and dolomitic lenses is consistent with such an environmental interpretation.

In the Norwegian sector very little data are available on the Rotliegendes and no subdivision of the group is possible. Only two wells presently available (7/3-1 and 17/4-1) have penetrated appreciable sections of the Rotliegendes. The Rotliegendes section of Amoco/Noco well 7/3-1 has been released as an illustration of the lithology but unfortunately there are no petrophysical logs in the lower part of the section and the base of the Rotliegendes may not have been reached (Figure 7). In the well 293 m (961 ft) of Rotliegendes were penetrated, the maximum thickness known so far in the Norwegian sector. The rocks are a continental red-bed sequence of reddish brown, very fine grained sandstone, argillaceous in part, with variable amounts of siliceous and carbonate cements. Dark, red micaceous non-calcareous shales are interbedded with the sandstone and become more common towards the base where the whole section becomes finer grained.

In well 17/4-1 (Petronord) (Figure 11), rocks of probable Rotliegendes age include conglomerate with pebbles of quartzite, gneiss, acid volcanic rocks and mica schist in a well-cemented argillaceous and sandy matrix. Owing to a lack of organic material no definitive dates have been obtained from the Rotliegendes Group. Although the group has been penetrated in only two releasable wells so far it is thought to be extensive in the Norwegian sector of the North Sea, being missing only on local structural highs.

Zechstein Group

The configuration of the Central North Sea Basin in Upper Permian times was similar to that during the Rotliegendes. The Zechstein sediments can be subdivided into a basin-centre sequence dominated by halites, and a marginal sequence (particularly well seen around UK quadrant 15) consisting mainly of dolomite and anhydrite. Towards the basin centre halokinesis frequently causes severe correlation problems.

Two provisional nomenclatures are proposed for these rocks, one for the basinal sequence and one for the marginal sequence. The correlation between these two is not firmly established, owing to the lack of wells drilled in intermediate positions. In both areas the name Zechstein Group is used in order to emphasise the depositional unity of all of the Upper Permian carbonate/evaporite rocks.

BASINAL SEQUENCE

Illustrative wells for the basinal sequence, Shell/Esso 21/11-1 (Figure 8) and Petronord 17/4-1 (Figure 11), show thick halite-rich sections which are not significantly distorted by halokinesis. The top and bottom boundaries of the Zechstein Group are conformable in these wells and the cyclic nature of Zechstein deposition recognised in Germany and the Southern North Sea Basin can also be tentatively recognised. The sequence is however somewhat different in detail, and it is recommended that the formation names used in the Southern Basin (for example Plattendolomit) should not be applied in the Central North Sea until more information is available as to the precise correlation. The only possible exception is the basal unit, the Kupferschiefer, which is thin but appears to be developed uniformly throughout the North Sea. This unit was given formation status by Rhys (1974).

Much consideration was given by the committee to the status to be accorded to the cyclic units, which in a full sequence pass from a basal shale bed through dolomite, anhydrite and halite to potassium salts. These cycles are the basis of the stratigraphical interpretation of Zechstein deposition, and in the Southern North Sea they were given Group status. In the Central North Sea, however, where data are not yet sufficient to establish the relationship of the units in detail, it was felt that interpreted cyclic deposition was not an appropriate basis for lithostratigraphic subdivisions. It was pointed out that each cycle could contain any or all of the Zechstein lithologies, and therefore the cycles could not be distinguished on a purely lithological basis, but required considerable interpretation based on certain preconceived depositional concepts. It is therefore proposed that the cycles should be considered as informal subdivisions of the Zechstein Group, and be referred to as Z_1 cycle, etc. The only formally defined unit is the Kupferschiefer Formation.

Kupferschiefer Formation

Name: An old German mining term meaning 'Copper Shale'.

Well type section: UK well 49/26-4 (Shell/Esso) (see Rhys, 1974), from 2012 m (6600 ft) to 2013 m (6604 ft) below KB.

Well reference section: The formation is illustrated in the following wells which may be considered as reference sections. UK wells 30/16-1 (Shell/Esso) (Figure 5), 21/11-1 (Shell/Esso) (Figures 6 and 8), and 15/26-1 (BP) (Figure 9), and Norwegian wells 7/3-1 (Amoco/Noco) (Figure 7) and 17/4-1 (Petronord) (Figure 11).

Thickness: 1 m (4 ft) in the type well. In the reference wells it is 1 to 2 m thick and appears to be of the same order of thickness throughout the North Sea Basin.

Lithology: In the type well it is a dark brown to black dolomitic shale. In the reference wells it is dark grey to black, carbonaceous and micaceous shale, usually laminated and fissile.

Boundaries: The formation is easily distinguished on wireline logs by a very high gamma ray response and a low velocity. Since it normally occurs between the arenaceous sediments of the Rotliegendes Group and the carbonates and evaporites of the Zechstein Group it forms a distinctive marker horizon.

Distribution: Despite the fact that the formation is very thin it is widely distributed over the Southern and Central North Sea. It is present on land in the UK and northern Europe.

Age: Late Permian.

In well 21/11-1, the Z_1 cycle is taken to include the Kupferschiefer and a 19 m (63 ft) dolomite unit only. This is based on the Southern North Sea Basin sequence in which Z_1 is thinly developed in the basin centre, and does not usually contain halite. This cycle, as interpreted in the 17/4-1 well, is only 5 m thick and the upper part is anhydrite. The Z_2 cycle in 17/4-1 has an anhydrite unit overlying a very thin shale at the base, followed by halite and carnallite; the remainder of the section consists of halite and carnallite with some anhydrite beds which may be interpreted as the basal beds of cycles. An anhydrite at the top of the Zechstein may be representative of the Z_4 cycle. The suggested cycle boundaries are shown in Figures 8 and 11.

MARGINAL SEQUENCE

Well 15/26-1 is considered to be representative of the marginal sequence of the Zechstein Group. The fully developed evaporite cycles cannot be recognised here and it is possible that only the lower part of the Zechstein is present, with a regional disconformity separating these beds from the overlying Triassic rocks. The Zechstein Group here can be divided into three units (Figure 9). At the base is the Kupferschiefer which is similar in lithology to that in well 21/11-1. Above this are two subdivisions which are distinctive enough to be recognised as formal formations. These are designated the Halibut Bank and Turbot Bank Formations (Figure 9). Although marginal to the salt basin these formations are not necessarily typical shallow water or shelf deposits. Where the marginal sequence becomes much thinner and the lithologies are more thinly interbedded these formations may be difficult to distinguish.

Halibut Bank Formation

Name: From a North Sea bathymetric feature.

Well type section: UK well 15/26-1 (BP) (Figure 9). The formation occurs from 3115 m (10 220 ft) to 3131 m (10 272 ft) below KB.

Well reference section: None.

Thickness: The formation is 16 m (52 ft) thick in the type well.

Lithology: In the type well it consists of dolomite interbedded with minor amounts of mudstone and shale. The dolomite is light grey-brown to tan coloured, microcrystalline, argillaceous, silty and anhydritic. The mudstones and shales are greenish-grey to dark grey, anhydritic, silty, carbonaceous and calcareous or dolomitic. Away from the type well the dolomite is sometimes vuggy and sometimes contains carbonaceous bands.

Boundaries: The formation is characterised by the irregular nature of both gamma ray and sonic logs, indicating thinly interbedded lithologies. The lower boundary with the Kupferschiefer Formation is well defined by a decrease in the gamma log response, and the boundary with the overlying Turbot Bank Formation is marked by log breaks and changes in log character.

Distribution: The formation is very variable in thickness and occurs near the northern margins of the Central North Sea Permian basin particularly in the Moray Firth Basin.

Age: Late Permian.

Turbot Bank Formation

Name: From a North Sea bathymetric feature.

Well type section: UK well 15/26-1 (BP), (Figure 9). The formation occurs from 3087 m (10 128 ft) to 3115 m (10 220 ft) below KB.

Well reference section: None.

Thickness: 28 m (92 ft) in the type well but it may reach a maximum of about 146 m (480 ft) in places.

Lithology: In the type well the formation consists of anhydrite with interbedded shales and minor amounts of dolomite. The anhydrite is white, firm and granular or crystalline, with crystalline dolomite and gypsum. The dolomites are buff coloured and sucrosic or microcrystalline.

Boundaries: The formation is clearly defined on petrophysical logs (Figure 9). It has a distinctive log character and is clearly separated from adjacent formations by strong log breaks.

Distribution: The formation is normally closely associated with the underlying Halibut Bank Formation and it has a similar distribution.

Age: Late Permian.

On some structural highs such as the Argyll and Auk fields, the Zechstein is represented only by a relatively thin dolomite overlying the Kupferschiefer. These dolomites are pyritic and vuggy, and it has been suggested that they are brecciated due to salt solution (Pennington, 1975). This section can probably be equated with the dolomites in the basal (Z_1) cycle of the basinal sequence described above, but a separate formation name is considered justified. The name Argyll Formation is proposed.

Argyll Formation

Name: The formation is named after the Argyll Field where it is well developed.

Well type section: UK well 30/24-2 (Hamilton) (Figure 10). The formation occurs from 2728 m (8950 ft) to 2759 m (9053 ft) below KB.

Well reference section: None.

Thickness: In the type well the formation is 31 m (103 ft) thick. Within the area of the Auk and Argyll Fields it varies generally between 15 m and 46 m.

Lithology: In the type well the formation consists of dark grey microcrystalline dolomite, often vuggy and highly fractured, especially in the upper part. Cores show a pelletoidal-oncolitic fabric with stromatolitic laminations, containing some replacement anhydrite, recognisable from crystal moulds. The vugs and fractures are often filled with crystals of pyrite. Thin interbeds of dark grey, carbonaceous and radioactive shale are present in some wells.

Boundaries: The lower boundary is normally a sharp lithological change which is clearly reflected in the petrophysical logs, especially when the formation is underlain by the Kupferschiefer. The upper boundary is in most cases a major unconformity.

Distribution: On the basis of present information the formation appears to be confined largely to the area around the Auk and Argyll Fields.

Age: Late Permian in the Auk Field.

In the Norwegian sector few wells have penetrated the Zechstein. Petronord well 17/4-1 (Figure 11) has been released to illustrate the Zechstein sequence in the Norwegian part of the Central North Sea. In this well the Zechstein is 1169 m (3836 ft) thick and is thought to be undisturbed by halokinesis.

The Zechstein in this well mainly consists of clear massive halite with minor beds of anhydrite, carnallite, polyhalite, red shale and fine grained red sandstone. The classical four cycles of evaporite deposition are thought to be present but no formal designation is made here for the reasons given earlier in the discussion of the Zechstein. The probable position of the cycles is however indicated on Figure 11.

The lower boundary of the Zechstein is normally marked by the change from the Kupferschiefer into the red-bed facies of the Rotliegendes and the upper boundary is normally marked by the passage into red shale of the lower Triassic sediments (as in Figure 11), although in some cases the Zechstein Group is overlain by a silty or sandy basal Triassic unit. Where the section has been disturbed by halokinesis the Zechstein may pass up into Upper Triassic, Jurassic or Cretaceous strata.

The Zechstein is widely distributed over the southern Norwegian sector but has not yet been proved north of 60°N latitude in the North Sea. Accurate dating has not yet been achieved, owing to lack of fossils.

TRIASSIC

During the Triassic the Central and Northern North Sea formed part of an intracratonic basin in which dominantly continental sequences of clastic sediments were deposited together with subordinate anhydrite and carbonate beds. Distribution and thickness patterns, particularly of the coarser-grained units, indicate that major source areas lay to the west and north-west of the Northern North Sea and to the east, north-east and south of the Central North Sea. Local tectonics and halokinesis had a significant influence on the patterns of deposition.

Owing to the oxidised nature of the sediments, diagnostic floral suites are uncommon, resulting in poor time-stratigraphic control, which imposes limits on lithostratigraphic correlation. Because of this it is considered prudent at this time not to attempt to correlate the sediments of the Central and Northern North Sea with the German Triassic sequence or with the sediments of the Southern North Sea; marker horizons such as the Bröckelschiefer or the Röt evaporite cannot be recognised, and new lithostratigraphic units are therefore proposed.

In the Central North Sea Triassic sediments are normally unconformably overlain by Jurassic to Lower Cretaceous rocks. In parts of the Northern North Sea, particularly in the Brent–Statfjord area, there is a continuous passage from Triassic to Jurassic sediments and the Statfjord Formation spans this chronostratigraphic boundary.

Lithostratigraphy

On the basis of dominant lithology the Triassic sediments have been subdivided into three formations which are in part time equivalents and interdigitate to an unknown degree (Table 1). These three formations are considered to constitute an informal Triassic Group but this group is not defined here, for as with the Rotliegendes and Zechstein the type area is in Germany (whether formally defined or not). When more data become available it should be possible to decide whether the Central and Northern North Sea section can be related to the German succession.

The Triassic depositional basin was fringed by coarse grained alluvial sediments which passed basinwards, and interdigitated with red mudstones and evaporites. A thick marginal sandy sequence in the Northern North Sea is named the Cormorant Formation and a similar development in the eastern part of the Central North Sea is named the Skagerrak Formation. The basinal mudstones are named the Smith Bank Formation and this contains one local subdivision, the Josephine Member.

Smith Bank Formation

Name: The name is derived from a North Sea bathymetric feature.

Well type section: UK well 15/26-1 (BP) (Figure 12), from 2488 m (8163 ft) to 3087 m (10 128 ft) below KB.

Well reference section: Norwegian wells 10/8-1 (Petronord), (Figure 14), and 17/10-1 (Norske Shell) (Figure 15). The basal part of the formation was not penetrated in 17/10-1.

Thickness: 599 m (1965 ft) in the type well. The formation is thickest in the western part of the Central Graben and thins towards the Norwegian sector as shown in the reference wells.

Lithology: The formation consists of a monotonous sequence of brick red, somewhat silty, claystones with a few thin sandstone streaks and some anhydrite bands, especially in the lower part. Minor components, particularly in the Norwegian sector, are conglomerate, dark shale, marl, limestone and dolomite. In some localities sandy units may be present at the base. Over most of the eastern sector of the North Sea these sandy units are local and unconnected but south-eastward they become more continuous.

Boundaries: In the type well the formation is overlain unconformably by Middle Jurassic volcanics. Elsewhere in the western and central parts of the Central North Sea overlying rocks range from Lower Jurassic to Lower Cretaceous. This boundary almost invariably coincides with the highest occurrence of red beds in the section. To the east the top of the formation is the interdigitating contact with the Skagerrak Formation, although on a few structures where the Skagerrak Formation has been eroded away, Jurassic or younger sediments are in unconformable contact with the Smith Bank Formation.

The lower boundary is normally conformable with the underlying Permian sediments and there is no major time hiatus (Brennand, 1975). However on some structures the formation may rest on basement rocks of Precambrian or Early Palaeozoic age. In the type well (Figure 12) and again in 10/8-1 (Figure 14) the basal contact is clearly marked by gamma ray and sonic log breaks reflecting the change from the evaporitic Zechstein sequence to the clastic Triassic beds.

Distribution: The formation is widely distributed throughout the Central North Sea and probably occurs in Denmark north of the Ringkøbing-Fyn High. Within the Moray Firth Basin Triassic sediments have not been considered in any detail but Brennand (1975) shows the succession to consist of a basal sandstone unit passing upwards into siltstones and sandy claystones which he considers to represent a marginal facies. It is felt that, while the name Smith Bank Formation can be applied to the complete succession, member names may be needed for the sandstone units.

In this context it should be noted that while a variety of bed names have been used for the onshore sandstones in the Elgin area (Peacock and others, 1968) it is unlikely that any individual bed can be correlated with the offshore sequence.

Age: Early to possibly Late Triassic.

Depositional environment: The formation probably represents a range of distal continental environments where predominantly fine grained clastics were deposited.

Subdivisions: In a few wells geographically restricted sandstone units are present particularly within the upper part of the formation. Some of these probably result from the erosion of local tectonic highs and others may be westerly tongues of the Skagerrak Formation. It is suggested that these sandstone units be given member status, and one such example is the unit which forms the reservoir in the Josephine Field, for which the name Josephine Member is proposed.

Josephine Member

Name: From the Josephine Field.

Well type section: UK well 30/13-1 (Phillips) (Figure 13) from 3765.5 m (12 354 ft) to 3835 m (12 582 ft) below KB.

Well reference section: None at present.

Thickness: 69.5 m (228 ft) in the type well. This thickness being enhanced by relatively steep dips in the well.

Lithology: The formation consists of brown, fine- to medium-grained, friable sandstones with interbedded red to grey shales. Individual sandstone units range from 2 to 20 m in thickness.

Boundaries: The upper and lower boundaries are marked by the lithological contrast between the sandstones of this member and the claystones of the remainder of the Smith Bank Formation. The boundaries are reflected in the well logs, although major log breaks are not apparent (Figure 13).

Distribution: On the presently available data the formation appears to be restricted to the area of the Josephine Field, although other sandstone units may occur elsewhere at this stratigraphic level. Well log profiles can be interpreted as indicating that the Josephine Member is a westerly tongue of the Skagerrak Formation but continuity cannot be demonstrated and it is now geographically part of the Smith Bank Formation.

Age: Probably Late Triassic.

Skagerrak Formation

Name: From the channel separating Norway from Denmark.

Well type section: Norwegian well 10/8-1 (Petronord) (Figure 14) from 1567 m (5140 ft) to 2749 m (9017 ft) below KB.

Well reference section: Norwegian well 17/10-1 (Norske/ Shell), (Figure 15).

Thickness: The formation is 1182 m (3877 ft) thick in the type well and thicker further east where seismic data indicate that it may reach a maximum thickness of over 3000 m. Westward from the type well the formation interdigitates with and progrades over the associated claystone sequence (Smith Bank Formation). The maximum thickness at the north-west limit of well control is 660 m and at the south-west limit 250 m.

Lithology: The formation consists of interbedded conglomerates, sandstones, siltstones and shales. Various shades of reds and browns are the dominant colours but light to dark grey beds are also present. Sandstones may be orthoquartzitic arkosic or highly lithic. Anhydrite, dolomite and limestone are subordinate lithologies.

Boundaries: The formation has gradational to sharp contacts with the claystone sequence of the Smith Bank Formation. Dip meter surveys suggest that in places this contact is an unconformity. Over some structures the formation rests on pre-Triassic rocks. The formation is normally overlain unconformably by Jurassic or younger sediments but in a few wells it passes up into the Gassum Formation (of Rhaetian age).

Distribution: The formation is present throughout the eastern part of the Central North Sea and the western Skagerrak. It may be missing over certain structures because of erosion or halokinesis.

Age: Middle and Late Triassic. It may possibly extend down to the Early Triassic in the areas of maximum development.

Depositional environment: The bulk of the Skagerrak Formation was probably deposited in a coalescing and prograding system of alluvial fans along the eastern and southern flanks of a structurally controlled basin. The limited areal extent and poorly preserved faunal components suggest that some of the dark shale, carbonate and anhydrite beds were deposited in lakes. Better preserved microfossils and other indicators such as glauconite show that some beds were deposited when minor marine incursions occurred between floods of continental clastics.

Cormorant Formation

Name: From the Cormorant Field in UK block 211/21.

Well type section: UK well 211/21-1A (Shell/Esso) (Figure 16) from the Cormorant Field. The formation occurs from 2977 m (9767 ft) to 3443 m (11 295 ft) below KB.

Well reference section: None at present.

Thickness: 466 m (1528 ft) in type well and generally thicker in all directions away from this well.

Lithology: In the type well the formation consists of an alternating sequence of fine-grained, argillaceous, sometimes calcareous, white to red brown sandstones and siltstones, with some sandy claystones. Individual lithological units range in thickness from 2 to 30 m. To the north and south of the type well the sequence becomes sandier and to the west it thickens with the incoming of a sequence of coarser sandstones and conglomerates underlying the more typical Cormorant Formation facies. This may represent a lateral facies change of the lower part of the Cormorant Formation or it may be an additional unit overlain by the formation. Eastward from the type locality the claystone units are thicker and the well log patterns suggest cyclic deposition.

Boundaries: In the Brent–Statfjord area there is continuous passage from the Cormorant Formation to the Statfjord Formation and the boundary between these two units is not always clear (see p. 12 and Figure 17). In 211/21-1A the boundary is not well expressed because of erosion of the upper part of the Cormorant Formation and a very limited development of the Statfjord Formation. As implied in Figure 18 this boundary must change towards the west due to the westerly overstep of higher members of the Statfjord Formation. Well 211/21-1A is taken as the type section because it is the only one available to the subcommittee which reaches the base of the Triassic section in this area, and also it has a good suite of logs and side wall cores.

Away from the Brent–Statfjord area the top of the Cormorant Formation is normally placed at the change from the interbedded sandstones and siltstones of the Cormorant Formation to the relatively massive clean sandstones of the Statfjord Formation. This is normally represented by a change from an irregular sonic log response in the Cormorant Formation to a more regular or blocky one in the Statfjord Formation. A similar change in log response is sometimes, but not always, seen in the gamma ray curve. In addition the upper boundary of the Cormorant Formation is often close to the top of the red beds in the section. In the type well the base of the formation is the contact with the Caledonian metamorphic basement but in other wells it rests on Permian sediments.

Distribution: The formation is known to be present within the area of the Cormorant, Magnus Brent, Statfjord and Alwyn fields.

Age: In a regional context the type locality exhibits a relatively attenuated section of the formation and its age is here restricted to the Late Triassic (Norian and possibly Rhaetian). In the Brent area to the east where the formation may be four times as thick as the type locality, some of the older Triassic stages are present (Brennand, 1975: Brennand and Siri, 1975).

Depositional environment: The whole formation appears to have been deposited in a continental environment. The increase in sand content towards the west suggests that a major source of sediment lay in that direction.

JURASSIC

The most prominent control on Jurassic sedimentation in the Central and Northern North Sea was the rift system which developed after a period of basin initiation in the Permo-Triassic (P. A. Ziegler, 1975). The main components of this rift system included the Central Graben, the Viking Graben, and the Moray Firth Basin. The limits of the rifts are defined by prominent structural highs, notably the East Shetland Platform, the Vestland Arch and the Mid North Sea High.

Block faulting, tilting and erosion occurred throughout the Jurassic at varying times and varying rates, with climaxes occurring at approximately the end of the Early Jurassic, the end of the Middle Jurassic and again at the end of the Late Jurassic. This tectonic control of sedimentation is reflected in a series of unconformities or transgressive and regressive cycles throughout the Jurassic, which are best displayed near the margins of the rifts. Jurassic sediments within the rifts are now normally related to a system of tilted fault blocks, over which more recent sediments have been deposited (Brennand and Siri, 1975, fig. 4). These fault blocks constitute a major trapping mechanism for hydrocarbons in the Northern North Sea.

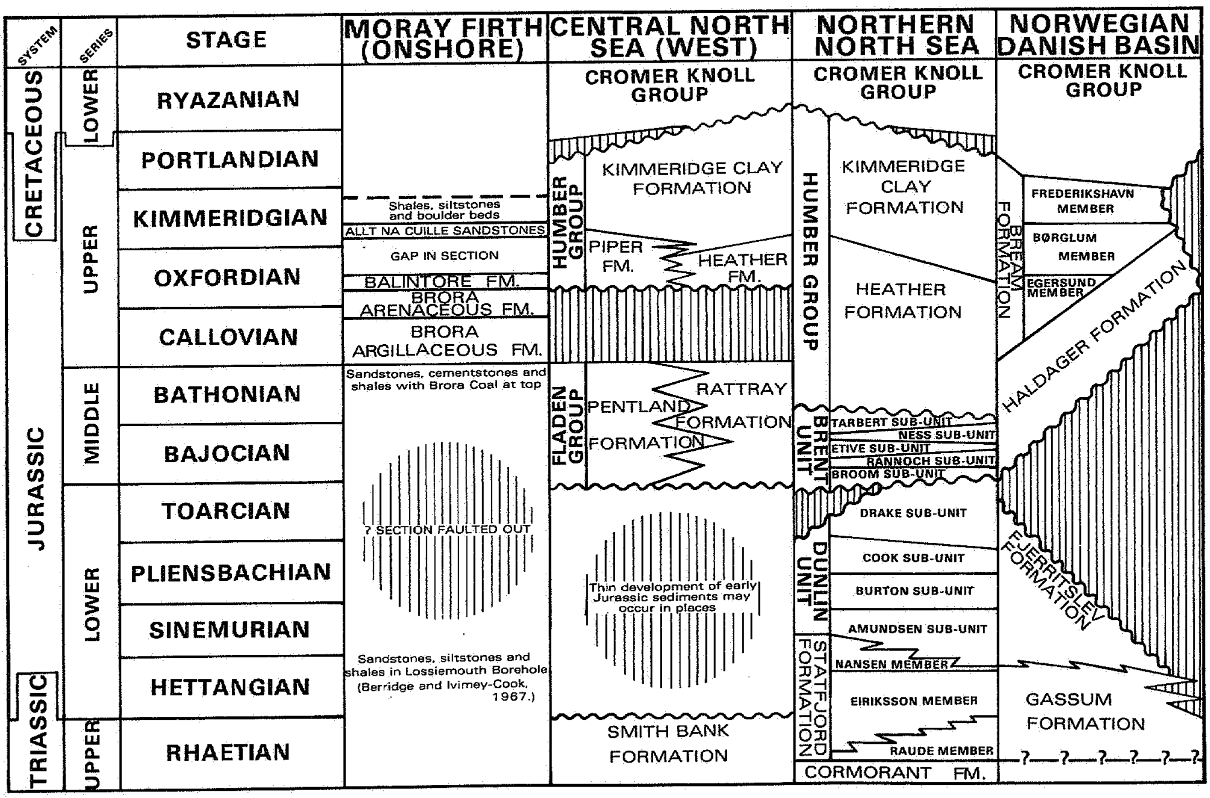
Distribution of the Jurassic

Jurassic rocks occur in the Viking Graben, the Norwegian-Danish Basin, the Central Graben and the Moray Firth Basin. At the western extremity of the Moray Firth Basin they outcrop on the coast of north-east Scotland from Golspie to Helmsdale and again at Balintore and Ethie. No data exist on the relationship between those onshore outcrops (described by Sykes, 1975) and the Jurassic of the Eastern Moray Firth–Central Graben region. Therefore the UK sub-committee considered only the lithostratigraphy of the Central North Sea (Easterly Moray Firth and Central Graben), and the Northern North Sea. The area between the Central and Northern North Sea, around UK quadrant 9 and Norwegian quadrant 24, is very complex and could not be considered by the sub-committees because of lack of well control.

Information on the distribution, thickness and facies of the Jurassic is given by Brooks and Chesher (1975) and Yonge and others (1975). The broad relationship between the lithostratigraphic units recognised in this report is given in Table 2.

The Lower Jurassic deposits are the most areally restricted; they are thickest in the Viking Graben and the Norwegian-Danish Basin, thin in the Western Moray

Table 2 Jurassic lithostratigraphic nomenclature



Firth and absent in parts of the Central Graben. Locally, for example in the Norwegian-Danish Basin, there are some Lower Jurassic sediments containing tuffaceous bands which are probably precursors of the Middle Jurassic vulcanism.

The Middle Jurassic of the Northern North Sea consists mainly of arenaceous deltaic deposits. The onshore deposits of the Moray Firth Basin are massive sandstones overlain by bituminous shales and coal, while in the eastern part of the basin the Middle Jurassic consists of a volcanic sequence of lavas and pyroclastics intercalated with fluviodeltaic sediments (Howitt and others 1975). The volcanics seem to have been part of a distinct province centred roughly in the area between the Piper and Forties fields. To the north and east the lavas become increasingly intercalated with deltaic sediments, but to the south they are in contact with a structural high containing barren red-beds. To the south of this high some Middle Jurassic sediments probably occur in the Central Graben (Brooks and Chesher, 1975, figs. 8 and 9).

Fine-grained sediments representing the early stages of the Upper Jurassic are more widespread than the underlying Lower or Middle Jurassic strata. During the later part of the Upper Jurassic fine-grained sediments were deposited over most of the North Sea area (the Kimmeridge Clay and Bream Formations) and in places these have subsequently been eroded on structural highs (Brooks and Chesher, 1975).

Lithostratigraphy

The most complete sedimentary sections of the Jurassic are in the Northern North Sea and the Norwegian-Danish Basin. In the Northern North Sea, where the principal Jurassic oilfields have been found, the wealth of geological data has made possible the recognition of a number of distinctive subdivisions. The UK and Norwegian committees, in considering these, have differed in their opinion as to the status of certain of the units that have been recognised. This difference of opinion concerns two subdivisions, namely the Dunlin and Brent units (see Table 2). Since agreement could not be reached with the data presently available it was decided that for this report the two subdivisions would be referred to as units with the understanding that they are considered to be of different status in the UK and Norwegian sectors. Thus the Dunlin and Brent units are regarded as groups in the UK sector, and their constituent sub-units are therefore formations, while in the Norwegian sector the units are regarded as formations with sub-units of member status (see Table 2). The UK and Norwegian committees are in agreement with respect to the Triassic/Lower Jurassic Statfjord Formation and the more widespread Upper Jurassic Humber Group, which is the only unit common to the Southern, Central and Northern North Sea.

In the western part of the Central North Sea the volcanic rocks and the closely associated continental and shallow water sediments are defined as two broad formations which are included within the Fladen Group. Additional data will clearly permit considerable refinement within this group. The Fladen Group is overlain by the distinctive argillaceous sediments of the Humber Group which, in the northern part of the Central North Sea, contains the more localised Piper Formation (Table 2).

The sequence in the Norwegian-Danish Basin is described and its approximate equivalence to the Northern North Sea section is shown on Table 2. Some of the units defined by Larsen (1966) from Danish onshore boreholes can be extended seawards and some new units are defined here.

The chronostratigraphic limits of the Jurassic in the Northern and Central North Sea are not yet established but workable lithostratigraphic boundaries have been erected. In the axial part of the Viking Graben the lower boundary is marked by a change from the thinly bedded, continental deposits of the mainly Triassic Cormorant Formation to the thicker bedded, fluviodeltaic and shallow marine sediments of the Statfjord Formation (which appears to span the Triassic–Jurassic chronostratigraphic boundary here). This boundary is frequently close to the top of red-beds in the section. Near the margins of basins and on structural features, such as the Vestland Arch, the lower boundary of the Jurassic may be an unconformity. In the western part of the Central North Sea the lower boundary is normally marked by the incoming of Jurassic volcanic rocks but in places where pre-volcanic Jurassic sediments are present the boundary may not be so clear.

In the Northern and Central North Sea the upper lithostratigraphic boundary of the Jurassic is normally taken at the top of the Kimmeridge Clay Formation or the Bream Formation. This contact is usually either an unconformity or a disconformity overlain by Cretaceous shales. However there are places in all these areas, particularly away from structural highs, where there is apparently conformable passage from Jurassic to Cretaceous sediments.

It should be noted that in this report the Callovian stage is considered to be in the Upper Jurassic and the Aalenian is equated with the Lower Bajocian. In this account the lithostratigraphy of the Northern North Sea is dealt with first followed by that of the Central North Sea (west) and Norwegian-Danish Basin (see Table 2).

Statfjord Formation

Name: From the Statfjord Field in Norwegian quadrant 33. The formation was first fully penetrated in UK well 211/24–1 (Conoco) and informally defined as 'Statfjord Sand Formation' by Bowen (1975), using data from UK wells 211/24–1 (Conoco) and 211/29–3 (Shell/Esso, from the Brent Field). Bowen (1975) noted that the formation probably ranges in age from Early Jurassic (Hettangian–Sinemurian) to Rhaetian in the lower part. He recognised three units on a sedimentological basis, the lowermost and thickest unit consisting of braided stream deposits and the upper two units comprising field-wide sheets of coastal barrier sands.

Yonge and others (1975) temporarily defined Rhaetian–Lower Jurassic sediments as the 'Lower Unit', in the Norwegian well 33/12–2 (Mobil) and they subdivided this 'Lower Unit' into two sub-units, the upper sub-unit corresponding grossly but not in detail with the 'Statfjord Sand Formation' of Bowen (1975).

In this report the base of the formation is taken slightly higher in the section than the base of the 'Lower Unit' of Yonge and others (1975). The top of the formation is the same as the top of the 'Lower Unit' of Yonge and others, and equates with the top of the 'Statfjord Sand Formation' of Bowen (1975).

Well type section: Norwegian well 33/12–2 (Mobil) (Figure 17), from the Statfjord Field. The formation occurs from 2700 m (8860 ft) to 2951 m (9681 ft) below KB.

Well reference section: UK well 211/24–1 (Conoco/Gulf/NCB). Figure 17 shows the proposed correlation with the type well. Part of the Statfjord Formation in UK well 211/29–3 (Shell/Esso) is also shown (Figure 19), but the interpretation of the subdivisions at member level is not included.

Thickness: 251 m (821 ft) in the type well, and 322 m (1057 ft) in UK well 211/24–1. The formation is thinner on the crests of fault blocks and thicker on the downthrow sides of faults. It attains its fullest development in the central part of the Viking Graben; to the west, e.g. in the area of the Cormorant Field, only the upper member is present and this is reduced to a sandstone only a few feet in thickness.

Lithology: The formation exhibits a transition from continental to shallow marine sediments. At the base is a transitional 'coarsening upwards' sequence consisting of grey, green and sometimes red shale interbedded with thin siltstones, sandstones and dolomitic limestones. Above this are massive white to grey sandstone bodies interbedded with greenish-grey to red-brown shales. At the top of the formation thick, white to grey, fossiliferous and glauconitic sandstones occur and these pass eastwards into dark grey calcareous siltstones and shales of the Dunlin Unit. (Figure 17).

Boundaries: The base of the Statfjord Formation is very difficult to define (Yonge and others, 1975) and different operators have established different boundaries. The presently proposed boundary is preferred because it marks the base of the main sandstone development of the Statfjord Formation. It is also interpreted as the base of the thin transitional unit (coarsening upward sequence) which marks the passage from the more shaly Cormorant Formation to the massive sandstones of the Statfjord Formation. In addition the base here coincides approximately with the highest occurrence of predominantly red-beds in the section although occasional thin red shales may occur at slightly higher levels. It should be emphasised that the base of the formation as defined can only be clearly recognised in the area of the Brent and Statfjord Fields where it reaches its fullest development. Elsewhere the nature of the base changes, particularly towards the west where there is overlap by higher units of the formation. This is indicated diagrammatically in Figure 18.

The top of the formation is marked by the contact between medium- to coarse-grained calcareous sandstones and dark coloured, micromicaceous shale or siltstone of the overlying Dunlin Unit. It should be noted that the top part of the calcareous sandstones in the UK sector (e.g. in the Brent Field and the UK part of the Statfjord Field), passes laterally into calcareous shales and siltstones in the Norwegian sector (Figure 17). The formation boundary, being a lithological one, however, is placed at the top of the sandstones, regardless of age.

Distribution: The Statfjord Formation can be recognised in the entire area between the East Shetland Platform and the axis of the Viking Graben. East of the Viking Graben and in Denmark, a comparable formation of similar age exists called the Gassum Formation (Larsen, 1966). Surlyk and others (1975) describe a comparable formation of the same age from Greenland, the Kap Stewart Formation.

Age: The formation ranges in age from Rhaetian to Hettangian or early Sinemurian. The transition from sand to shale at the top of the formation suggests that the top of the formation is older nearer the basin axis. A similar age change takes place basinwards in the Gassum Formation, and sands of Rhaetian age only occur in more distal sections (Michelsen, 1975).

Depositional environment: The lower transitional unit appears to represent a passage from the purely continental deposits of the Cormorant Formation to the lower alluvial plain and braided stream deposits of the main part of the Statfjord Formation. Towards the top of the formation coarse sandstones with pebble beds, cross-bedding and channel structures appear to have been deposited in a coastal environment. The uppermost sandstones are relatively structureless but the presence of fossils and glauconite suggests a shallow marine environment.

Subdivisions: The Statfjord Formation is divided into three members, the Raude Member (base), the Eiriksson Member and the Nansen Member (top).

Raude Member

Name: The member is named after Eirik Raude (Raude = Red), the Viking discoverer of Greenland.

Well type section: Norwegian well 33/12–2 (Mobil) (Figure 17), from 2790 m (9153 ft) to 2951 m (9681 ft) below KB.

Well reference section: UK well 211/24–1 (Conoco/Gulf/NCB) (Figure 17).

Thickness: In the type well the member is 161 m (528 ft) thick and in 211/24–1 it is 119 m (391 ft).

Lithology: In the type well the basal part of the member consists of a 'coarsening upward' sequence of grey, green and red-brown silty claystones, grey arkosic sandstones and white, pink and grey-brown dolomitic limestones. This basal part of the section is often difficult to recognise away from the type well and is locally absent. Above 2905 m (9530 ft) in the type well the member consists of approximately equal amounts of sandstone and silty shale. These sandstones are fine to medium grained and poor to moderately sorted with subangular grains. They are generally micaceous and have a kaolinitic matrix. The silty shales are grey to light green or occasionally red-brown in colour, and micromicaceous. Carbonaceous debris, sometimes in thin laminae, is present but distinct lignite beds are absent. Away from the type well the sandstone percentage in this upper part of the member may vary from about 15 to about 75. In the area of the Brent and Statfjord Fields the average sandstone bed thickness is about 2.5 m (8 ft) and shale beds average about 4 m (13 ft) in thickness. Correlation of individual beds from well to well is virtually impossible. The lithological content and sedimentary structures in the upper part of the member, particularly large scale cross-bedding and scour and fill, are consistent with deposition in a braided stream environment.

Boundaries: The base of the member is the base of the Statfjord Formation defined above. The change from the more argillaceous Cormorant Formation sediments to the more sandy Statfjord Formation via the transitional 'coarsening upward' unit is clearly defined on the gamma ray and sonic logs. The top of the member is the base of the first massive sandstone of the overlying more arenaceous member. This boundary is normally clearly marked by a change from an irregular to a more blocky log response, particularly in the gamma ray log. Individual sandstone beds in the overlying Eiriksson Member are more laterally extensive and the base of the lowest sandstone which is correlatable between wells will generally indicate the top of the Raude Member.

Distribution: The member can generally be recognised wherever the Statfjord Formation is well developed. The basal 'coarsening upward' unit is thought to have a more limited distribution but this cannot be defined as many wells terminated in or just above this basal unit.

Age: Rhaetian. The top of the member may approximate to the Rhaetian–Lower Jurassic boundary in the type well but is probably older to the west (Figure 18).

Eiriksson Member

Name: Named after Leiv Eiriksson, the discoverer of North America in the year AD 1000, according to the Norse sagas. He was the son of Eirik Raude.

Well type section: Norwegian well 33/12–2 (Mobil) (Figure 17), from 2719 m (8919 ft) to 2790 m (9153 ft) below KB.

Well reference section: UK well 211/24–1 (Conoco/Gulf/NCB) (Figure 17).

Thickness: 71 m (234 ft) in the type well. In the reference well the member is 157 m (514 ft) thick. The thickness is relatively constant over the area of the Statfjord Field but the member thickens towards the south and west (Figure 18) where sandstones characteristic of this member occur at lower levels in the section.

Lithology: In the type well the member is characterised by massive sandstone beds, generally correlatable between wells, interbedded with hard grey shales. The sandstones are white to light grey, medium to very coarse grained with thin horizons of granules, pebbles, and lignite fragments, often concentrated in channels and along cross-bedding foresets. They contain slightly less kaolinite matrix, mica and rock fragments than the sandstones of the Raude Member. The shales are silty and commonly micaceous and carbonaceous.

In the area of the Statfjord Field the sandstone beds average about 5 m (16 ft) in thickness and the shales average about 2.5 m (8 ft). The sediments of this member appear more mature than those of the Raude Member, and marine fossils and glauconite are present near the top of the member in the type well. The data suggest that deposition occurred in marginal marine environments varying from coastal backswamp and river mouth situations to coastal barriers.

Boundaries: The lower boundary is formed by the base of the lowest massive sandstone which is correlatable between wells. The upper boundary is marked by the base of the distinctive sandstones of the Nansen Member which are frequently calcareous. The Eiriksson Member has a characteristic 'blocky' gamma ray and sonic log response but the boundaries may not always be marked by prominent log breaks.

Distribution: The member can be recognised over an extensive area around the Brent and Statfjord Fields.

Age: In the type well it is Hettangian, possibly extending into the early Sinemurian. However to the west and south the base of the member appears to be progressively older.

Nansen Member

Name: After the Norwegian polar scientist, explorer and statesman, Fridtjof Nansen.

Well type section: UK well 211/24–1 (Conoco/Gulf/NCB) (Figure 17) from 3112 m (10 209 ft) to 3158 m (10 361 ft) below KB.

Well reference section: Norwegian well 33/12–2 (Mobil), Figure 17).

Thickness: 46 m (152 ft) in the type well and 19 m (59 ft) in the reference well.

Lithology: In the type well the member consists of medium- to coarse-grained, fairly well sorted, homogeneous, white sandstones with a calcite cement and a subordinate kaolinite matrix. Occasional horizons with granules or pebbles are present. Carbonaceous material and mica are rare but glauconite is quite common. Thin shale beds containing marine fossils are present.

At the top of the member, from 3112 m (10 209 ft) to 3135 m (10 283 ft) in the type well is a more prominent calcareous horizon defined informally as the calcareous sandstone bed. This may grade locally into a sandy limestone, for example, in the Brent Field.

The Nansen Member thins towards the east and passes laterally into calcareous siltstones and shales in the Norwegian sector (Figure 17). Although these siltstones and shales are lateral equivalents of the Nansen Member they are placed in the overlying Dunlin Unit on lithological grounds.

Boundaries: The lower boundary is marked by the change from the non-calcareous sandstones of the Eiriksson Member to the cleaner, generally calcareous sandstones of the Nansen Member. The upper boundary is marked by the change from calcareous sandstone to the argillaceous sediments of the Dunlin Unit. Both boundaries are well marked on gamma ray and sonic logs particularly in the UK sector where the member is best developed. The calcareous sandstone bed at the top of the member is normally reflected by a distinctive sonic log response (Figure 17). However as this passes laterally into calcareous siltstones and shales the sonic log still responds to the calcareous nature of the sediments.

Distribution: The member is well developed in the Brent Field area. The lower part of the member overlaps westwards to the Cormorant Field area where it is probably the only representative of the Statfjord Formation. The calcareous sandstone bed at the top does not extend as far west as the lower part of the member.

Age: Probably Hettangian to Early Sinemurian.

Dunlin Unit

Name: The unit is named after the Dunlin Field in UK quadrant 211 in the Northern North Sea. It was originally proposed as a formation by Bowen (1975) who figured a section of UK well 211/29–3 as an illustration. Bowen (1975) subdivided the formation into two informal members, an upper shale member and a lower silt member. In this account the unit is subdivided into four sub-units, the lower three being equal to Bowen's 'Dunlin silt member', and the uppermost being equal to Bowen's 'Dunlin shale member'.

Type area/well type section: According to UK usage the unit has group status and its type area is the northern Viking Graben, particularly around the Brent Field area. According to Norwegian usage it has formation status, the type well being UK well 211/29–3 (Shell/Esso) (Figure 19) from the Brent Field. In the 211/29–3 well the unit occurs from 2829 m (9283 ft) to 3051 m (10 009 ft) below KB.

Well reference section: According to Norwegian usage Norwegian well 33/9–1 (Mobil) (Figure 20), from the Statfjord Field is a reference section for the formation.

Thickness: 222 m (726 ft) in well 211/29–3 and 255 m (837 ft) in 33/9–1. Although the unit is named after the Dunlin Field it is thickest in the region of the Brent and Statfjord Fields.

Lithology: The unit consists almost exclusively of argillaceous marine sediments. These are primarily light to dark grey or black siltstones and shales with intercalated thin grey sandstone beds in places. It tends to be somewhat more calcareous in the Norwegian sector and in places contains limestone bands some of which have chamosite and siderite ooliths.

Boundaries: The lower boundary with the calcareous Nansen Member of the Statfjord Formation and the upper boundary with the arenaceous Brent Unit are clearly marked by sonic and gamma ray log breaks. The unit generally has a more regular log character than the underlying or overlying sediments.

Distribution: The unit is more widespread than the underlying Statfjord Formation and is thickest and best developed in the Brent Field area where sudden variations in thickness probably reflect local fault control of sedimentation. It is recognisable over most of the Viking Graben north of 59°. In the Brent area the lowest sub-unit of the Dunlin Unit rests with apparent conformity on the Statfjord Formation but to the north-west higher sub-units of the formation are thought to be transgressive onto Permo-Triassic sediments; the extent to which the East Shetland Platform was submerged at this time is not known because of subsequent erosion.

Age: The unit probably ranges from Hettangian to Early Bajocian.

Depositional environment: The Dunlin Unit contains exclusively marine sediments. It thins and becomes coarser grained towards the west suggesting that the shoreline lay in that direction. During deposition it is clear that water depth varied both areally and through time probably largely due to penecontemporaneous fault movement.

At the top of the unit a distinctive shale horizon appears to mark a transgressive phase and towards the west this shale appears to overlap onto lower horizons of the unit. In UK well 211/29–3 the upper ten feet or so of the unit contain sandstone and shale clasts, presumably marking the initiation of the regressive cycle represented by the overlying Brent Unit. This situation is clear in the Brent area where sedimentation was most continuous but to the west the relationships are not so simple as there was probable uplift and erosion there during the time the uppermost beds of the Dunlin Unit were being laid down in the Brent area.

The Dunlin Unit is generally considered to have been deposited in prodeltaic and delta front environments. This view is reinforced by the fact that the overlying Brent Unit is interpreted to be delta front to delta top deposits.

Subdivisions: The Dunlin unit is divided into four subunits. These are named the Amundsen (base), Burton, Cook and Drake (top) sub-units, and they can be most clearly differentiated on the sonic log (Figure 19). According to UK usage these sub-units have formation status while in Norwegian usage they have member status. It should be stressed that the Nansen Member of the Statfjord Formation passes laterally (in the Norwegian sector) into calcareous siltstones and shales, which on lithological grounds are included in the Amundsen Sub-unit of the Dunlin Unit. The characteristic sonic log 'bulge' which on the UK side marks the calcareous sandstone bed of the Nansen Member, extends into the lower part of the Amundsen Sub-unit in the Norwegian sector; this is because the sonic log is here responding to calcareous content, not grain size.

Amundsen Sub-unit

Name: Named after the Norwegian polar scientist Roald Amundsen, the first man to reach the South Pole. The sub-unit has formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2993 m (9819 ft) to 3051 m (10 009 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20). The sub-unit is also shown on UK well 211/24–1 (Conoco/Gulf/NCB) and Norwegian well 33/12–2 (Mobil) (Figure 17).

Thickness: 58 m (190 ft) in the type well and 85 m (280 ft) in 33/9–1. The sub-unit is thickest in the Norwegian sector because of the shale-out of the upper part of the Nansen Member.

Lithology: In the type section the sub-unit consists of light to dark grey, firm non-calcareous siltstones and shale, which is carbonaceous and pyritic in part. Thin, fine- to coarse-grained, grey, calcareous and glauconitic sandstone beds are present, and these become more common towards the west. In the Norwegian sector the sub-unit is more calcareous with limestone stringers and a distinctive chamosite/siderite oolitic bed (Figure 20).

Boundaries: The base of the sub-unit is the base of the Dunlin Unit (defined above). The top is marked by the change to the more regular gamma ray and sonic log response of the overlying Burton Sub-unit (Figure 19).

Distribution: The sub-unit is widely distributed in the Viking Graben north of 59°N. Towards the north-west the member appears to overstep the Statfjord Formation and rests on the Cormorant Formation.

Age: Probably Hettangian to Sinemurian.

Burton Sub-unit

Name: Named after Sir Richard Francis Burton, the 19th century British explorer. The sub-unit has formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2950.5 m (9680 ft) to 2993 m (9819 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20). The sub-unit is also shown on UK well 211/24–1 (Conoco/Gulf/NCB) and Norwegian well 33/12–2 (Mobil) (Figure 17).

Thickness: 42.5 m (139 ft) in the type well and 37 m (121 ft) in 33/9–1.

Lithology: In the type well it consists of a uniform development of dark grey to reddish-grey, soft non-calcareous claystone and shale which may be slightly carbonaceous in part.

Boundaries: The sub-unit is normally represented on both gamma ray and sonic logs by smooth linear almost constant readings, reflecting the lithological uniformity (Figure 19). The upper and lower contacts are taken where this log character changes.

Distribution: Although the log character changes slightly away from the type section the sub-unit can be recognised over a wide area and appears to have a similar distribution to the underlying sub-unit.

Age: Sinemurian–Pliensbachian.

Cook Sub-unit

Name: Named after Captain James Cook, the British circumnavigator, hydrographer and explorer. The sub-unit has formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2887 m (9471 ft) to 2950.5 m (9680 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20).

Thickness: 63.5 m (209 ft) in the type well and 86 m (281 ft) in 33/9–1.

Lithology: In the type well section this is dominantly a marine siltstone with minor grey, silty claystone intercalations. The siltstones and claystones may contain sandy streaks and these become more prominent away from the type well especially in the Norwegian part of the Statfjord Field. These sandy streaks are grey, fine grained and well sorted with traces of muscovite, chlorite and glauconite; a calcareous cement may sometimes be present. In the Norwegian sector the upper part of the sub-unit is more calcareous and contains sandy limestone beds. One sandy limestone with flattened chamosite and siderite oolites forms a distinctive marker bed.

Boundaries: On both gamma ray and sonic logs it has a similar response to that of the Amundsen Sub-unit. It can be distinguished from the more uniform sediments above and below by a decrease in gamma ray response and an increase in velocity (Figure 19). In many cases the sub-unit has a distinctive half moon shape on both sonic and resistivity logs.

Distribution: It has a similar distribution to that of the two underlying sub-units.

Age: Pliensbachian–Toarcian.

Drake Sub-unit

Named: Named after Sir Francis Drake, the 16th century British admiral and circumnavigator. The sub-unit has formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2829 m (9283 ft) to 2887 m (9471 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20).

Thickness: 58 m (188 ft) in the type well and 47 m (155 ft) in 33/9–1.

Lithology: In the type well the lower part of the sub-unit consists of medium grey, slightly sandy calcareous claystone, while the upper part is dark grey to black, fissile, micaceous shale containing calcareous nodules. The upper ten feet or so may contain sandstone and shale clasts. The lithology is identical to this in the Norwegian sector.

Boundaries: It has a more regular gamma ray and sonic log response than that of the underlying sub-unit, the gamma ray response being uniformly higher and the velocity lower. The upper boundary is clearly marked by the incoming of the arenaceous sediments of the overlying Brent Unit.

Distribution: The sub-unit is thickest in the area of the Brent and Statfjord fields and thins towards the western side of the Viking Graben where it may be absent in places due to erosion.

Age: ? Pliensbachian–Toarcian, possibly extending into the Early Bajocian.

Brent Unit

Name: The unit was first named by Bowen (1975) as the 'Brent Sand Formation'. The name is derived from the Brent Field in UK block 211/29 for which it is the major reservoir interval. Bowen (1975) figured a section of well 211/29–3 in which he recognised three subdivisions of his 'Brent Sand Formation' at the member level (lower, middle and upper). He further subdivided the lower member into three beds. Bowen's five subdivisions are distinguished in the present account as sub-units.

Type area/well type section: According to UK usage the unit has group status and its type area is the northern Viking Graben particularly around the Brent and Statfjord Fields. According to Norwegian usage it has formation status, the type well being UK well 211/29–3 (Shell/Esso) (Figure 19). In the type well the unit occurs from 2602.5 m (8539 ft) to 2829 m (9283 ft) below KB.

Well reference section: In Norwegian usage Norwegian well 33/9–1 (Mobil) (Figure 20), is considered to be a reference well for the formation.

Thickness: 226.5 m (744 ft) in well 211/29–3 and 204 m (670 ft) in 33/9–1.

Lithology: The unit is composed of pale grey to brown sandstones, often conglomeratic and arkosic, with subordinate siltstones, shales and coals.

Boundaries: In the Brent–Statfjord area the unit normally rests with minor disconformity on the Dunlin Unit but to the west it cuts down onto lower levels within the Dunlin Unit. The upper contact is more complex due to post-middle Jurassic tectonism and erosion. Variable amounts of the unit may be missing, particularly towards the crests of tilted fault blocks, and the overlying Upper Jurassic argillaceous sediments may rest unconformably on different horizons of the Brent Unit.

Distribution: The distribution of the unit is not precisely known at present but it is well developed in that part of the Viking Graben around the Brent and Statfjord fields.

Age: Palaeontology so far indicates that the unit is mainly of Bajocian age but indeterminate amounts of Bathonian strata may have been removed by erosion.

Depositional environment: Previous authors (Bowen, 1975; Hodson, 1975) agree that the unit represents a major regressive phase and fluviodeltaic and shallow marine deposits can be recognised within it. The lower three sub-units are generally thought to have been deposited in coastal and shallow marine environments and represent the progradational deposits of the deltaic complex. The overlying coaly sub-unit is thought to represent delta top or delta plain deposition and within this interval more specific environments can be recognised, for example, distributary channels, levees and coal swamps. The environment of deposition of the upper sub-unit was probably marginal marine. In places this may rest with minor disconformity on the coaly sub-unit (Hodson, 1975), and possibly represents the reworking of the delta plain deposits at the onset of the marine transgression which deposited the overlying Upper Jurassic argillaceous sediments.

Subdivisions: The unit is divided into five sub-units. These are named the Broom (base), Rannoch, Etive, Ness and Tarbert (top) sub-units. It may be noted that as an aide mémoire the initial letters of the sub-units make up the word Brent. According to UK usage these sub-units have formation status while in Norwegian usage they have member status.

Broom Sub-unit

Name: The name is derived from Loch Broom in Scotland. This sub-unit corresponds to the 'basal sand bed' of Bowen (1975), and is given formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2818 m (9245 ft) to 2829 m (9283 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20).

Thickness: 11 m (38 ft) in the type well and 4 m (12 ft) in 33/9–1. In the Brent–Statfjord area it varies from a few feet to about forty feet in thickness.

Lithology: In the type well it is a pale grey to brown, coarse-grained poorly sorted conglomeratic sandstone containing shale clasts. Within the Brent–Statfjord area it can be kaolinitic and may contain unstable accessory minerals. The rock type has been classified as a degraded arkose by Hodson (1975).

Boundaries: The lower boundary with the Dunlin Unit is usually distinct and marked by log breaks, particularly on the gamma ray log. Intraformational clasts may occur at the top of the Dunlin Unit marking the onset of the new sedimentary cycle which resulted in the deposition of the Brent Unit. The Broom Sub-unit has a distinctive log character, notably a rather irregular bell shaped gamma ray response (Figure 19 and Hodson, 1975) which serves to distinguish it from the surrounding sediments.

Distribution: It has a similar distribution to that of the Brent Unit although it is somewhat patchily developed in places.

Age: Probably Early Bajocian.

Rannoch Sub-unit

Name: The name is derived from Loch Rannoch in Scotland. It corresponds to the 'micaceous sand bed' of Bowen (1975) and is given formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2783 m (9130 ft) to 2818 m (9245 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20).

Thickness: 35 m (115 ft) in the type well and 62 m (204 ft) in 33/9–1.

Lithology: In the type well the sub-unit is light brown, fine-grained well sorted friable extremely micaceous sandstone. In the Brent Field area the lower part is more argillaceous and contains micaceous siltstones and thin shales. Thin tightly cemented calcareous bands are locally present and the sandstone tends to be more homogeneous towards the top of the sub-unit. It is possible locally to divide the sub-unit into two parts, based on grain size and mica content, as noted by Hodson (1975).

Boundaries: The high micaceous content of the sandstone easily distinguishes the sub-unit from the non-micaceous sandstones above and below. In addition this mica content causes the sub-unit to have an anomalously high gamma ray response. Towards the top the sub-unit tends to be coarser grained and less micaceous often resulting in a distinctive gamma ray pattern suggesting a 'coarsening upward' sequence (see also Hodson, 1975, fig. 2).

Distribution: The sub-unit is widely distributed throughout the Viking Graben and is well developed in the region of the Brent and Statfjord fields. It thickens into the Norwegian sector but does not change significantly in lithology.

Age: Probably Early Bajocian.

Etive Sub-unit

Name: The name is derived from Loch Etive in Scotland. It corresponds to the 'massive sand bed' of Bowen (1975) and is given formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2772 m (9095 ft) to 2783 m (9130 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20).

Thickness: 11 m (35 ft) in the type well and 27 m (90 ft) in 33/9–1.

Lithology: In the type well it consists of brown to grey, massive fine- to medium-grained clean non-micaceous cross-bedded sandstone. Although the sub-unit thickens into the Norwegian sector the lithology is essentially similar, although some thin lignitic beds may occur.

Boundaries: In the type well and particularly in the reference well the sub-unit is characterised by a distinctive gamma ray deflection. Its lower boundary can usually be recognised by a lower gamma ray reading and the marked lack of mica in comparison with the Rannoch Sub-unit. In places this lower boundary may be transitional. The upper boundary is taken at the first significant argillaceous bed, frequently a coal, in the overlying sub-unit.

Distribution: Not known in detail but the sub-unit is well developed in the Brent–Statfjord area.

Age: Probably Early Bajocian.

Ness Sub-unit

Name: The name is derived from Loch Ness in Scotland. It corresponds to the 'Middle Brent Sand Member' of Bowen (1975) and is given formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2633.5 m (8640 ft) to 2772 m (9095 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20).

Thickness: 138.5 m (455 ft) in the type well and 66 m (216 ft) in 33/9–1.

Lithology: In the type well the sub-unit consists of interbedded sandstones, and shales with subordinate siltstones and coals. It is carbonaceous throughout and contains a number of rootlet horizons. The sandstones are grey-brown, clean, fine to medium grained and fairly well sorted. The shales are dark grey, silty, fissile, and usually pyritic and micaceous. The sub-unit is thinner and more shaly in the Norwegian sector. Further subdivision of this sub-unit is possible but no proposals are made here.

Boundaries: The contact with the Etive Sub-unit below is taken as the lowest occurrence of significant argillaceous beds, this change often coinciding with the first appearance of coals in the section. The upper contact is marked by the change to the more massive cleaner sandstone of the overlying Tarbet Sub-unit noted earlier; this upper contact may be a minor disconformity. The sub-unit normally has a distinctive gamma ray and sonic log response and the contacts are usually marked by log breaks. This is particularly well seen in the reference well section.

Distribution: Not known in detail but it is well developed in the areas of the Brent and Statfjord fields.

Age: Bajocian.

Tarbert Sub-unit

Name: The name is derived from Loch Tarbert in Scotland. It corresponds to the 'Upper Brent Sand Member' of Bowen (1975) and is given formation status in the UK sector and member status in the Norwegian sector.

Well type section: UK well 211/29–3 (Shell/Esso) (Figure 19), from 2602.5 m (8539 ft) to 2633.5 m (8640 ft) below KB.

Well reference section: Norwegian well 33/9–1 (Mobil) (Figure 20).

Thickness: 31 m (101 ft) in the type well and 45 m (148 ft) in 33/9–1.

Lithology: In the type well section it consists of grey to brown, relatively massive fine- to medium-grained sandstone with subordinate thin siltstone, shale and coal beds and some calcareous bands. The sub-unit thickens into the Norwegian sector where it sometimes contains coaly beds.

Boundaries: The base of the sub-unit is taken at the top of the last prominent argillaceous bed in the underlying Ness Sub-unit, and the upper boundary is clearly marked by the abrupt change to the argillaceous sediments of the Heather Formation. It usually has a distinctive gamma ray response, and as it is surrounded by more argillaceous units its contacts are usually marked by good log breaks. The upper boundary may be an unconformity, reflecting the phase of post-Middle Jurassic tectonism and erosion. Some or all of the sub-unit may be eroded in some sections depending on the position of the section within the system of tilted fault blocks.

Distribution: The distribution of the sub-unit is not known in detail but it is well developed in the Brent–Statfjord area.

Age: Probably Late Bajocian to ? Bathonian.

Humber Group

Name: The group is extended from the Southern North Sea where it was defined by Rhys (1974).

Type area: The type area is the Southern North Sea Basin and Rhys (1974) illustrated UK well 47/15–1 (Phillips) as a typical section of the group.

Thickness: The thickness of the group may vary considerably (see Figure 22) since the sediments were deposited on a series of tilted fault blocks produced by pre- and syndepositional tectonic activity (Cimmerian earth movements). In addition, uplift and erosion associated with later Cimmerian movements at the end of the Jurassic resulted in some degree of erosion of the Humber Group in all but the most protected structural positions.

Lithology: In the Southern North Sea the group consists of two marine shale formations separated by a prominent limestone formation (Rhys, 1974). In the Central and Northern North Sea it consists almost entirely of dark coloured, marine mudstones, claystones and shales with areally restricted intercalations of sandstone. These sandstones may be very important hydrocarbon reservoirs, for example the Piper Formation.

Boundaries: In the Northern North Sea the lower boundary is marked by the distinct contrast between the fine grained sediments (usually the Heather Formation), and the arenaceous deposits of the Brent

Unit. In the Central North Sea the group normally rests unconformably on the volcanics or the associated paralic sediments of the Fladen Group. The upper boundary of the group in most wells in the Central and Northern North Sea is an unconformity (the 'Cimmerian Unconformity') normally overlain by Cretaceous sediments of varying age.

Distribution: The group is widely distributed throughout the Southern, Central and Northern North Sea.

Age: The group ranges from Early Bathonian to Portlandian and possibly Ryazanian in age. The group is a time and facies equivalent of the Oxford, Ampthill and Kimmeridge Clays of Southern England (Rhys, 1974).

Subdivisions: Three formations are recognised within the group namely the Heather, Kimmeridge Clay and and Piper formations. The Heather and Kimmeridge Clay formations are widely distributed while the Piper Formation is restricted to the area around the Piper Field. Elsewhere within the group locally thick sandstone or siltstone units occur (Brennand and Siri, 1975). These are not given any formal status here but the reservoir of the Magnus Field (UK block 211/12) is known to be an example.

Heather Formation

Name: The formation is named after the Heather Field where is is well developed. In terms of the sub-divisions suggested by Bowen (1975) it corresponds to the 'Brent Shale' of the 'Brent Sand Formation', plus the 'non-radioactive member', of his 'Kimmeridge Clay Formation'. It corresponds to the Heather Formation of Hodson (1975).

Well type section: UK well 211/21–1A (Shell/Esso) (Figure 21), from the Cormorant Field. The formation occurs from 2810 m (9218 ft) to 2840 m (9317 ft) below KB.

Well reference section: Figure 22 shows a correlative cross section between the type well and three adjacent wells illustrating the variations in the Heather and Kimmeridge Clay formations. These other three wells can be considered as reference sections. They are UK well 210/30–1 (Arpet), UK well 211/29–3 (Shell/Esso) and UK well 211/24–1 (Conoco/Gulf/NCB). A thin development of the formation is also shown in Norwegian well 33/9–1 (Figure 20).

Thickness: 30 m (99 ft) in the type well. The variation in thickness between the reference wells is indicated on Figures 20 and 22.

Lithology: The formation consists dominantly of grey silty claystone. It is possible to subdivide the formation, and within the northern part of the Viking Graben two divisions are recognised although these are not accorded any formal status at present. The upper of these two divisions is a dark grey silty claystone, carbonaceous in parts with limestone horizons, while the lower division is a light to dark grey silty claystone which is hard, micaceous and calcareous. These two subdivisions are shown on Figure 21. In the type well there is an unconformity within the upper division but this is not always apparent elsewhere and since there is no distinct lithological difference between the sediments on either side of the unconformity then the upper division is not further subdivided. This unconformity may be an angular discordance (detected by dipmeter or core data) or a disconformity (biostratigraphic gap). On the higher parts of some of the tilted fault blocks it may cut down into the Brent Unit having removed much of the Heather Formation, as in the 211/24–1 well (Figure 22).

Boundaries: The lower boundary is the contact with the arenaceous Brent Unit and the upper boundary is the contact with the Kimmeridge Clay Formation, which has an anomalously high gamma ray response and slow velocity. Both boundaries are therefore marked by log breaks and changes in log character.

Distribution: The formation can be recognised over most of the Northern North Sea and in parts of the Central North Sea.

Age: The lower division is mainly Early Bathonian and the upper division is Middle Bathonian to Early Oxfordian (Calloman, 1976).

Depositional environment: The coastal to shallow marine sandstones of the youngest sub-unit of the Brent Unit mark a transgression which continued with the deposition of the open marine silty claystones of the Heather Formation. In the type section the sediments above the unconformity in the upper division represent continued marine transgression following a break in sedimentation. Since the deposition of the formation was affected by continued fault movements the magnitude of this break in sedimentation at any place is a function of the amount of onlap which occurred on each particular fault block.

Kimmeridge Clay Formation

Name: The formation is named from the type locality of the Kimmeridge Clay at Kimmeridge Bay, Dorset, Southern England (Arkell, 1947). It has been recognised in the Southern North Sea (Rhys, 1974) and can be traced northwards from there. It corresponds to the 'radioactive member' of the 'Kimmeridge Clay Formation' of Bowen (1975), and to the Magnus Formation of Hodson (1975).

Well Type Section: The formation was defined in UK well 47/15–1 (Phillips) from the Southern North Sea by Rhys (1974, Figure 6). It occurs from 885 m (2902 ft) to 919 m (3014 ft) in this well.

Well reference section: UK well 211/21–1A (Shell/Esso) (Figure 21). Figure 22 shows the variations in the Kimmeridge Clay Formation between UK wells 211/21–1A, 210/30–1, 211/29–3 and 211/24–1, and these other three wells can also be considered as reference sections. In addition UK wells 15/17–4 (Occidental) (Figure 24) and 21/10–1 (BP) (Figure 23) from the Central North Sea can be considered as additional reference sections. A thin development of the formation is also shown in Norwegian well 33/9–1 (Figure 20).

Thickness: 34 m (112 ft) in the type well. The thickness variation of the formation is clearly illustrated in the reference wells (Figures 20 to 24).

Lithology: In the reference well section (211/21–1A) the formation is dark grey-brown to black, non-calcareous, carbonaceous claystone becoming fissile in places. It is characterised by a very high level of radioactivity which is a function of organic carbon content. In addition it has an anomalously low velocity, a high resistivity and a low density. The formation in the Southern North Sea is less radioactive but still has the typical low velocity (Rhys, 1974, Figure 6). In the Central North Sea the formation contains some interbeds of siltstone and shale which may have a lower radioactivity than normal as in UK well 15/17–4 (Figure 24).

Boundaries: The Kimmeridge Clay Formation is defined as having a very high gamma ray response and an anomalously low velocity. A gamma ray response of greater than 100 API units is taken to be indicative of the formation. These proporties ensure that the boundaries of the formation are normally marked by strong log breaks.

Over most of the Northern North Sea the formation has a diachronous contact with the Heather Formation, and the base of the Kimmeridge Clay Formation may range from Oxfordian to early Kimmeridgian in age. In the Central North Sea (west) the formation may overlie the Piper Formation, as in UK well 15/17–4 (Figure 24) or the Fladen Group, as in UK well 21/10–1 (Figure 23). In both cases the boundary is well marked, particularly on the gamma ray log. The upper boundary in most wells in the Central and Northern North Sea is an unconformity (the 'Cimmerian Unconformity'), normally overlain by Cretaceous sediments of varying age. The Cretaceous sediments have a higher velocity and lower radioactivity than the Kimmeridge Clay Formation so there are normally strong log breaks at this boundary (see Figure 24). In a few wells there are intervals of non-radioactive shale of Late Jurassic age occurring above the Kimmeridge Clay Formation but no formal units can be recognised with the data available at present; these strata are lithologically distinct from the overlying Cromer Knoll Group. In areas away from the structural highs there may be a conformable passage from Jurassic to Cretaceous strata.

Distribution: This formation is one of the most widespread in the North Sea. At the time of deposition much of the UK landmass and considerable areas of northern Europe were submerged by the late Jurassic marine transgression. Johnson (1975) describes these sediments and illustrates their distribution.

Age: The formation ranges from Early Oxfordian to Portlandian and possibly Ryazanian in age.

Depositional environment: The Kimmeridge Clay Formation is considered to have been deposited in a marine environment with high organic productivity and restricted bottom circulation (Ager, 1975; Johnson, 1975). In places in the Viking and Central grabens these argillaceous sediments may contain deep water turbidites (P. A. Ziegler, 1975).

Piper Formation

Name: From the Piper Field in UK Block 15/17, where the formation is the main reservoir.

Well type section: UK well 15/17–4 (Occidental) (Figure 24), from 2574 m (8444 ft) to 2666 m (8746 ft) below KB.

Well reference section: None at present.

Thickness: 92 m (302 ft) in the type well.

Lithology: In the type well the formation is an alternating sequence of thin transgressive and thicker regressive sandstones, with occasional shales marking the more extensive transgressions. The main sandstones are quartzose, very fine to coarse grained, well sorted and poorly cemented. They contain small quantities of feldspar, muscovite, tourmaline chert and zircon with rare quartz and feldspar overgrowths. Local concentrations of heavy minerals, particularly zircon, may produce anomalously high gamma log readings, e.g. that between 8644 and 8652 feet in Figure 24. Bioturbation is common throughout the sandstones but the only preserved macrofossils are concentrations of large bivalves (*Ostrea* sp.) near the top of the formation. The interbedded shales however contain numerous macrofossils including ammonites, bivalves and belemnites.

The lowermost unit of the formation is a basal sandy siltstone, grading into a series of silty shales with thin glauconitic horizons (8710–8746 ft on Figure 24). The shales are carbonaceous and thin coals are developed away from the type well. Bioturbation is common in this lower unit but only a restricted fauna of gastropods and bivalves has been found. In the area of the Piper and Claymore fields this basal unit is the initial deposit of the Late Jurassic marine transgression which covered the continental clastics, coals and volcanics of the Middle Jurassic.

Boundaries: The formation normally rests unconformably on the Middle Jurassic as in the type well. It is distinguished from the underlying paralic deposits by a more regular sonic log response and a generally blocky gamma ray pattern reflecting the interbedding of thin shales and thick clean sandstones. However the base of the formation may not be easy to recognise on logs, for as in the type well the basal unit of the formation is a marine sandy siltstone grading into shale, and the log character only changes at the first clean marine sandstone above this. The upper boundary of the formation is marked by a sharp lithological contact with one of the argillaceous formations of the Humber Group. In the type well the Kimmeridge Clay Formation is the overlying unit but in more complete sections the Heather Formation may be represented. It should be noted that in this part of the Central North Sea the nature of the complex interdigitation of the Heather, Piper and Kimmeridge Clay Formations is not yet precisely known.

Distribution: The formation has only been clearly recognised in the area of the Piper Field. The Late Jurassic sandstones of the Claymore Field could probably be included in this formation as they are an arenaceous marine facies which, from sparse palaeontological data, is at least in part synchronous with the Piper Formation. The Claymore sandstones are fine grained and slightly argillaceous with interbedded shales. These shales differ from those in the Piper Formation, being dark grey to black and very carbonaceous with a high gamma ray response of over 100 API units.

Age: The Piper Formation is Oxfordian to Early Kimmeridgian (see Williams and others, 1975).

Depositional environment: The bulk of the formation is considered to be a series of stacked and possibly imbricated barrier bar and other littoral and shallow marine sand bodies.

In the eastern Moray Firth and Central Graben there are breaks within and at the base of the Jurassic succession. The Lower Jurassic is virtually absent west of the graben axis and the principal lithostratigraphic units in this area are volcanics and associated sediments of mainly Middle Jurassic age, and Upper Jurassic clastic sediments.

The volcanic rocks attain their maximum thickness just to the north of the Forties Field area. Away from here they are thinner and are intercalated with shallow water sediments (Howitt and others, 1975). In the Piper Field area only thin tuffs are present in a clastic sedimentary sequence. Therefore the Middle Jurassic rocks of this region consist essentially of two end members, a thick volcanic pile and an essentially non-volcanic sedimentary sequence containing at most only thin tuff horizons. Between the end members there are a variety of sections showing volcanic rocks and sediments in varying proportions. With the data available to the sub-committee it was not possible to define the relationships between the end members in detail.

The volcanic rocks are here named the Rattray Formation and the non-volcanic sedimentary rocks are named the Pentland Formation. To emphasise the fact that there is a complex interdigitating relationship between the two formations they are grouped together as the Fladen Group.

Fladen Group

Name: From the Fladen Ground Spur, a structural feature.

Type area: The group is typically developed in the UK sector of the Central North Sea particularly in the area between the Piper and Forties oilfields.

Thickness: Within the volcanic province the thickest section penetrated so far is 1100 m and in this well the base of the volcanics was not reached. A considerable amount of thickness information was presented by Howitt and others (1975).

Lithology: As noted above the group embraces both volcanic and non-volcanic formations. Therefore the group contains a wide range of lithologies including basalts, tuffs agglomerates, and normal continental to shallow water sediments.

Boundaries: The group normally rests on pre-Jurassic rocks, frequently Triassic sediments, and the lower boundary is marked either by the incoming of igneous rocks or the change from Triassic continental sediments to paralic sediments containing tuff horizons. The upper boundary is the contact with the marine sediments of the Humber Group. The Piper or Kimmeridge Clay formations may overlie the Fladen Group and in some sections the Heather Formation may be present but as noted earlier the complex interdigitations of the component formations of the Humber Group are not precisely known for this part of the Central North Sea.

Distribution: The group is largely restricted to the area of UK quadrants 14, 15, 16, and the more northerly parts of 21 and 22.

Age: Middle Jurassic.

Subdivisions: As noted above the rocks of the Fladen Group are divided into two formations which are essentially end members of an interdigitating sequence. These are named the Rattray and Pentland formations. For present purposes if the encountered section contains more than half volcanics it is assigned to the Rattray Formation while if it contains more than half sedimentary rocks then it is placed in the Pentland Formation. As more data become available it will almost certainly be possible to subdivide the two formations further, and a proper understanding of the relationship between these end members may necessitate revision of the nomenclature in the future.

Rattray Formation

Name: From Rattray Head on the coast of Scotland adjacent to the volcanic province.

Well Type Section: UK well 21/10–1 (BP) (Figure 23), from 2680 m (8792 ft) to 3422.3 m (11 228 ft) below KB.

Well reference section: None at present but Howitt and others (1975, fig. 2) illustrate the nature of the formation in wells adjacent to the type well.

Thickness: 742.3 m (2436 ft) in the type well but the base of the formation was not reached.

Lithology: In the type section and adjacent wells (BP 21/9–1 and Shell/Esso 22/6–1), the formation consists of a thick series of basaltic lava flows (1 to 9 m thick where cored), with interbedded agglomerates, tuffs and tuffaceous sediments. The lavas are grey or purplish, vesicular and often partially altered, and locally completely laterised. Large fresh pyroxene phenocrysts and smaller altered olivine phenocrysts are set in a groundmass of pyroxene and feldspar. Autobrecciation, late hydrothermal activity and deep weathering and oxidation are fairly common. The epiclastics, ranging from agglomerate to tuffs, comprise lava and phenocryst clasts, or primary pumice and ? lapilli fragments. Only minor pyroclastics have been recognised. Interbedded sediments are present towards the base of the type section, consisting of dominantly red to brown mudstone, which is soft to firm and locally calcareous. Minor amounts of red-brown or grey-green siltstone and fine grained, friable, brown sandstone are present. Lateral lithological and petrographical variations have been described by Howitt and others (1975).

Boundaries: The base of the formation generally rests on pre-Jurassic rocks and is marked by the incoming of igneous rocks. The upper boundary of the formation is normally a distinctive contact with Late Jurassic or Cretaceous rocks and is marked by clear changes of log character (Figure 23).

Distribution: The volcanic province extends from approximately 0° to 1°40′E and from 57°40′ to 58°45′N in the UK sector. Scattered occurrences of thin volcanics have been reported from the Norwegian sector but no details are available. The province appears to be controlled by faults at the junction of the Viking and Central grabens and the Moray Firth Basin. Both the amount of volcanic detritus and the percentage of lava decrease sharply along the south-eastern and western margins, with a more gradual change towards the north and east. The thickest sections of lavas and volcanic detritus pass into an outermost zone dominated by volcanic clastics with much interbedded non-volcanic sediment.

Age: Present evidence indicates a Middle Jurassic age (Bajocian–Bathonian). In the southern part of the volcanic province the interbedded red-beds are barren, but sparsely fossiliferous grey beds in the north near the base and top of the formation yield Bajocian–Bathonian dates, based on floral dating and rare ostracods. Radiometric dating on whole-rock samples which are sheared, altered and often with secondary mineralisation has provided a range of minimum ages from 165 ± 4 Ma (million years) to 109 ± 2 Ma. No systematic change in age has been recognised and the volcanics are assumed to be essentially the product of one synchronous episode.

Pentland Formation

Name: From the Pentland Firth.

Well type section: UK well 15/17–4 (Occidental) (Figure 24) from 2666 m (8746 ft) to 2778 m (9112 ft) below KB.

Well reference section: None.

Thickness: 112 m (366 ft) in the type well.

Lithology: In the type well the formation consists of light to dark grey, carbonaceous siltstone, shale and claystone which is slightly calcareous and locally pyritic. Interbedded coals are prominent as are red, brown, green and grey tuffaceous horizons. Towards the south-east the percentage of volcanics in the formation increases as it passes into the Rattray Formation.

Boundaries: As in the type well the formation is normally slightly unconformable on Triassic continental sediments. It is marked by an irregular gamma ray and sonic log pattern in contrast to the more regular log response of the underlying Triassic sediments (Figure 24). The upper boundary is the unconformable contact with the Piper Formation which tends to have a more regular sonic log response and a more 'blocky' gamma ray pattern.

Distribution: The formation is widely distributed in UK quadrants 14, 15 and 16. To the south it passes gradually into the Rattray Formation as the percentage of volcanics in the section increases. The formation is probably broadly homotaxial with the Brent Unit of the Viking Graben but the relationship between these two units could not be studied by the sub-committee because of a lack of available data in UK quadrants 9 and 16.

Age: Middle Jurassic.

In the Norwegian-Danish Basin many of the stratigraphic units are extensions of those recognised onshore in Denmark.

Larsen (1966) presented a lithostratigraphic subdivision of the Rhaetian, Jurassic and Lower Cretaceous sediments in the Danish Embayment and recognised the following major formations in the north-west part of his study area.

Frederikshavn Formation (top)	Siltstone, sandstone and dark coloured shale
Børglum Formation	Dark coloured shale
Haldager Formation	Sandstone
Fjerritslev Formation	Dark coloured shale
Gassum Formation (base)	Sandstone

The lower three formations can easily be recognised as separate formations throughout the Norwegian part of the Norwegian-Danish Basin and onto the Vestland Arch. The upper two formations are difficult to separate in places where dark coloured shale becomes the predominant lithology in the Frederikshavn Formation. Member status appears to be more appropriate for these two units and this report recommends that their status be changed accordingly (see also Michelsen, 1976).

An interval of dark-coloured mixed lithology (silty shale, carbonates and sandstone) is present between the Haldager Formation and the Børglum Formation in the entire north-eastern area of the Norwegian part of the Norwegian-Danish Basin, and it is proposed to designate this interval the Egersund Member. After consultation with the Danish Lithostratigraphic Nomenclature Committee the following subdivisions have been agreed for the Norwegian-Danish Basin.

Bream Formation (top)	Frederikshavn Member
	Børglum Member
	Egersund Member
Haldager Formation	
Fjerritslev Formation	
Gassum Formation (base)	

In places above the Frederikshavn Member (Figure 25) there may be dark-coloured shales of uppermost Jurassic age. On lithological grounds these are included with the argillaceous Early Cretaceous sediments of the Valhall Formation.

Gassum Formation

Larsen (1966) erected the Gassum Formation to encompass a predominantly sandy, deltaic sequence of Rhaetian–Early Sinemurian age. The type section is in the Gassum No. 1 well near Gassum in Jutland.

Several wells in the Norwegian-Danish Basin and on the Vestland Arch have encountered a partially eroded Gassum Formation with 7/9–1 (Figure 26) being the only available well with a complete, but condensed sequence. Well 7/9–1 (Conoco), (Figure 26) is here considered as a reference well for the formation. In this well the formation overlies Triassic (Keuper) sediments unconformably and is entirely of Rhaetian age in this part of the basin. The top of the formation appears to be time-transgressive and varies in age from Late Rhaetian in the basin centre to Early Sinemurian in more marginal parts of the basin.

A description of the formation is given on Figure 26 and it may be regarded as homotaxial with the Statfjord Formation of the Northern North Sea.

Fjerritslev Formation

Larsen (1966) gave the name Fjerritslev Formation to a predominantly shaly sequence of Early Jurassic age. The type section is in the Fjerritslev No. 2 well near Fjerritslev in Jutland. The base of the formation is time-transgressive and varies in age from Early Hettangian to Late Sinemurian. The top of the formation is the base of the sandstones of Bajocian–Early Kimmeridgian age (Haldager Formation). Within the formation the presence of two silty intervals in the Danish offshore area (Danish Lithostratigraphic Nomenclature Committee, personal communication), may facilitate subdivision at the level of the sub-units of the Dunlin Unit.

The only presently available well in the Norwegian-Danish Basin/Vestland Arch area which encountered the Fjerritslev Formation is 7/9–1 (Figure 26) and this is here considered as a reference well even though the top of the formation is eroded.

Haldager Formation
Larsen (1966) erected the Haldager Formation to encompass a predominantly sandy, deltaic sequence intercalated between his argillaceous Fjerritslev and Børglum Formations. The type section of the Haldager Formation is in the Haldager No. 1 well near Haldager in Jutland.

Norwegian wells 9/4–1 (Amoseas) (Figure 25) and 7/9–1 (Conoco) (Figure 26) are considered as reference sections for the formation. In the eastern and north-eastern parts of the area of the Norwegian-Danish Basin and Vestland Arch the formation appears to have been deposited in fluvial to lacustrine environments while to the west and south-west shallow marine conditions seem to have prevailed. To the west and south-west also the age of the formation is diachronous from Bajocian/Bathonian to Kimmeridgian.

Bream Formation
Name: A new name derived from the Bream Field in Norwegian block 17/12.

Well type section: Norwegian well 9/4–1 (Amoseas) (Figure 25), from 2047 m (6718 ft) to 2288 m (7508 ft) below KB.

Well reference section: None at present for the formation as a whole but Norwegian well 7/9–1 (Figure 26) shows a reference section for the Børglum Member of the Bream Formation.

Thickness: 241 m (790 ft) in the type section. It thickens to over 300 m (1000 ft) towards the north-east and thins towards the west and south-west where it locally pinches out against the Vestland Arch.

Lithology: In the type well the lower part of the formation is shale with some siltstone and sandstone intercalations. Thin dolomite and limestone bands are also present. Overlying this is an interval of carbonaceous claystone which is highly radioactive in part, and which becomes coarser grained upwards. The upper part of the formation consists of siltstones and shales with carbonate bands containing shell fragments and coral, crinoid and sponge particles. Well developed sandstone units occur in other wells.

Boundaries: The base of the formation is marked by the occurrence of dark-coloured argillaceous sediments above the coarser sandstones of the Haldager Formation. This contact is marked by good log breaks (Figure 25). The top of the formation is marked by the contrast between the predominantly silty upper member of the Bream Formation and the finer grained carbonaceous shales of the Valhall Formation. This is usually quite well seen on gamma ray and sonic logs in the Norwegian-Danish Basin but towards the Vestland Arch the upper part of the formation may be removed by erosion as in well 7/9–1 (Figure 26).

Distribution: The formation is present throughout the Norwegian-Danish Basin and over most of the Vestland Arch and Ringkøbing-Fyn High. The basal member is present only in the north-eastern and eastern parts of the Norwegian-Danish Basin.

Age: Callovian to Portlandian in the east and north-east but Kimmeridgian only in the west and south-west.

Subdivisions: As noted above the formation is subdivided into three members, the Egersund Member (base), the Børglum Member and the Frederikshavn Member (top).

Egersund Member
Name: From a town on the south-west coast of Norway. The formation is typically developed in the Egersund Sub-basin, a structural feature recognised by Rønnevik and others (1975).

Well type section: Norwegian well 9/4–1 (Amoseas) (Figure 25), from 2251 m (7386 ft) to 2288 m (7508 ft) below KB.

Well reference section: None.

Thickness: 37 m (122 ft) in the type well. The member thickens slightly to the east and north-east and pinches out rapidly towards the west and south-west.

Lithology: In the type well the formation consists of dark grey, micromicaceous shales and siltstones with brownish, locally oolitic, microcrystalline carbonate beds and occasional sandstone streaks. The latter become more important east and north-east of the type well.

Boundaries: The lower boundary is also the junction of the Bream Formation with the Haldager Formation and is described above. The upper boundary is marked by the appearance of the dark grey to black organic-rich shales of the overlying Børglum Member. The shales of the Børglum Member have a high radioactivity and a low velocity (compare the Kimmeridge Clay Formation), and therefore the upper boundary of the Egersund Member is marked by strong log breaks (Figure 25).

Distribution: The member is distributed throughout the Egersund Sub-basin (Rønnevik and others, 1975) and its immediate surroundings.

Age: Callovian to Early Oxfordian. The member is broadly homotaxial with the upper part of the Heather Formation of the Northern North Sea.

Børglum Member
For reasons given above the status of Larsen's (1966) Børglum Formation has been reduced to member level. The type section is defined in the Børglum No. 1 well near Børglum in Jutland. The member consists of black organic rich shales, occasionally containing thin siltstones bands. In the area approximately west of 5°E the lower part of the member is highly radioactive. The lower contact of the member with the Egersund Member (Figure 25) or the Haldager Formation (Figure 26) is usually quite distinct. The top of the member may be either sharp or gradational and is defined by the appearance of massive siltstone or sandstone units of the Frederikshavn Member. The member is present throughout the Norwegian-Danish Basin and over much of the Vestland Arch although towards the west it may be eroded to some extent (Figure 26).

Frederikshavn Member
As noted above Larsen's (1966) Frederikshavn Formation has been reduced to member status. The type well section is in the Frederikshavn No. 1 well near Frederikshavn in Jutland. In the type well, near the margin of the Danish Embayment, the member is very sandy but it becomes finer grained basinwards. In the Norwegian-Danish Basin the member is characteristically siltstone with carbonate streaks containing fossil fragments, and locally developed sandstone beds. The lower boundary with the Børglum Member is described above and the upper boundary is the top of the Bream Formation. The member is widely distributed in the

eastern and north-eastern part of the Norwegian-Danish Basin but it tends to be partially or completely eroded towards the Vestland Arch.

CRETACEOUS

By the close of the Jurassic period Cimmerian tectonic activity had reached a climax. The principal expression of this tectonism is the Cimmerian unconformity, which is a major tectonic and sedimentary break. Situations where continuous deposition occurred from the Jurassic to the Cretaceous are uncommon away from the deeper segments of the graben system. Cimmerian earth movements continued into the Early Cretaceous but the graben system, which acted as a main control on Jurassic deposition, became progressively less influential on Cretaceous sedimentation.

Distribution

Lower Cretaceous sediments are widely distributed throughout the Central and Northern North Sea (P. A. Ziegler, 1975). They are locally thin or absent on pre-Cretaceous highs owing mainly to non-deposition. In the UK sector the Lower Cretaceous strata reach a maximum thickness of about 793 m (2600 ft) but average about 244 m (800 ft). In the Norwegian sector the thickness ranges from about 335 m (1100 ft) to 610 m (2000 ft).

Upper Cretaceous sediments are more widespread than the Lower Cretaceous (P. A. Ziegler, 1975), forming a blanket over the whole North Sea area and overlapping onto the East Shetland Platform, the Mid North Sea High and the Vestland Arch. They reach a maximum thickness of about 1370 m (4500 ft) in the Viking Graben but generally range between 488 m (1600 ft) and 1005 m (3300 ft) in the UK sector of the Central North Sea and between 198 m (650 ft) and 762 m (2500 ft) in the Norwegian sector. By Late Cretaceous times the North Sea had become the site of a gently subsiding basin and fault movements had only a very minor influence on sedimentation.

Lithostratigraphy

Table 3 indicates the lithostratigraphic subdivisions of the Cretaceous and Danian strata in the Central and Northern North Sea. No reference wells are yet available to illustrate the section in the Danish part of the Norwegian-Danish Basin but discussions with the Danish Nomenclature Committee indicate that the sequence is similar to that in the Central North Sea although generally thinner.

In general terms the Cretaceous and Danian sediments of the Central North Sea are similar to those of the Southern North Sea, but in the Northern North Sea the facies changes, particularly in the Late Cretaceous. The Moray Firth Basin has not been considered because of lack of available well control. However there are records of Lower Cretaceous black shales and sandstones and Upper Cretaceous chalk within the Moray Firth Basin (Chesher and others, 1972; W. H. Ziegler, 1975).

The Cromer Knoll Group, erected by Rhys (1974) to cover the Lower Cretaceous sediments of the Southern North Sea, has been extended to the Central and Northern North Sea. In the Central North Sea it is a sequence of marine clays, shales, marls and sandstones while in the Northern North Sea it is less arenaceous.

The name Chalk Group has been extended from the Southern North Sea to cover the Upper Cretaceous and Danian sediments of the Central North Sea. In both of these areas the thickest chalk deposits accumulated in a trough that essentially paralleled the axis of the Jurassic Central Graben. Sedimentation was most

Table 3 Cretaceous lithostratigraphic nomenclature

SYSTEM	SERIES	STAGE	CENTRAL NORTH SEA: Group	CENTRAL NORTH SEA: WEST	CENTRAL NORTH SEA: EAST AND CENTRAL	NORTHERN NORTH SEA	NORTHERN NORTH SEA: Group
TERTIARY	PALAEOCENE	DANIAN	CHALK GROUP	EKOFISK FORMATION	EKOFISK FORMATION	'FORMATIONS' A TO F (SEE FIGURE 32)	SHETLAND GROUP
CRETACEOUS	UPPER	MAASTRICHTIAN		TOR FORMATION	TOR FORMATION		
		CAMPANIAN		FLOUNDER FORMATION	HOD FORMATION		
		SANTONIAN					
		CONIACIAN					
		TURONIAN		HERRING FM. / PLENUS MARL FM.	PLENUS MARL FM		
		CENOMANIAN		HIDRA FORMATION	HIDRA FORMATION		
	LOWER	ALBIAN	CROMER KNOLL GP.	RØDBY FM.	RØDBY FORMATION	UNDIFFERENTIATED CALCAREOUS MUDSTONES AND THIN LIMESTONES	CROMER KNOLL GROUP
		APTIAN		VALHALL FORMATION	VALHALL FORMATION		
		BARREMIAN					
		HAUTERIVIAN					
		VALANGINIAN		DEVIL'S HOLE FORMATION			
JURASSIC		RYAZANIAN					
	UPPER	PORTLANDIAN		KIMMERIDGE CLAY FORMATION	KIMMERIDGE CLAY OR BREAM FORMATIONS	KIMMERIDGE CLAY FORMATION	
		KIMMERIDGIAN					

continuous in the deeper parts of this trough and all the Late Cretaceous stages are present. There was little change in the composition of the material deposited (with the notable exception of the Plenus Marl Formation), and formation differentiation is based on subtle lithological changes. These changes are laterally extensive, are reflected by wire-line log traces, and often coincide approximately with chronostratigraphic subdivisions. Away from the chalk depocentre (e.g. UK well 22/1–2A), argillaceous intercalations provide a further basis for subdivision.

In the Northern North Sea the Upper Cretaceous and Danian section is an argillaceous and calcareous marine sequence. The name Shetland Group has been erected to cover these strata. In the 3/29–1 (BP) well, which is a typical section of the Shetland Group, a number of subdivisions of probable formation status can be recognised on the basis of subtle lithological changes. However there were insufficient wells available to the sub-committee to demonstrate lateral continuity and therefore no recommendations are made at this stage.

It should be noted that strata of Danian age, here called the Ekofisk Formation, are included with the Late Cretaceous Chalk Group in the Central North Sea. This is because the Ekofisk Formation is highly calcareous and is most logically grouped with the Chalk Group; it is normally quite distinct from the overlying Tertiary non-calcareous clastic sediments.

CENTRAL NORTH SEA

Cromer Knoll Group

Name: From the Cromer Knoll buoy in the Southern North Sea.

Type area: The type area is the Southern North Sea Basin and Rhys (1974) illustrated UK well 48/22–2 (Burmah) as a typical section of the group. In this report the group is illustrated in UK wells 29/25–1 (Shell/Esso) (Figure 27) and 22/1–2A (Sun Oil) (Figure 28), and Norwegian well 2/11–1 (Amoco) (Figure 29). UK well 3/29–1 (BP) (Figure 32) illustrates the group in the Northern North Sea and is discussed later in the text.

Thickness: 229 m (752 ft) in the 48/22–2 well. In 29/25–1 the group is 223.5 m (740 ft) thick and it is 240 m (790 ft) in 22/1–2A. To the east in the 2/11–1 well it is much thicker reaching 653 m (2137 ft). Average thicknesses however are generally between 91 and 244 m (300 to 800 ft).

Lithology: In 29/25–1 a basal sandstone unit is overlain by a calcareous mudstone sequence which exhibits reddening at the top. This basal sandstone is not present everywhere in the Central North Sea and cannot be recognised in the Norwegian sector or to the north of 59°N. In the Norwegian sector the lower part of the sequence is a calcareous mudstone and the upper part normally a reddish marl.

Boundaries: The upper boundary is the base of the Chalk Group where there is a decrease in gamma ray response and an increase in velocity into the overlying carbonates. In the 29/25–1 well the lower boundary is the contact with Triassic continental sediments, marked by distinct log breaks (Figure 27). More often the underlying sediments are part of the Jurassic Kimmeridge Clay Formation or the Bream Formation, and the contact is marked by very strong gamma ray and sonic log breaks.

Distribution: The group is widely distributed over the North Sea Basin and is absent only on some structural highs.

Age: Portlandian to Albian.

Subdivisions: In the UK sector the basal sandstone unit is distinguished as the Devil's Hole Formation. Above this in UK and Norwegian waters the calcareous mudstone sequence is designated the Valhall Formation. At the top of the group in the Norwegian sector a red, fine grained, calcareous unit has been designated the Rødby Formation, a formation extrapolated from onshore Denmark. In the UK sector some wells exhibit reddening at the top of the Cromer Knoll Group and it may be possible to identify the formation in places. However in the UK wells available to the sub-committee it was felt that the formation could not be irrevocably defined and hence it is not picked in the UK wells illustrated here. Where the Rødby Formation is not present or not defined the Valhall Formation is taken to include all the fine-grained calcareous sediments up to the top of the Cromer Knoll Group. It should be noted that there are certainly other units of formation status within this group which cannot yet be defined because of data restrictions.

Devil's Hole Formation

Name: From a North Sea bathymetric feature.

Well type section: UK well 29/25–1 (Shell/Esso) (Figure 27), from 2418.5 m (7935 ft) to 2482 m (8150 ft) below KB.

Well reference section: none at present.

Thickness: 63.5 m (215 ft) in the type well.

Lithology: In the type well it is a grey to greenish grey sandstone with angular to rounded grains. It is argillaceous and slightly calcareous with traces of biotite, muscovite and glauconite, and contains scattered anhydritic nodules. It may locally grade into sandy marl.

Boundaries: The upper contact is marked by a slight increase in gamma ray response and a slight decrease in velocity into the finer grained sediments of the overlying part of the Cromer Knoll Group. The base of the formation is the same as the base of the Cromer Knoll Group defined above.

Distribution: The formation has a limited distribution in the UK sector of the Central North Sea. A sandstone unit can be recognised in a similar position in the Southern North Sea (Rhys, 1974), but it is not yet clear whether this should be equated with the Devil's Hole Formation.

Age: The formation has been dated as Ryazanian to Valangian or lowermost Hauterivian.

Valhall Formation

Name: From the Valhall Field in Norwegian block 2/8.

Well type section: Norwegian well 2/11–1 (Amoco) (Figure 29), from 2910 m (9548 ft) to 3540 m (11 610 ft) below KB.

Well reference section: UK well 29/25–1 (Shell/Esso) (Figure 27) and UK well 22/1–2A (Sun Oil) (Figure 28).

Thickness: 630 m (2062 ft) in the type well, 160 m (525 ft) in 29/25–1 and 240 m (790 ft) in 22/1–2A. In basinal areas the average thickness is 300–600 m but along the Vestland Arch and on small local highs the formation normally averages about 150 m.

Lithology: In the type well the formation is a soft grey, calcareous mudstone or shale grading into a marl. The colour may be light grey to reddish grey but does not vary in any systematic fashion. In the type well mudstone and marl occur in about equal proportions but in many wells mudstone predominates.

Boundaries: In the type well the lower boundary is formed by the contact with Jurassic shales containing limestone streaks. These shales have a higher velocity and the contact is marked by gamma ray and sonic log breaks. In other wells the lower boundary is marked by the passage into cleaner, more highly radioactive shales of the Kimmeridge Clay Formation or the Bream Formation. The upper boundary is the base of the more calcareous, reddened sediments of the Rødby Formation. Where the Rødby Formation is absent the Valhall Formation is overlain by later Cretaceous limestones and chalks.

Distribution: The formation is widely distributed in the Central North Sea and is thin or absent only on structural highs. It may well be at least partly equivalent to the Speeton Clay Formation of the Southern North Sea (Rhys, 1974).

Age: Late Jurassic to Albian–Aptian.

Rødby Formation

Name: From the Rødby No. 1 well in Denmark where the formation was first defined.

Well type section: Rødby No. 1 well in Denmark (Larsen, 1966).

Well reference section: Norwegian well 2/11–1 (Amoco) (Figure 29).

Thickness: 23 m (75 ft) in the reference well. It generally ranges in thickness between 15 and 30 m in the Central North Sea but reaches about 210 m in the region of Norwegian block 16/6.

Lithology: In the reference well it is a grey to reddish-brown, soft slightly sandy marl, with siltstones near the base. In other wells it is pink to red in colour and varies from claystone to calcareous shale and marl with scattered limestone streaks. A thin limestone bed may be locally present at the base of the formation. Sandstone units are known to be present in some wells.

Boundaries: The upper boundary is defined at the base of the Chalk Group, usually the Hidra Formation, in the Central North Sea. This contact is marked by an increase in velocity and a decrease in gamma ray response in the overlying sediments. Where the overlying Hidra Formation consists of impure limestone the contact with the Rødby Formation may be more gradational.

The lower boundary is usually placed at the top of a particularly pure shale unit within the Valhall Formation (Figure 29), and this contact is marked by good log breaks. In places a limestone bed may be present at the base of the Rødby Formation and in such cases the formation boundary is defined at the base of that bed.

Distribution: The formation, though relatively thin, is widespread over much of the Central North Sea, particularly in the Norwegian sector, although structural flexures at the end of the Early Cretaceous have resulted in numerous local unconformities where the formation may be missing. It is probably approximately equivalent to the Red Chalk Formation of the Southern North Sea (Rhys, 1974).

Age: Usually dated as Albian.

Chalk Group

Name: The name is derived from the distinctive chalk lithology which is common in the group.

Type area: The type area is in the Southern North Sea Basin and Rhys (1974) illustrated UK well 49/24–1 (Shell/Esso) as a typical section of the group. In this report Norwegian well 1/3–1 (Shell) (Figure 30) illustrates the section in the Central Graben, UK well 29/25–1 (Shell/Esso) (Figure 27) shows a section on the flank of the graben, and UK well 22/1–2A (Sun Oil) (Figure 28) illustrates the slightly more argillaceous developments to the north and west. These wells in the Central North Sea show a more complete succession than the 49/24–1 well where some section is missing in the lower part.

Thickness: 664 m (2180 ft) in the 49/24–1 well. In 1/3–1 it is 1185 m (3888 ft), in 29/25–1 it is 389.5 m (1278 ft) and in 22/1–2A it is 848 m (2780 ft) thick. Norwegian well 1/3–1 is located in the Ekofisk area where intra- and interformational erosion and stylolite development have locally reduced the thicknesses of the chalk units and a complete sequence has not been penetrated in any well. However, piecing together maximum thicknesses of the units from a number of wells suggests that the total depositional thicknesses may have been of the order of 1500 m. The Chalk Group thins in all directions away from the Ekofisk area.

Lithology: The group is composed of white and pale cream, light grey and light brown chalk, limestone, argillaceous limestone and calcareous shale. Chert (flint) is irregularly distributed within the sequence as are carbonate nodules and pebbles. A thin but widespread marly shale horizon occurs near the base of the group.

Boundaries: The top of the Chalk Group (the Ekofisk Formation) is usually marked by a transitional decrease in calcareous content into the overlying Tertiary clastic sediments. This results in a characteristically stepped sonic log curve which is not shown clearly in the wells illustrated but is very marked in adjacent wells. The overlying Tertiary sediments have a distinctly higher gamma ray response than the Chalk Group. The group normally overlies the calcareous mudstones of the Cromer Knoll Group and strong breaks are usually apparent (Figures 27 and 28). On local structures the Chalk Group may overlie rocks ranging in age from Palaeozoic (? Silurian) to Portlandian. In a few localities the lower part of the group is penetrated by Zechstein evaporites.

Distribution: The group is well developed in the Southern and Central North Sea and can be traced northwards to the southern end of the Viking Graben (approximately 59°N), where the facies changes to that of the Shetland Group. The characteristic chalk facies is also present in south-east England, Denmark, and a number of other European basins (W. H. Ziegler, 1975).

Age: Cenomanian to Danian.

Subdivisions: Within the area of maximum thickness of the chalk lithologies (Ekofisk area) the group has been subdivided into five formations. To the north and west the incoming of more argillaceous facies allows the recognition of additional formations. These subdivisions are shown on Table 3. The Plenus Marl and Hidra Formations can be equated with the two lower units described by Rhys (1974, p.9), from the deeper parts of the Southern North Sea Basin.

Hidra Formation

Name: From the Hidra High in Norwegian blocks 1/3 and 2/1 which was named after an island off the south-west coast of Norway.

Well type section: Norwegian well 1/3–1 (Shell) (Figure 30) from 4372 m (14 340 ft) to 4442 m (14 570 ft) below KB.

Well reference section: UK wells 22/1–2A (Sun Oil) (Figure 28), and 29/25–1 (Shell/Esso) (Figure 27).

Thickness: 70 m (230 ft) in the type well, 45 m (145 ft) in 22/1–2A and 30.5 m (100 ft) in 29/25–1.

Lithology: In the type section the formation is white to light grey, hard dense limestone. Thin dark grey to black shale partings are present towards the base and the formation becomes more argillaceous northwards. In places chalky and marly intervals are present and the formation commonly has a pink colouration. At the base of the formation in the 22/1–2A well, black hard carbonaceous and argillaceous limestone is present; traces of pink waxy tuff also occur in places.

Boundaries: The upper boundary is the contact with the distinctive Plenus Marl Formation which has a higher gamma ray response and a lower velocity. The lower boundary in most localities is a sharp, generally unconformable contact with the marls and shales of the Cromer Knoll Group. The lower contact is marked by distinctive log breaks since the sediments of the Cromer Knoll Group have a higher gamma ray response and a lower velocity than the Hidra Formation.

Distribution: The formation is widely distributed in the Southern and Central North Sea as far north as approximately 59°N.

Age: Essentially Cenomanian although it may locally extend down into the Albian or up into the Turonian.

Plenus Marl Formation

Name: From the belemnite *Actinocamax plenus.*

Well type section: UK well 22/1–2A (Sun Oil) (Figure 28), from 3732 m (12 245 ft) to 3738 m (12 265 ft) below KB.

Well reference section: Norwegian well 1/3–1 (Shell) (Figure 30) and UK well 29/25–1 (Shell/Esso) (Figure 27).

Thickness: 6 m (20 ft) in the type well, 28 m (92 ft) in 1/3–1 and 3 m (10 ft) in 29/25–1. While the formation is normally thin it may be as much as 90 m thick in parts of the Norwegian sector.

Lithology: In the type section it is a red to green, moderately calcareous, soft claystone. In the Ekofisk area it is a dark grey to greenish-black calcareous shale. The colour and fissility of the formation are variable as are the content of mica, pyrite and glauconite. The formation sometimes has a high montmorillonite content, which has led to the suggestion that it may represent weathered volcanic detritus. This is supported by the fact that although thin it is very widely distributed.

Boundaries: Both upper and lower boundaries are usually well marked by the passage into chalks or limestones of the surrounding formations which have a lower gamma ray response and a higher velocity. In some cases the upper boundary may be more gradational as in 1/3–1 (Figure 30), but the lower boundary seems to be invariably sharp.

Distribution: The formation is widespread over the Southern and Central North Sea and is absent only from local structural highs. It may well equate with the Plenus Marl of south-eastern England (Jefferies, 1963), and appears to be present in similar lithology and thickness over a vast area.

Age: Late Cenomanian to Turonian.

Hod Formation

Name: From the Hod Field in Norwegian block 2/11.

Well type section: Norwegian well 1/3–1 (Shell) (Figure 30) from 3827.5 m (12 558 ft) to 4344 m (14 248 ft) below KB.

Well reference section: UK well 29/25–1 (Shell/Esso) (Figure 27).

Thickness: 516.5 m (1690 ft) in the type section and 230 m (758 ft) in 29/25–1.

Lithology: In the type well the formation is a thick sequence of white to light grey, crypto- to microcrystalline hard limestones, which may become argillaceous or chalky in places. Silty marls, dark grey to black micaceous and carbonaceous shales, greenish-grey fissile shales and foraminiferal limestones are minor lithologies which may be present. In places the limestones may be pink or pale orange in colour. The formation becomes slightly dolomitic and glauconitic in the lower part.

Boundaries: Where the chalk facies is well developed the boundary between the Hod Formation and the overlying Tor Formation may be difficult to pick out. The Hod Formation is normally less pure carbonate and hence tends to have a slightly higher gamma ray response and a slightly lower velocity than the Tor Formation. In some places the Hod/Tor contact is close to the first appearance of pink limestone in the section. The lower contact with the Plenus Marl is normally distinct, as noted above. In places where it is gradational there may be slightly different opinions as to the position of the base of the formation.

Distribution: The formation is widely distributed over the central and eastern parts of the Central North Sea but it tends to pass laterally into argillaceous sediments (Flounder Formation) to the north-west.

Age: Turonian to Campanian locally extending into the earliest Maastrichtian.

Herring Formation

Name: From the fish of the same name.

Well type section: UK well 22/1–2A (Sun Oil) (Figure 28), from 3605 m (11 826 ft) to 3732 m (12 245 ft) below KB.

Well reference section: None at present.

Thickness: 127 m (419 ft) in the type well, although the thickness more commonly ranges from about 25 m to 75 m.

Lithology: In the type well the formation is white to light grey, hard to very hard cryptocrystalline limestone. It is occasionally chalky and contains traces of pyrite and glauconite.

Boundaries: Both the overlying and underlying formations consist of calcareous mudstone or claystone which have a lower velocity and a higher gamma ray response than the Herring Formation. The boundaries of the formation are therefore marked by good log breaks (Figure 28).

Distribution: The formation is easily recognisable in the western part of the Central North Sea but cannot be distinguished in the eastern part or in the Southern North Sea. The Herring Formation and the overlying Flounder Formation are homotaxial with the Hod Formation which was desposited closer to the Chalk depocentre. When more data are available it may transpire that the Herring Formation should more logically be considered as a member of the Hod Formation.

Age: Turonian for the most part.

Flounder Formation

Name: From the fish of the same name.

Well type section: UK well 22/1–2A (Sun Oil) (Figure 28) from 3245 m (10 646 ft) to 3605 m (11 826 ft) below KB.

Well reference section: None at present.

Thickness: 360 m (1180 ft) in the type well. However, this is a particularly thick section and the formation normally ranges between 100 and 150 m in thickness.

Lithology: In the type section it consists of light to dark grey, very calcareous mudstones and shales grading into light to dark grey hard limestone. Thin beds of white brittle cryptocrystalline limestone are also present.

Boundaries: The formation is overlain and underlain by formations containing a much higher proportion of harder limestone and therefore it has a higher gamma ray response and a lower velocity than the surrounding formations.

Distribution: The formation is largely confined to the north-western part of the Central North Sea. However when more data are available it may be possible to carry it into part of the Northern North Sea. As noted above the formation is homotaxial with part of the Hod Formation.

Age: Coniacian to Campanian.

Tor Formation

Name: From the Tor Field in Norwegian blocks 2/4 and 2/5.

Well type section: Norwegian well 1/3–1 (Shell) (Figure 30) from 3354 m (11 004 ft) to 3827.5 m (12 558 ft) below KB.

Well reference section: UK wells 22/1–2A (Sun Oil) (Figure 28) and 29/25–1 (Shell/Esso) (Figure 27).

Thickness: 473.5 m (1554 ft) in the type well, 262.5 m (861 ft) in 22/1–2A and 126 m (410 ft) in 29/25- 1.

Lithology: In the type well the formation consists of white to light grey, tan and pink hard chalky limestones. The limestones may become earthy and less firm in places but generally the formation is a long, homogenous fine-grained sequence. Intraformational conglomerates, diagenetic nodules and stylolites are unevenly distributed throughout the formation. In UK well 22/1–2A the formation contains thin stringers of medium grey to green, firm moderately calcareous shales.

Boundaries: The upper contact of the formation is with the Ekofisk Formation or younger sediments. The Ekofisk Formation tends to be a less pure carbonate than the Tor Formation and has a slightly higher and more irregular gamma ray response and a lower velocity than it. In many wells the contact between the Tor and Ekofisk Formations is picked below a marked 'shoulder' in the gamma ray curve (Figures 28 and 30). In localities where the Ekofisk Formation is not present and younger, predominantly clastic sediments overlie the Tor Formation the 'shoulder' in the gamma ray curve is very pronounced. In the area of the Ekofisk Field there is a hard dense limestone unit at the base of the Ekofisk Formation. This unit has a particularly high velocity and where present the base of this unit is taken as the boundary between the Ekofisk and Tor Formations.

The Tor Formation rests either on the Hod Formation or the Flounder Formation and both of these contacts are described above.

Distribution: The formation is widespread in the Central North Sea. To the north it passes into a sequence of interbedded clean limestones and shales.

Age: Predominantly Maastrichtian but probably extending down into the Late Campanian in places.

Ekofisk Formation

Name: From the Ekofisk Field in Norwegian block 2/4.

Well type section: Norwegian well 2/4–5 (Phillips) (Figure 31) from 3037 m (9964 ft) to 3164 m (10 380 ft) below KB.

Well reference section: Norwegian well 1/3–1 (Shell) (Figure 30) and UK well 22/1–2A (Sun Oil) (Figure 28).

Thickness: 127 m (416 ft) in the type well, 97 m (322 ft) in 1/3–1 and 47.5 m (155 ft) in 22/1–2A. Away from the type well the formation thins as a result of both erosion and non-deposition.

Lithology: In the type well it is a white, tan or beige, hard dense, sometimes finely crystalline limestone, although softer chalky textures are also present. It is mainly composed of clay-sized particles of foraminifera and coccoliths and has been variously termed micrite, chalk, lime mud, lime ooze and calcilutite. Fractures and stylolites are common and chert occurs in thin zones. As the formation is traced into the Northern North Sea it becomes more argillaceous passing into mudstones and marls but retaining its high calcareous content.

Boundaries: In the type well the formation is overlain by marls of Danian age. Elsewhere the upper contact is with coarser clastics which are mostly of Late Danian age. Locally younger Tertiary clays and mudstone overlie the formation. The boundary between the Ekofisk Formation and the overlying clastics is usually marked by a transitional decrease in calcareous content resulting in a characteristically stepped sonic log profile. Unfortunately this is not shown to advantage in any of the wells illustrated but is very clear in adjacent wells. In the type well this boundary coincides with the 9⅝-inch casing shoe and the logs are not very clear. As the Ekofisk Formation changes in facies, particularly towards the north, it preserves its lithological contrasts with the surrounding formations, particularly with the non-calcareous sediments above.

The lower contact of the formation with the Tor Formation is described above.

Distribution: The formation can be recognised in the Danish, Dutch and German sectors of the North Sea. It is widespread in the UK and Norwegian sectors of the Central North Sea.

Age: Danian.

NORTHERN NORTH SEA

The Cromer Knoll Group has been extended to the Northern North Sea and is 422 m (1384 ft) thick in UK well 3/29–1 (BP) (Figure 32). In this well it consists of medium to dark grey calcareous mudstones with intercalations of reddish-brown, fissile mudstone. There are numerous interbeds of light grey, sparry to micritic limestone, which is often sandy or argillaceous, and yellow-brown micritic dolomite. Thin fine- to medium-grained sandstones and silty sandstones occur near the base and in some wells slight reddening is seen at the top of the group. In the Northern North Sea the Group normally rests with a distinctive contact on the Kimmeridge Clay Formation but the upper contact with the Shetland Group is not always so clear. The Shetland Group however is normally significantly more calcareous than the Cromer Knoll Group and this normally allows a boundary to be picked on the petrophysical logs.

Shetland Group

Name: From the Shetland Islands off the north coast of Scotland.

Type area: Northern North Sea. UK well 3/29–1 (BP) (Figure 32) shows a typical section of the group.

Thickness: In the 3/29–1 well it is 1401 m (4597 ft) thick and generally ranges between 1000–2000 m in thickness.

Lithology: In the 3/29–1 well the group consists of a rather monotonous sequence of light to dark grey or reddish-brown calcareous mudstones, occasionally grading into hard fissile grey shale. The mudstone is locally glauconitic and pyritic and contains numerous bands of white to brownish-grey, fine grained sandy limestones, which are sometimes dolomitic. At the top of the group in the 3/29–1 well ('Formation' F), is a unit of very fine-grained dense hard white chalky limestone.

Boundaries: The lower contact with the Cromer Knoll Group is described above. The Shetland Group is more calcareous than the overlying clastic sediments, which are normally of Late Danian age, and it tends to have a higher velocity and a lower gamma ray response. This is particularly true when the chalky limestone unit ('Formation' F) is present at the top of the group and good log breaks are present.

Distribution: The group is widespread in the Northern North Sea.

Age: Cenomanian to Danian.

Subdivisions: In the 3/29–1 well the Shetland Group can be subdivided into smaller units. However with the data available the sub-committee could not establish unequivocally that these units fulfilled the criteria necessary to be designated as formations. These units are indicated on Figure 32 as 'Formations' A to F and they can be formally named at a later date if they prove to be valid formations. Some of these 'Formations' may well be homotaxial with formations in the Chalk Group; for example 'Formation' B may equate with the Plenus Marl Formation, and 'Formation' F probably equates with the Ekofisk Formation. More data is required to establish the detailed relationships between the Chalk Group and the Shetland Group.

TERTIARY

The North Sea was an important basin of deposition throughout the Tertiary and a complete sequence of all the Tertiary series from Palaeocene to Pliocene is present in the centre of the Tertiary depositional basin. The Tertiary sediments blanket the Mesozoic graben system and attain a thickness in excess of 3000 m at the depocentre, which coincides approximately with the centre of the present North Sea.

The chronostratigraphic term Tertiary is used in an informal sense in this report to include the thick clastic section that extends from the top of the calcareous deposits of the Danian and Cretaceous to the sea floor. The Quaternary deposits are therefore included with the Tertiary lithostratigraphic sequence, since at present they cannot be easily differentiated.

Distribution and sedimentary framework

Tertiary sediments were deposited in a broad downwarp that roughly corresponds to the present North Sea Basin. Although no significant Tertiary sediments are known on land in Scotland or Norway they occur close to the coasts of both countries. Maps of the distribution of Tertiary sediments have been published by P. A. Ziegler (1974), and W. H. Ziegler (1974).

During latest Cretaceous and earliest Tertiary time tectonic activity resulted in downwarping of the North Sea Basin and rejuvenation of surrounding source areas, principally those to the north and west. Localised erosion of marginal and intra-basinal uplifts of Cretaceous and Danian strata also occurred, resulting in clastic deposition which replaced the earlier carbonate regime. This phase of tectonism also caused rejuvenation of pre-existing faults and stimulated a renewal of halokinesis in places.

During the Early Palaeocene submarine fans developed along the faulted basin margins in the west and spread out and overlapped to form continuous sand bodies that wedged out and became finer grained towards the basin centre. At the same time the intrabasinal uplifts were being gradually submerged by the deepening sea and marine muds were deposited over them and in distal areas.

The depositional framework of this fan system has been elucidated by the most recent studies of seismic sections and well data. This concept of submarine fan sedimentation, involving turbidity flow, mass flow and slump processes, was first applied to the Palaeocene sediments of the North Sea by Parker (1975).

At this time the primary sources of sediment lay to the north and west. Sediment transport and deposition occurred in a south-easterly direction from the Moray Firth Basin to the Forties Field area and eastwards from the East Shetland Platform into the Viking Graben. This pattern of erosion and deposition was operative until Early Eocene times.

During the Late Palaeocene and Early Eocene this progressive infilling of the basin from the west resulted in the development of a new sedimentary regime of relatively shallow marine to non-marine shelf and deltaic deposits. These sediments prograded eastwards across the gently sloping surface of the underlying fan deposits. Deltaic sedimentation, which culminated in widespread lignite deposition in the Moray Firth Basin, also appears to have occurred in the Viking Graben, centred around the northern part of UK Quadrant 3. Some local accumulations of shallow marine/deltaic sands are also present on the Norwegian side of the Central North Sea but the source areas to the west seem to have been much more significant than those to the east.

During this period also, volcanic eruptions, which occurred intermittently throughout the Palaeocene, culminated in a series of ash-fall deposits several tens of metres thick, which are preserved over most of the North Sea Basin. This ash unit (the Balder Formation) is an excellent seismic reflector and a reliable marker horizon. The main volcanic centres from which the ash was derived appear to have lain to the west and north of the UK landmass, with a possible centre also in the Skagerrak.

Further downwarping of the basin, probably associated with the vulcanism, resulted in a major Early Eocene transgression. Marine muds were deposited above the ash beds throughout the basin, except in the marginal areas around the East Shetland Platform where localised sand deposits accumulated.

Deposition during the remainder of the Tertiary has not been analysed in detail, but appears to have consisted primarily of fine-grained clastic sedimentation associated with continued downwarping of the basin. Local uplifts, particularly in marginal areas such as the Vestland Arch provided sources for sands and gravels which were deposited in marginal marine environments.

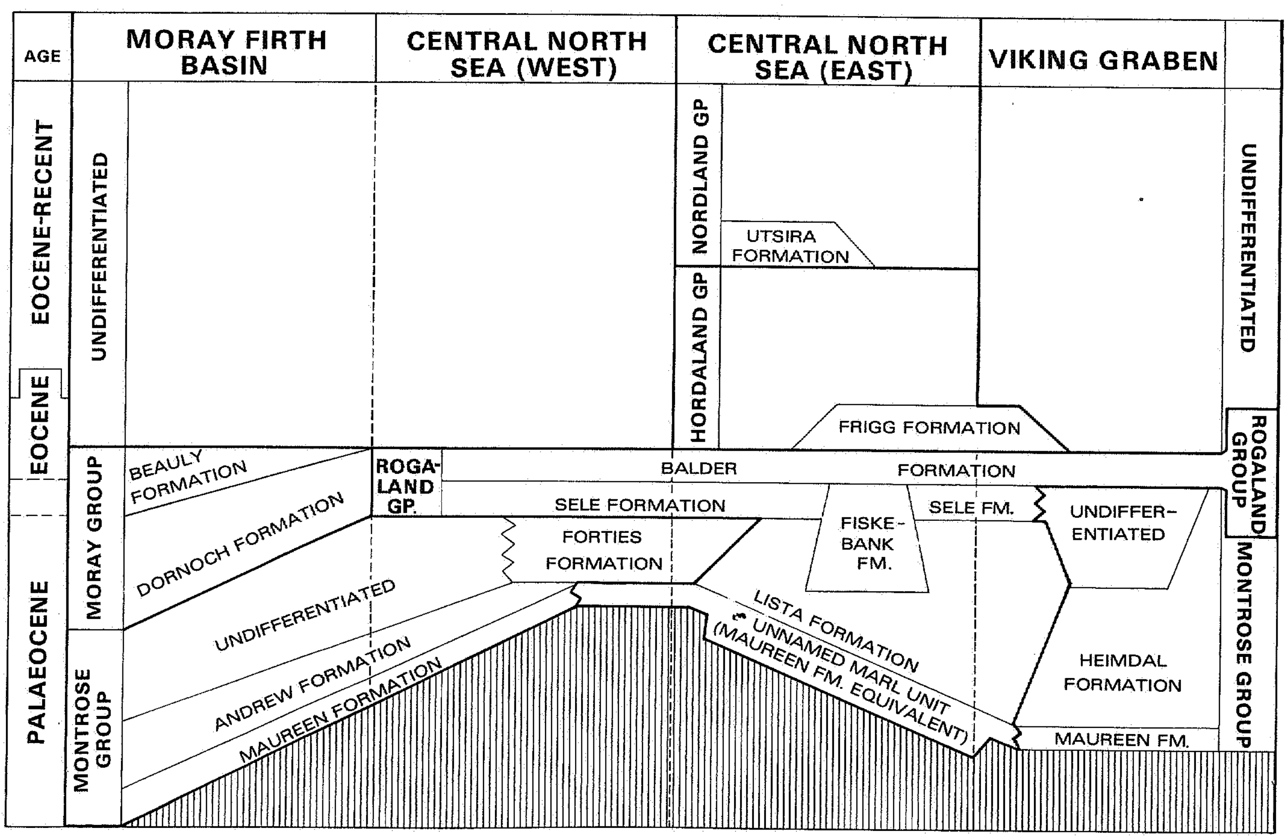
Lithostratigraphy

The Tertiary sequence is composed of five major groups: the Montrose, Moray, Rogaland, Hordaland and Nordland Groups (Table 4). Within the Palaeocene–Lower Eocene sediments of the outer Moray Firth–Forties area the recognition of a twofold subdivision into a lower sedimentary fan sequence (Montrose Group) and an upper shelf/deltaic sequence (Moray Group) forms the basis of the lithostratigraphic nomenclature in this western part of the Central North Sea. To the east and north-east these dominantly arenaceous groups pass into the more distal argillaceous sediments of the Rogaland Group.

The Montrose and Moray Groups, and their distal equivalent the Rogaland Group, include all the sediments deposited between the top of the Chalk and the top of the ash marker (Balder Formation). These three groups are genetically related and represent the initial phase of Tertiary erosion, transport and deposition. They are of considerable economic importance as they contain the bulk of the Tertiary oil accumulations.

Figure 33 shows the lithostratigraphy of these groups and Figure 34 shows a seismic section illustrating their subdivisions in the area south-eastwards from the Halibut Horst.

Table 4 Tertiary lithostratigraphic nomenclature



The base of the Montrose–Rogaland sequence is taken at the abrupt lithological change from the calcareous deposits of the Chalk Group to the overlying clastic deposits, often containing reworked fragments of chalk or marl. This basal unit of reworking is called the Maureen Formation.

Within the Montrose Group two further formations are defined in this area. Overlying the Maureen Formation is a sequence of overlapping sand fans which have coalesced into a sand sheet; this is named the Andrew Formation, and its upper boundary is a distinctive seismic reflector. An upper arenaceous unit, probably deposited within a submarine fan system, is distinguished as the Forties Formation.

The Moray Group, which overlies the Montrose Group, consists of deltaic units deposited in shallow marine and paralic environments. Two formations are defined in the group, namely the Dornoch Formation and the Beauly Formation. The Beauly Formation is distinguished by the presence of significant lignite beds.

The Rogaland Group is more extensive than either the Montrose or Moray groups. It is their distal equivalent, and three widespread and one areally restricted formations are recognised within it. At the base it contains an unnamed marl unit which is laterally equivalent to the Maureen Formation of the Montrose Group. Above this is a shale unit which is the time equivalent of, and interdigitates with, the sand units of the Montrose Group. This is named the Lista Formation.

Above the Lista Formation are two relatively thin units which have a basin-wide distribution; these are named the Sele and Balder Formations. The Sele Formation consists primarily of tuffaceous shales while the Balder Formation contains a higher proportion of volcanic detritus and forms the distinctive 'ash marker'. A local deltaic sand body derived from the Norwegian margin of the basin is distinguished as the Fiskebank Formation. The uniformity of the Rogaland Group can be contrasted with the basinward wedging of the Montrose Group by comparing the seismic sections shown in Figures 34 and 35.

Major sediment accumulation also occurred along the western margin of the Viking Graben. However, much less information was made available to the sub-committee in this area, so only a skeleton lithostratigraphy is proposed here. Sand bodies however are present which appear to be homotaxial with those of the Montrose Group, and it is proposed that these be designated as the Heimdal Formation. It may be possible to subdivide this sequence in the future but for the present the Heimdal Formation is taken to include all the sands in the Viking Graben equivalent to those of the Montrose Group in the Moray Firth and Central Graben. The Montrose Group in this area therefore includes the Heimdal Formation and the Maureen Formation (where recognisable).

The sandstone units of the Heimdal Formation tend to be thicker but less areally extensive than those of the Montrose Group south-east of the Halibut Horst. Available information suggests that there are at least two types of sand deposit in this formation. One is composed of thick areally restricted, cone-like bodies which probably represent deposition at the mouth of short submarine canyons incised into the East Shetland Platform. The other type, which infills the valleys between cones, is more elongate and extensive, and may represent multi-canyon discharge of material which was subsequently modified by axial marine currents running southwards into the basin, parallel to the margin of the East Shetland Platform.

Upper Palaeocene–Lower Eocene sediments in the Viking Graben have not been considered by the sub-committees although it is known that overlying the Heimdal Formation there are sand bodies in that area which are probably homotaxial with those of the Moray Group (undifferentiated on Table 4).

In the Early Eocene the source areas that supplied the sands of the Heimdal Formation continued to deliver material to the Viking Graben. Several sand bodies were laid down during this time but only one is recognised at present. This is designated as the Frigg Formation, and since it is younger than the ash beds of the Balder Formation it is assigned to the overlying Hordaland Group. This formation contains the oil and gas accumulations of the Frigg Field.

The rest of the Tertiary sequence above the Moray and Rogaland groups, including the Recent sediments, consists predominantly of fine-grained clastics. Two groups, the Hordaland Group, as mentioned above, and the Nordland Group, have been recognised in the Norwegian sector, but not differentiated on the UK side because of facies variations. Norwegian well 2/7-1 (Phillips) (Figures 41, 49) shows the essentially argillaceous sections of the two groups, and Norwegian well 16/1-1 (Esso) (Figures 46, 47) illustrates sand developments within each. UK well 14/25-1 (Shell/Esso) (Figure 45) shows the predominantly sandy sequence in the undifferentiated equivalent section of these two groups.

Montrose Group

The Montrose Group lies between the tuffaceous Sele Formation or the Moray Group, and the Chalk or Shetland groups. It consists of a basal reworked unit overlain by a complex of primarily arenaceous sedimentary fans which also include some argillaceous facies. The lithologies of the group are variable to some extent because of the facies changes between the coarse clastics of the proximal part and the more argillaceous lithology of the distal part of the sedimentary fans.

Name: From the Montrose Oil Field, in UK blocks 22/17 and 22/18.

Type area: The group is typically developed in the area south-east of the Halibut Horst as shown in UK wells 14/25-1 (Shell/Esso) (Figure 38), and 21/10-1 (BP) (Figure 36). The group has been extended northwards into the southern Viking Graben to include similar homotaxial sediments as shown in UK well 10/1-1A (Total) (Figure 37) and Norwegian wells 16/1-1 (Esso) (Figure 40), and 25/4-1 (Elf Norge) (Figure 39). It seems probable that the group will be extended into the northern Viking Graben in the future.

Thickness: In UK wells 14/25-1 and 21/10-1 it is respectively 646 m (2120 ft) and 393 m (1289 ft) thick. In Norwegian well 16/1-1 it is 436 m (1430 ft) thick, and in UK well 10/1-1A it is 668 m (2192 ft) thick. In general the group becomes thinner and the sand developments pinch out towards the east and south.

Lithology: The dominant lithology is sandstone with variable amounts of argillaceous interbeds. The basal deposits contain reworked limestones and marls.

Boundaries: The top of the group normally corresponds to a depositional boundary marked by a change in lithology from the sandstones, clays and shales of the Montrose Group to the distinctively laminated, tuffaceous shales of the Sele Formation. The base of the group is taken at the contact with the underlying non-clastic chalk or marl sequence of the Danian and Cretaceous. These boundaries generally hold true for the Viking and Central Grabens, and can be identified on the sonic and gamma logs. The dipmeter log, where available, also clearly defines the upper boundary with the laminated Sele Formation sediments and also helps distinguish the poorly bedded clastics from the well-bedded Chalk or Shetland Group deposits. In the Moray Firth Basin area a distinctive greenish, fossiliferous shale with a low sonic velocity is often present at the top of the Montrose Group, which contrasts with the more silty, brownish and poorly fossiliferous clays of the Moray Group (see well 14/25–1, Figure 38). This upper boundary can also be identified on the dipmeter log where the regular dips of the deltaic Moray Group sediments contrast with the irregular dips of the underlying sedimentary wedge complex.

Distribution: The group is well developed in the Moray Firth and the Central and Viking grabens. Its northern limit in the Viking Graben has not yet been defined.

Age: Palaeocene.

Subdivisions: In the area south-east of the Halibut Horst the Maureen, Andrew and Forties formations are defined within the group, and in the Viking Graben the Heimdal Formation is recognised (see Table 4).

Maureen Formation

Name: From the Maureen Field, in UK block 16/29.

Well type section: UK well 21/10–1 (BP) (Figure 36), from 2464 m (8085 ft) to 2524 m (8281 ft) below KB.

Well reference section: UK well 10/1–1A (Total) (Figure 37), UK well 14/25–1 (Shell/Esso) (Figure 38), Norwegian well 16/1–1 (Esso) (Figure 40).

Thickness: In the type well, the Maureen Formation is 60 m (196 ft) thick, in well 14/25–1 it is 32 m (107 ft). In the Viking and Central grabens, in wells 10/1–1A and 16/1–1, the thickness is 77 m (253 ft) and 110 m (361 ft) respectively.

Lithology: The formation consists of mixed lithologies with rather irregular distribution patterns. It is frequently conglomeratic and contains pebbles and clasts of reworked limestones and shales of Danian and Late Cretaceous age, in a matrix of, or interbedded with, brown and dark grey shales, siltstones and sandstones. However in certain parts of the basin the formation passes into a light grey marl facies which is presently unnamed (see Figure 41). When named this unit will be grouped into the argillaceous sediments of the Rogaland Group.

Boundaries: The Maureen Formation rests on the Chalk Group or Shetland Group and the change from the primarily non-clastic deposits of the Chalk Group, or the calcareous mudstones of the Shetland Group, to the heterogeneous deposits of the Maureen Formation is well shown on the sonic, gamma and dipmeter logs. The upper boundary is marked by the change from variably sandy deposits containing reworked limestone fragments, to the commencement of submarine fan and turbidite deposits. This boundary can be difficult to identify as the first deposits of the fan wedges may also be calcareous in nature. Where the formation is represented by a marl facies the gamma ray and sonic log pattern tends to be characteristic as shown by Norwegian well 2/7–1 (Figure 41).

Distribution: The generally coarse Maureen Formation deposits were mainly derived from erosion and reworking of underlying Danian and Cretaceous rocks, although fragments of pre-Cretaceous rocks may be locally present. This coarse detrital facies is mainly developed in the Central Graben and southern Viking Graben, particularly around intra-basinal highs. It thins to the northwest in the Moray Firth Basin. A marl facies equivalent of the Maureen Formation is present over highs, and away from sand sources where the underlying rock is marly. When properly defined and named this marl unit will be assigned to the Rogaland Group.

Age: Palaeocene.

Andrew Formation

Name: From the Andrew Field, in UK blocks 16/27 and 16/28.

Well type section: UK well 14/25–1 (Shell/Esso) (Figure 38) from 1897 m (6223 ft) to 2199 m (7213 ft) below KB.

Well reference section: UK well 21/10–1 (BP) (Figure 36).

Thickness: 302 m (990 ft) in the type well, 94 m (309 ft) in the reference well.

Lithology: The formation consists predominantly of sandstone, with some claystone interbeds. The sandstone is generally very fine- to medium-grained, occasionally coarse, and composed of subangular to subrounded, clear to orange stained quartz grains. It is poorly sorted and often has a calcareous cement. The claystone is grey brown to grey green, silty and slightly calcareous. Thin stringers of limestone have been noted. The topmost 55 m (180 ft) or so in the type well are probably tuffaceous.

Boundaries: The Andrew Formation overlies the Maureen Formation in the type well, but in places may rest directly on the Chalk Group.

The upper boundary is identified on the sonic log as the break between the generally high velocity Andrew Formation and the overlying sandstones and siltstones (undifferentiated Montrose Group in the 14/25–1 well), which have a distinctly lower velocity.

Distribution: The Andrew Formation can be traced on seismic sections and is recognised in wells from the Moray Firth Basin south-eastwards into the Forties area. Its distribution northwards is not known.

Age: Palaeocene.

Forties Formation

Name: From the Forties Field, in UK block 21/10.

Well type section: UK well 21/10–1 (BP) (Figure 36) from 2131 m (6992 ft) to 2370 m (7776 ft) below KB.

Well reference section: None.

Thickness: 239 m (784 ft) in the type well.

Lithology: In the type well the formation consists of interbedded sandstones, siltstones and claystones, becoming predominantly sandy higher in the section. The sands are grey to white, fine to coarse grained, poor to moderately sorted and contain minor amounts of lignite, pyrite, glauconite and mica.

Boundaries: The lower boundary is placed at the strong change shown on the sonic log between the high velocity Andrew Formation and the overlying lower velocity sands of the Forties Formation.

The upper boundary is picked at the break between the massive Forties sandstones and the finely laminated shales of the overlying Sele Formation.

Distribution: The Forties Formation extends as a large-scale sedimentary wedge from the area south of the Halibut Horst to the Forties area. The lateral margins of this sand wedge have not yet been defined in detail.

Age: Late Palaeocene.

Heimdal Formation

Name: From the Heimdal Field in Norwegian block 25/4.

Well type section: Norwegian well 25/4–1 (Elf Norge) (Figure 39), from 2067 m (6781 ft) to 2423 m (7949 ft) below KB.

Well reference section: None.

Thickness: The formation is 356 m (1168 ft) thick in the type well section. It wedges out rapidly to the east and thickens and thins in an irregular fashion to the north and south of the type well.

Lithology: The formation is dominated by thick units of poorly sorted, fine- to coarse-grained, slightly cemented sandstone with variable amounts of mica, glauconite and detrital lignite. In the type section the sorting improves and the average grain size decreases downward. Elsewhere the reverse may occur. The sandstone units are interbedded with grey and black shales, limestones and sandy limestones and well-cemented very fine- to fine-grained sandstones. There is a wide range in the number and of the thickness of the interbedded lithologies. In general the amount of carbonate increases towards the base of the formation.

Boundaries: The upper boundary of the formation is the contact with the Balder Formation, the Lista Formation or the unnamed unit present in the north of Quadrant 3 (see Table 4). In the type well this contact is picked at the top of the blocky gamma ray and sonic log pattern. The lower boundary in the type well is the contact with an underlying shale and limestone sequence which is picked at the base of the blocky gamma ray–sonic log pattern. Elsewhere the formation may overlie the Maureen Formation or Danian or Late Cretaceous limestone.

Distribution: The sandstones of the Heimdal Formation are distributed in a broadly lobate pattern that has spread out from the western margin of the Viking Graben.

Age: Palaeocene.

Moray Group

Name: From the Moray Firth in north-east Scotland.

Type area: The group is confined to the vicinity of the Moray Firth Basin where it is typically developed in UK well 14/25–1 (Shell/Esso) (Figure 38).

Thickness: The group is 528 m (1731 ft) thick in UK well 14/25–1.

Lithology: The group contains sediments of paralic and terrestrial environments. At the base of the section in the 14/25–1 well, dark grey silty clays with interbedded friable sands occur. The clays become lighter grey in colour upwards and are eventually progressively replaced by sandstones towards the top of the section. In-situ lignites and scattered rock fragments are also present.

Boundaries: The poorly fossiliferous, well-bedded clays and sandstones of the Moray Group are commonly underlain by distinctive low-velocity fossiliferous, often greenish-grey shales of the Montrose Group. This break is exhibited on the dipmeter where the low regular dips of the generally silty basal sediments of the Moray Group are replaced by the scattered dips of the underlying low-velocity shale. The top of the group is placed at the commencment of an Early- to Mid-Eocene marine transgression, represented by glauconitic siltstones which overlie the essentially terrestrial post-deltaic deposits of the upper part of the group. This upper boundary is also reflected on the dipmeter where low consistent dips of the Moray Group contrast with the generally irregular dips of the unit immediately above.

Distribution: The group is confined to the Moray Firth Basin area, but laterally equivalent deltaic and shelf deposits extend northwards along the western margin of the Viking Graben. The distal equivalents of the group are the tuffaceous Sele and Balder Formations of the Rogaland Group. Tuffs are also present in the Moray Group but they are reworked in the deltaic deposits.

Age: Late Palaeocene to Early Eocene.

Subdivisions: Two formations are recognised in the group, namely the Dornoch and Beauly Formations (see Table 4 and Figure 33).

Dornoch Formation

Name: After the Dornoch Firth in north-east Scotland.

Well type section: UK well 14/25–1 (Shell/Esso) (Figure 38), from 1163 m (3815 ft) to 1585 m (5200 ft) below KB.

Well reference section: None.

Thickness: 422 m (1385 ft) in the type well.

Lithology: The dominant lithologies are sandstone, siltstone and clay. Thick clay deposits are developed in the lower part of the section and probably represent prodeltaic deposition. These clays are generally dark to light grey and often silty. Towards the top of the formation massive sandstones occur. They are friable fine to coarse grained, subangular to rounded, often poorly sorted, but occasionally well sorted.

Boundaries: The lower boundary is the same as that described for the Moray Group. The top is marked by the change from essentially shallow marine to paralic sediments and in the type well it is placed at the base of the lowest lignite bed.

Distribution: This formation is recognised in the Moray Firth Basin area.

Age: Late Palaeocene to Early Eocene.

Beauly Formation
Name: From the Beauly Firth in north-east Scotland.

Well type section: UK well 14/25-1 (Shell/Esso) (Figure 38), from 1057 m (3469 ft) to 1163 m (3815 ft) below KB.

Well reference section: None.

Thickness: 106 m (346 ft) in the type well.

Lithology: In the type well the formation consists predominantly of friable grey, fine- to coarse-grained poorly sorted sandstones. It contains beds of in-situ lignites and grey-brown clay.

Boundaries: The upper boundary is the same as that described for the Moray Group; the lower boundary with the Dornoch Formation is placed at the base of the basal lignite as previously described.

Distribution: This formation appears to be confined to the Moray Firth Basin area.

Age: Early Eocene.

Rogaland Group
Name: After the county of Rogaland in Norway.

Type area: The group is typically developed in the eastern part of the Central and Northern North Sea particularly in Norwegian waters. It is well illustrated in Norwegian wells 2/7-1 (Phillips) (Figure 41), from the Eldfisk Field and 33/9-1 (Mobil) (Figure 42) from the Statfjord Field.

Thickness: The group is 112 m (369 ft) thick in 2/7-1 and 196.5 m (653 ft) in 33/9-1.

Lithology: The group consists predominantly of argillaceous marine sediments. These are normally shales with some minor sandstone interbeds and the shales become increasingly tuffaceous towards the top of the group.

Boundaries: The top is marked by the change from finely laminated tuffaceous shales to the more irregularly bedded sediments above, which are much less tuffaceous. This upper contact is a disconformity surface, above which are the glauconitic basal deposits of the Lower Eocene transgression. The base is marked by a log break which reflects the change from non-clastic deposition of the regularly bedded Chalk Group to the clastic deposits of the Rogaland Group.

Distribution: The Rogaland Group is the distal argillaceous equivalent of the Montrose and Moray Groups and is widely distributed over the eastern part of the Northern and Central North Sea.

Age: Palaeocene to Early Eocene.

Subdivisions: Four formations are recognised within the group, namely the Lista, Fiskebank, Sele and Balder formations (see Table 4). In the area covered by the Rogaland Group there is frequently a basal marl unit present which is a lateral equivalent of the Maureen Formation. This unit is presently unnamed but when formally defined will constitute another formation within the Rogaland Group.

Lista Formation
Name: After the Lista structure in the Norwegian-Danish Basin (Rønnevik and others, 1975).

Well type section: Norwegian well 2/7-1 (Phillips) (Figure 41), from 2872.5 m (9425 ft) to 2917.5 m (9573 ft) below KB.

Well reference section: Norwegian well 33/9-1 (Mobil) (Figure 42).

Thickness: 45 m (148 ft) in the type well, 151 m (503 ft) in the reference well.

Lithology: The formation consists predominantly of shale, which is generally non-tuffaceous and non-laminated and contains only minor sandy interbeds.

Boundaries: In the type well the Lista Formation is overlain by the well-laminated, tuffaceous shales of the Sele Formation. The base is taken at the change from shale to the underlying marl unit which is equivalent to the Maureen Formation (Figure 41).

Distribution: The Lista Formation is a widespread prominent formation, particularly in the Norwegian sector east of the Viking Graben.

Age: Palaeocene.

Fiskebank Formation
Name: From the Fiske (Fisher) Bank, offshore southern Norway.

Well type section: Norwegian well 9/11-1 (Conoco) (Figure 43), from 1335 m (4380 ft) to 1483 m (4865 ft) below KB.

Well reference section: None at present.

Thickness: In the type well, the Fiskebank Formation is 148 m (485 ft) thick.

Lithology: The major lithology in the type section is sandstone. It is dark grey to grey-brown, very fine grained, well-sorted, subangular, slightly silty, glauconitic, friable and occasionally has a calcareous cement.

Boundaries: The formation is a basin margin deposit which appears to be equivalent to the upper part of the Lista Formation and the Sele Formation. It is bounded at the top by the Balder Formation and the basal contact is marked by the passage down into the shales of the Lista Formation (see Figure 43). These relationships are shown on the seismic record in Figure 35.

Distribution: The formation is a localised deltaic lobe in the Norwegian-Danish Basin.

Age: Palaeocene to Early Eocene.

Sele Formation
Name: From the Sele High, offshore Norway (Rønnevik and others, 1975).

Well type section: UK well 21/10-1 (BP) (Figure 36) from 2100 m (6890 ft) to 2131 m (6992 ft) below KB.

Well reference section: Norwegian wells 16/1-1 (Esso) (Figure 40) and 2/7-1 (Phillips) (Figure 41).

Thickness: 31 m (102 ft) in the type well, 43 m (140 ft) in 16/1-1 and 38.5 m (125 ft) in 2/7-1.

Lithology: The formation is composed of tuffaceous montmorillonite-rich shales and siltstones which are medium to dark grey or greenish-grey. They are finely laminated and carbonaceous, with minor interbeds of laminated sandstone which is frequently glauconitic.

Boundaries: The upper boundary with the Balder Formation is defined by the log characteristics described below. In the type well the lower boundary is marked by the change from the laminated shales of the Sele Formation to the non-laminated sediments of the underlying sand-wedge complex (Montrose Group). This boundary is particularly well marked on the dipmeter log as a change from regular to scattered dips downwards. Where the Sele Formation overlies the Lista Formation the contact is marked by the change from laminated tuffaceous shales to non-laminated, non-tuffaceous shale.

Distribution: The Sele Formation is widely distributed over the North Sea but may be absent in the extreme east.

Age: Palaeocene to earliest Eocene.

Balder Formation

Name: From the Balder Field in Norwegian block 25/11.

Well type section: Norwegian well 25/11–1 (Esso) (Figure 44) from the Balder Field. The formation occurs from 1705 m (5595 ft) to 1780 m (5840 ft) below KB.

Well reference section: UK well 21/10–1 (BP) (Figure 36), Norwegian wells 16/1–1 (Esso) (Figure 40), 2/7–1 (Phillips) (Figure 41), and 33/9–1 (Mobil) (Figure 42)

Thickness: 75 m (245 ft) in the type well, 29 m (96 ft) in 21/10–1, 42 m (140 ft) in 16/1–1, 12 m (42 ft) in 2/7–1 and 45.5 m (150 ft) in 39/9–1.

Lithology: The Balder Formation is composed of laminated varicoloured fissile shales with interbedded grey, green or buff, often pyritic, sandy tuffs and occasional stringers of limestone, dolomite and siderite. Sands are locally developed, as shown in the type well, which was selected for the amount of core available.

Boundaries: The upper boundary is placed at the change from the laminated shales of the Balder Formation to the non-laminated, often glauconitic, occasionally reddish, overlying sediments. The lower boundary with the Sele Formation is generally identified on wireline logs as the upward change from higher to lower gamma ray response and lower to higher sonic velocity readings, probably corresponding to the sharp increase in the tuffaceous component of the Balder Formation.

Distribution: This formation is distributed over most of the North Sea and may correspond in part to the Mo Clay Formation in Denmark.

Age: Palaeocene to early Eocene.

Hordaland Group

Name: After the county of Hordaland in Norway.

Type area: North Sea Tertiary Basin. A typical section through the group is shown in Norwegian well 2/7–1 (Phillips) (Figure 41). UK well 14/25–1 (Shell/Esso) (Figure 45) shows the undifferentiated equivalents of the Hordaland and Nordland Groups in the UK sector.

Thickness: The group is 1221 m (4003 ft) thick in Norwegian well 2/7–1 and it thins to the east away from the centre of the basin.

Lithology: The sediments of the group are predominantly marine shales with some thin limestone streaks. The shales are normally light grey to brown, soft, fissile and fossiliferous, and they may become green or red near the base of the group (Figure 41). In the upper part of the 2/7–1 well the shales contain thin dolomite streaks. Localised sandstone units occur within the group as shown in Norwegian wells 16/1–1 (Figures 46 and 47) and 25/1–1 (Figure 48). These sands are fine to medium grained with occasional shale streaks.

Boundaries: The basal contact is marked by the junction with the distinctive laminated tuffs of the Balder Formation (see Figure 41). The top of the group occurs at the passage into the more massive and blocky clays of the Nordland Group. This contact is usually marked by a break on the wireline logs which represents an unconformity of Middle Miocene age.

Distribution: The group is widely distributed over most of the North Sea Tertiary Basin.

Age: Eocene, Oligocene and Early Miocene.

Subdivisions: Only the Frigg Formation has been formally defined within the group. The other sandstone developments in the group (e.g. those in Figures 46 and 47), may be defined as formations in the future when more information is available.

Frigg Formation

Name: From the Frigg Field in UK block 10/1 and Norwegian block 25/1.

Well type section: Norwegian well 25/1–1 (Elf) (Figure 48), from the Frigg Field. The formation occurs from 1836 m (6024 ft) to 2115 m (6939 ft) below KB.

Well reference section: UK well 10/1–1A (Total) (Figure 37).

Thickness: 279 m (915 ft) in the type well, and 208.5 m (684 ft) in the reference well. The Frigg Formation is very variable in thickness over short distances.

Lithology: The formation consists of massive, poorly consolidated, light brown to buff coloured, micaceous and carbonaceous sandstones, occasionally calcareously cemented. The sandstones are normally subrounded, very fine to fine grained, occasionally coarse. Lenses and streaks of greenish grey, carbonaceous, silty shale sometimes occur, for example at the base of the formation in the type well.

Boundaries: The lower part of the formation in the type section contains grey-green shales and the basal contact is marked by the passage into the distinctive tuffaceous shales of the underlying Balder Formation. The top of the formation is taken where the sands are replaced by the shales of the Hordaland Group. In the type well this overlying shale is a distinctive green colour.

Distribution: The Frigg Formation is localised in its distribution, being confined to the central and southern portions of the Viking Graben.

Age: Eocene.

Nordland Group

Name: After the county of Nordland in Norway.

Type area: North Sea Tertiary Basin. Typical sections through the group are illustrated from Norwegian well 2/7–1 (Phillips) (Figures 41 and 49). Figure 45 shows the undifferentiated equivalents of the Hordaland and Nordland Groups in UK well 14/25–1 (Shell/Esso).

Thickness: The group is 1502.5 m (4932 ft) thick in the 2/7–1 well and it thins eastwards away from the centre of the basin.

Lithology: The sediments of the group are predominantly marine shales and clays. They are grey to grey-brown, blocky, slightly micaceous, silty in part, with occasional glauconite and some traces of sand. During regressive phases sands were deposited in the basin, and Norwegian well 16/1–1 (Figure 47) illustrates one such sand body (the Utsira Formation, defined below). The uppermost sediments of the group consist of uncompacted muds and these are usually overlain by glacial deposits. In places Recent unconsolidated sands and gravels occur interbedded with the glacial deposits.

Boundaries: The basal contact of the Nordland Group with the Hordaland Group has been defined. The upper boundary is the present sea bed.

Distribution: The group is present over the whole of the North Sea Basin.

Age: Middle Miocene to Recent.

Subdivisions: Only the Utsira Formation is recognised within the group at present.

Utsira Formation

Name: After the Utsira High on the Vestland Arch (Rønnevik and others, 1975).

Well type section: Norwegian well 16/1–1 (Esso) (Figure 47) from 644.5 m (2115 ft) to 1064 m (3491 ft) below KB.

Well reference section: None.

Thickness: 419.5 m (1376 ft) in the type well.

Lithology: The formation consists of marine sands and shales with abundant macrofossil fragments. The sands are light greenish grey, very fine grained and subrounded, with minor mica and green glauconite. The shales are light greenish grey, soft, plastic, non-calcareous and also contain green glauconite.

Boundaries: The formation is usually the first thick sand development below the Pliocene and Recent argillaceous sediments; the base is marked by the downward transition to brown shales of the Hordaland Group.

Distribution: The formation is only present near the centre of the North Sea Basin on the Norwegian side and has not been recognised on the UK side.

Age: Middle to Late Miocene.

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